Article

Poly(para-phenyleneethynylene)-Sensor Arrays Discriminate 22 Different Teas

Benhua Wang, Jinsong Han, Markus Bender, Sebastian Hahn, Kai Seehafer, and Uwe H. F. Bunz

ACS Sens., **Just Accepted Manuscript** • DOI: 10.1021/acssensors.7b00943 • Publication Date (Web): 05 Jan 2018

Poly(*para*-phenyleneethynylene)-Sensor Arrays Discriminate 22 Different Teas

*Benhua Wang,[†] Jinsong Han,[†] Markus Bender,[†] Sebastian Hahn,[†] Kai Seehafer,[†] and Uwe H. F. Bunz[†,‡,]**

[†]Organisch-Chemisches Institut, Ruprecht-Karls-Universität Heidelberg, Im Neuenheimer Feld 270, 69120 Heidelberg, Germany

[‡]CAM, Centre for Advanced Materials, Ruprecht-Karls-Universität Heidelberg, Im Neuenheimer Feld 225, 69120 Heidelberg, Germany

ABSTRACT: Two nine-element sensor arrays, consisting of either three cationic poly(*para*-phenyleneethynylene)s (PPE) or the same PPEs complexed by cucurbituril[8] (CB[8]) at pH 3, 7 and 13 in water, discriminate 22 different teas and some of their small molecule components, including caffeine, theobromine and theophylline. Both arrays distinguish all of the black, green and oolong teas. The discrimination occurs by differential fluorescence modulation of the components of the sensor array and the treatment of the collected data by linear discriminant analysis. The signal is generated by either simple quenching (PPE only array) or the disruption of the PPE/CB[8] complex and quenching of the complex's or the PPEs' fluorescence through the polyphenolic colorants of the teas. Added amino acids, theobromine, theophylline and caffeine give a fluorescence turn on of the PPE-CB[8] array, due to the disruption of the self-assembled complex, while for the PPE-alone tongue, only caffeine, theobromine and theophylline elicited useful fluorescence response. Both tongues discriminate different teas without any problem.

KEYWORDS: poly(*para*-phenyleneethynylene)s, cucurbituril[8], sensor array, linear discriminant analysis, tea

INTRODUCTION

Here we test the hypothesis that fluorescent sensor arrays discriminate different green, oolong and black teas. We also investigate if a simple fluorescent polyelectrolyte array suffices or if a more complex cucubituril-fluorescent polyelectrolyte complex is necessary for this type of discrimination.

The leaves, buds and stalks of the plant *Camellia sinensis* are, after fermentation and/or roasting used in infusions of hot water, "tea". Unfermented versions go as green teas, lightly fermented are oolong and fully fermented are black teas. A supremely popular beverage, it is suspected of health benefits - also, its caffeine content of around 4.5% refreshes the tired mind. Teas come in many price ranges and taste variants; the plants are cultivated in Africa and Asia.

Due to the economic impact, a large number of papers have dealt with quality control and discrimination of different types and qualities of tea. Typical in the older literature are GC-MS,[1-2] near IR-type approaches,[3-4] and electrochemical e-noses and e-tongues[5-7] that discriminate the main compounds in teas; recently the group of Hou[8] has developed an elegant colorimetric approach for the discrimination and identification of different green, oolong and black teas. There the sensor's response was calculated as result of the color change, yet, colorants from interfering substances could produce errors. Our fluorescence-based method is sensitive and robust, because the fluorescence intensity is modulated by even smallest amounts (micrograms per milliliter) of analyte. The system in this work does not need *any* sample preparation and is equal or superior to state-of-the-art methods with respect to speed, resolution and efficiency of discrimination; fluorescence-based hypothesis-free array methods have to our knowledge *not* been employed to discriminate teas and therefore this is a fundamentally attractive proposition.

Teas are attractive analytes as they consist of at least two very different classes of component mixtures that determine their character. On the one hand, there are small molecules such as amino acids, caffeine etc. determining the taste of tea. Amino acids are primary metabolites from the nitrogen cycle of tea trees and basic constituents of proteins in tea leaves. Caffeine and the amino acids are direct small molecule targets for the discrimination and the quality control of teas. On the other hand, teas contain macromolecules including polyphenols etc. that affect the flavor, consistency and are speculated to provide potential health benefits.

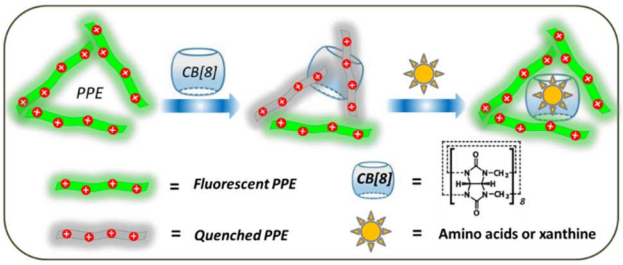

Figure 1. Schematic illustration of PPE/CB[8] tongue and fluorescence modulation after adding analytes.

We here develop two different libraries for the discrimination of teas. One is poly(*para*-phenyleneethynylene (PPE) based, similar to one that has been used for detection of other analytes (white wines, whiskies, amino acids, juices, proteins, non-steroidal anti-inflammatories, etc),[9-15] where hydrophobic and electrostatic interactions cause the signal generation,[10, 15] but also, a PPE-cucurbit[8]uril (CB[8]) complex, *where the disruption of the complex* generates a fluorescence turn on signal. This second library employs host-guest interactions that modify the sensory response of the PPEs.[16-17] Cucurbit[n]urils (CB[n]) are macrocyclic structures formed from an acid catalyzed condensation of glycoluril and formaldehyde. CB[n] have a toroidal structure and a hydrophobic interior cavity, which provides an encapsulation site for guest molecules and carbonyl-lined portals bind charged molecules by charge-dipole or hydrogen bonding interactions.[18-21] Water soluble CB[n] are promising hosts for binding of analytes. CB[8]

is also large enough to bind two organic guests simultaneously.[22] Therefore, host-guest complexes based on CB[8] are attractive for sensing in a displacement assay using arrays.[23-27]

RESULTS AND DISCUSSION

Complexation of PPEs by CB[8]. Figure 1 shows the schematic illustration of PPE-cucurbituril[8] complexes and their fluorescence intensity modulation after addition of analytes. CB[8] simultaneously complexes two PPE chains, which aggregates the PPE-chains and decreases their fluorescence intensity. CB[8] has a large cavity, which allows the encapsulation of amino acids or xanthine. When the analytes are incubated with the PPE/CB[8] complexes, we would expect competitive binding between them, and an expected fluorescence turn on under expulsion of the PPE-chains.

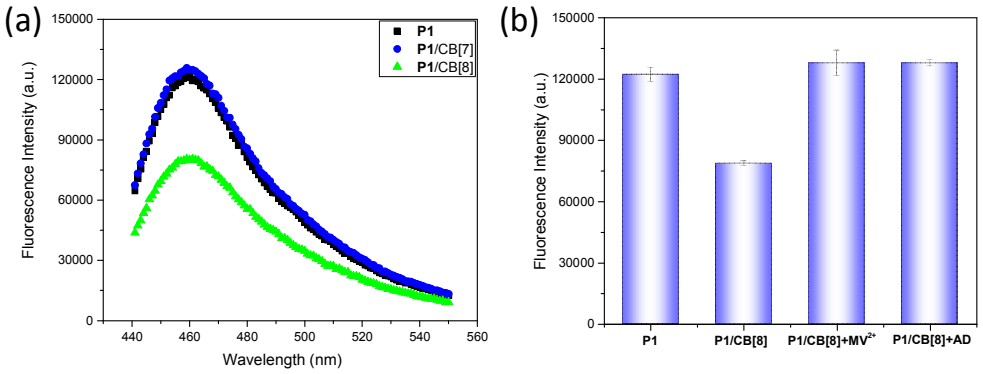

Figure 2. (a) Fluorescence intensity properties of **P1** (1 μM, black square), **P1**/CB[7] (1 μM/50 μM, blue circle) and **P1**/CB[8] (1 μM/6 μM, green triangle). (b) Fluorescence response pattern obtained by **P1**, **P1**/CB[8], **P1**/CB[8] + MV^{2+} and **P1**/CB[8] + AD (MV^{2+}: methyl viologen, AD: adamantylamine). Each value is from the average of two independent measurements.

Upon mixing of CB[8] and **P1** (Figure 2a) quenching is observed; while addition of CB[7] does not affect the fluorescence intensity of **P1**, even though the concentration of CB[7] is 8 times higher than that of CB[8]. The reversibility of the **P1**/CB[8] complexation was investigated by addition of CB[8]-binders methyl viologen (MV^{2+}) and adamantylamine (AD).[17, 28-29] Upon

adding MV^{2+} or AD, stable CB[8]/MV^{2+} or CB[8]/AD complexes are formed, the PPE chains are released, and fluorescence restored (Figure 2b). Therefore, PPE/CB[8] complexes might serve as a sensitive probe for strongly binding guests.

A library of 9 positively charged PPEs (for the structures, see Figure S1) was available. According to principal component analysis, three polymers, **P1** (positive charge), **P2** (higher positive charge) and **P3** (positive charge), were selected as they displayed the highest discriminative power for teas (Figure S2). Acidic, neutral and basic pH conditions were further investigated. This sensor system is much more sensitive at pH 7 (concentration of tea infusion: 0.01 mg/mL, Figure S5) than at pH 3 and 13 (concentration of tea infusion: 0.1 mg/mL, Figure S4). Finally, screening arrived at a suitable tongue consisting of 18 elements, **P1-P3** and **P1-P3**/CB[8] at pH 3, 7 and 13 (Figure 3, grey and purple circles).

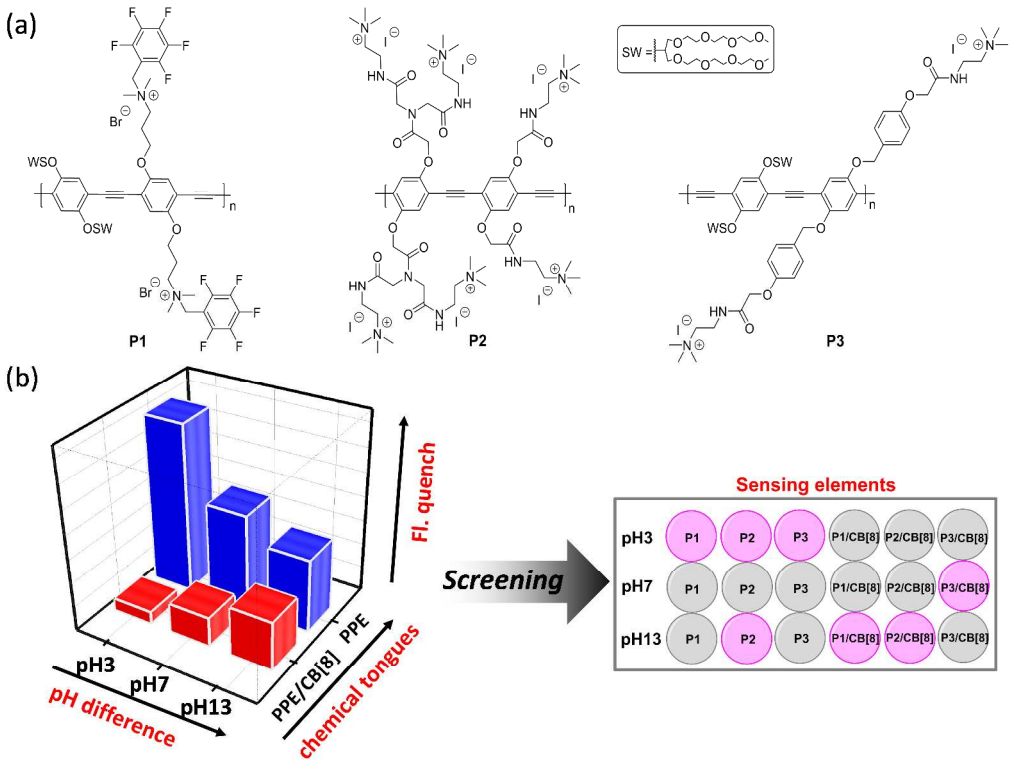

Figure 3. (a) Chemical structures of the used poly(*p*-phenyleneethynylene)s **P1-P3**. (b) Systematic evaluation and selection of the successful tongue elements for sensing.

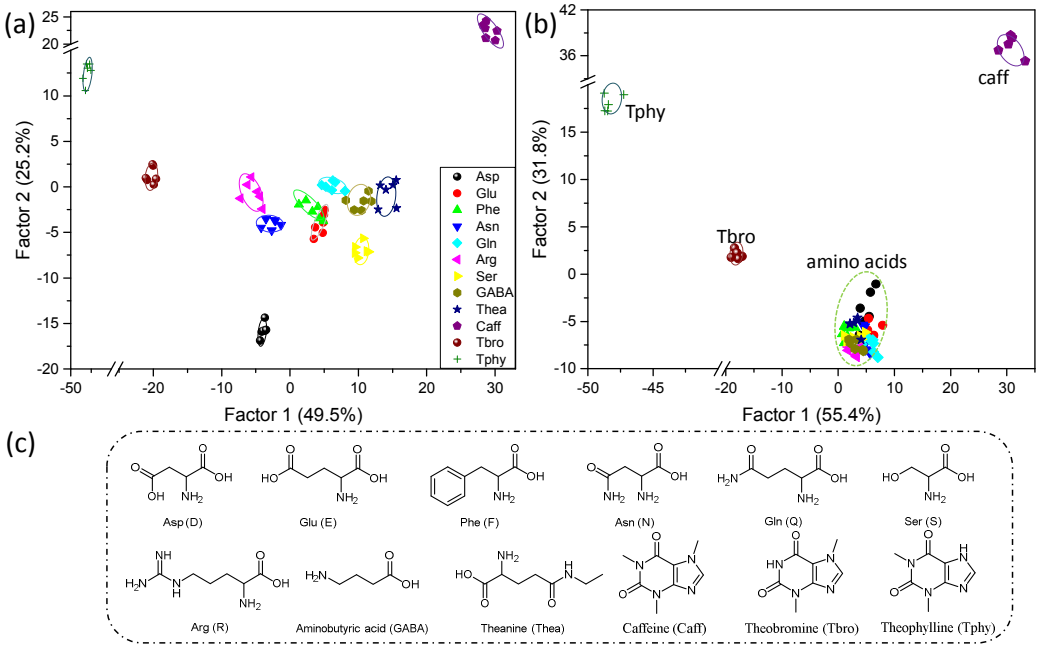

Figure 4. 2D canonical score plot for the first two factors obtained by (a) PPE/CB[8] tongue (1.2 μM/9.0 μM, at pH 3 and 13, buffered) and (b) PPE-only-tongue (1.2 μM, at pH 3 and 13, buffered) treated with tea related analytes (c = 10 mM) with 95% confidence ellipses. Each point represents the response pattern for a single analyte to the array. (c) Structures of key components in tea leaves.

Discrimination of tea-based amino acids and caffeine-types: Amino acids are one of the three key components (polyphenols, amino acids and caffeine) that determine the characteristic flavor and taste of tea.[30-31] More than 26 different amino acids have been found in tea, including the 20 basic amino acids and 6 non-proteinogenic amino acids. Theanine, aspartic acid, glutamic acid, phenylalanine, asparagine, glutamine, arginine, serine and γ -aminobutyric acid contribute most to the total amino acid content in tea.[8, 32-33] Theobromine and theophylline are also found in tea, but in smaller amounts.[34] In the following experiments we treated the two different libraries (PPE-CB[8]-array and PPE-only-array) with the 12 analytes (9 amino acids and three xanthine types, Figure 4c). The results indicated that the simple PPE tongue alone is useful for the discrimination of caffeine, theobromine and theophylline but does not discriminate the other key

components (amino acids, Figure 4b and Figure S7) well; however, the addition of CB[8] to the PPEs imbues selectivity towards all of these small molecule analytes (Figure 4a). According to the 2D-LDA (Figure 4a), the PPE/CB[8] tongue discriminates all of these compounds. 46 of 48 unknown samples were correctly identified, representing an accuracy of 96% (Table S1-3).

Table 1. Detailed Information of the Investigated Teas (8 Black Teas B1-B8, 6 Green Teas G1-G6 and 8 Oolong Teas O1-O8) Used in This Study

Abbr.	Category	Fermentation	Company	Brand name	Geographical origin
B1	Black tea	Fermented	Teekanne	Earl Grey	-
B2	Black tea	Fermented	Teekanne	Assam	Assam, India
B3	Black tea	Fermented	Teekanne	Ostfriesen Gold	-
B4	Black tea	Fermented	Teekanne	Darjeeling	Darjeeling, India
B5	Black tea	Fermented	Meßmer	Darjeeling	Darjeeling, India
B6	Black tea	Fermented	Tee Gschwendner	Flugtee Nepal	Nepal
B7	Black tea	Fermented	Tee Gschwendner	Flugtee Nordindien	India
B8	Black tea	Fermented	Tee Gschwendner	Flugtee Darjeeling	Darjeeling, India
G1[a]	Green tea	Non-fermented	-	Longjing	Hangzhou, China
G2[a]	Green tea	Non-fermented	-	Longjing	Hangzhou, China
G3	Green tea	Non-fermented	Teekanne	Grüner Tee	China
G4	Green tea	Non-fermented	Meßmer	Grüner Tee	China
G5	Green tea	Non-fermented	-	Linglong	Guidong, China
G6	Green tea	Non-fermented	-	Biluochun	Dongting, China
O1[a]	Oolong tea	Semi-fermented	-	Tieguanyin	Anxi, China
O2[a]	Oolong tea	Semi-fermented	-	Tieguanyin	Anxi, China
O3	Oolong tea	Semi-fermented	-	Huangguanyin	Wuyishan, China
O4	Oolong tea	Semi-fermented	-	Tieluohan	Wuyishan, China
O5[a]	Oolong tea	Semi-fermented	-	Rougui	Wuyishan, China
O6[a]	Oolong tea	Semi-fermented	-	Rougui	Wuyishan, China
O7	Oolong tea	Semi-fermented	-	Shuixian	Wuyishan, China
O8[a]	Oolong tea	Semi-fermented	-	Rougui	Wuyishan, China

[a] Tea samples (G1, G2; O1, O2 and O5, O6, O8) are obtained from different manufacturers in China. "-" means not known.

Discrimination of Teas: The two investigated tongues allow differentiation of teas by brand, price, quality grades and geographic origins. Table 1 displays the teas selected for study. In the

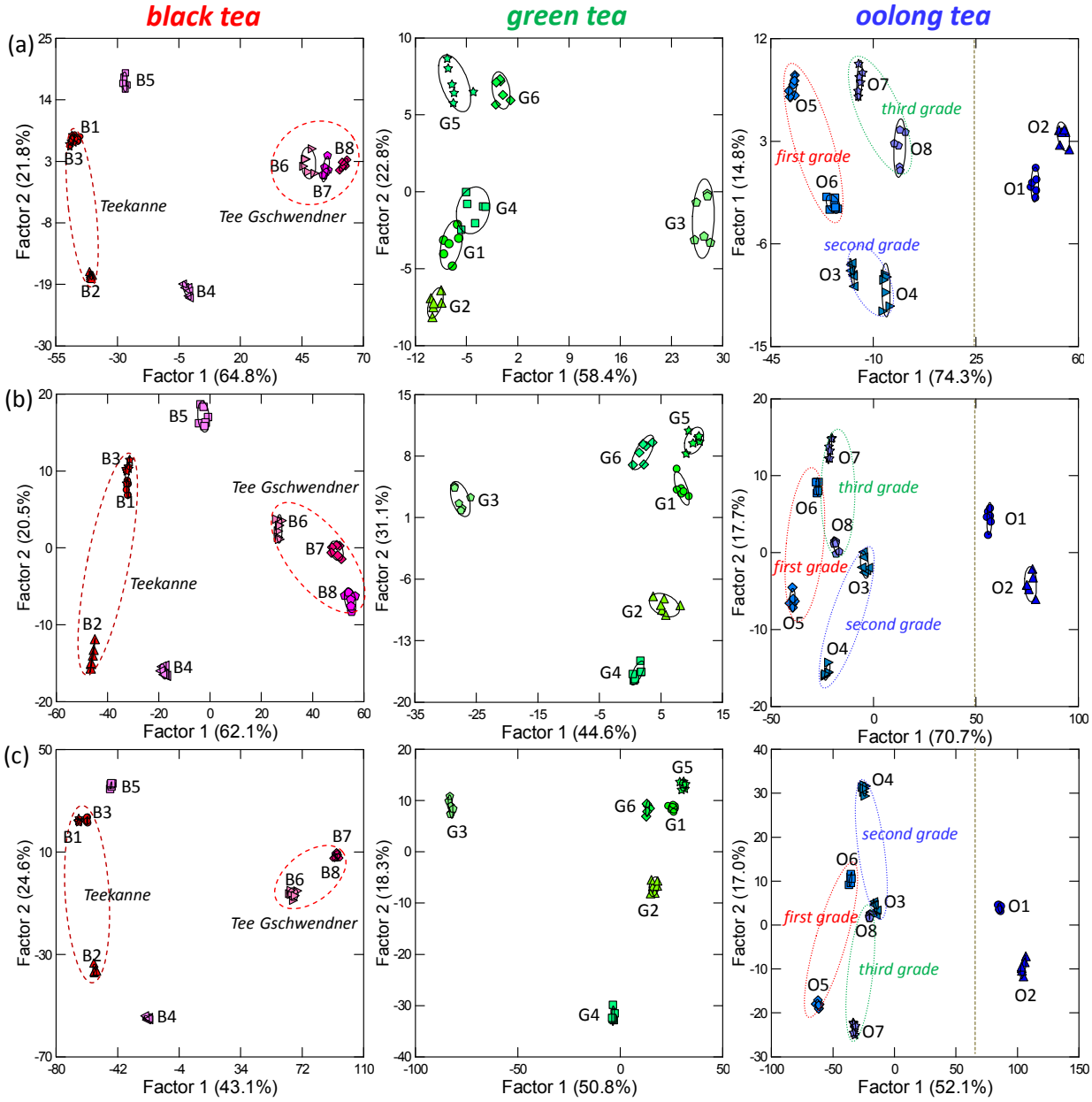

Figure 5. 2D canonical score plot obtained by an array of (a) PPE/CB[8] tongue (1.2 μM/9.0 μM, at pH 3, 7 and 13, buffered); (b) single PPE-tongue (1.2 μM, at pH 3, 7 and 13, buffered); (c) combined tongue of PPE/CB[8] tongue and single PPE-tongue treated with different black teas, green teas and oolong teas (0.1 mg/mL at pH 3 and 13, 0.01 mg/mL at pH 7, respectively) with 95% confidence ellipses. Each point represents the response pattern for a single analyte to the array. The vertical line in oolong tea denotes geography. O1 and O2 share the brand (Tieguanyin) and grow in same district, but were obtained from different manufacturers.

LDA plot of the data of the PPE-CB[8]-array (Figure 5a) black tea samples B1, B2 and B3 cluster together; B6, B7 and B8, high quality Darjeeling teas, expensive, are of the same type but from a different producer and also group. The quality grade of the tea products determines their value, of which the price may vary from cents to multiple of dollars per gram, and therefore, it is attractive to be able to perform simple quality control.[5]

Table 2. Jackknifed Classification Matrix and Unknown Sample Identification Obtained From LDA

Tongue	Tea samples	Jackknifed classification matrix			Unknown samples identification		
		Number of samples	Correctly classified	Accuracy (%)	Number of samples	Correctly classified	Accuracy (%)
PPE-CB[8] tongue	black tea	48	47	98	32	29	91
	green tea	36	35	97	24	24	100
	oolong tea	48	48	100	32	32	100
	all teas	132	132	100	88	85	96
PPE tongue	black tea	48	48	100	32	31	97
	green tea	36	36	100	24	24	100
	oolong tea	48	48	100	32	32	100
	all teas	132	132	100	88	85	96
Combined tongue	black tea	48	48	100	32	30	94
	green tea	36	36	100	24	24	100
	oolong tea	48	48	100	32	32	100
	all teas	132	132	100	88	87	99

Eight oolong tea samples, produced in two different districts (Anxi and Wuyishan, Fujian, China) were further analyzed. Oolong tea samples from Anxi (O1 and O2) are located in the upper right corner of the score plot, while Wuyishan teas (O3-O8) are located in the left region of the scatter plot (Figure 5a); the three quality grades, first grade (O5, O6), second grade (O3, O4) and third grade (O7, O8) are well discriminated. In Figure 5b, the PPE tongue was employed. Overall, the discriminative power is similar to that of the PPE/CB[8] tongue and in some better for black teas. The six Wuyishan teas of three different quality grades also cluster well. Figure 5c shows the 2D score plot of the first two canonical scores obtained by the combination of both tongues. As

expected, the overall resolution of the combined array has increased; however, the system does not distinguish between the black teas B7 and B8 when only looking at two scores.

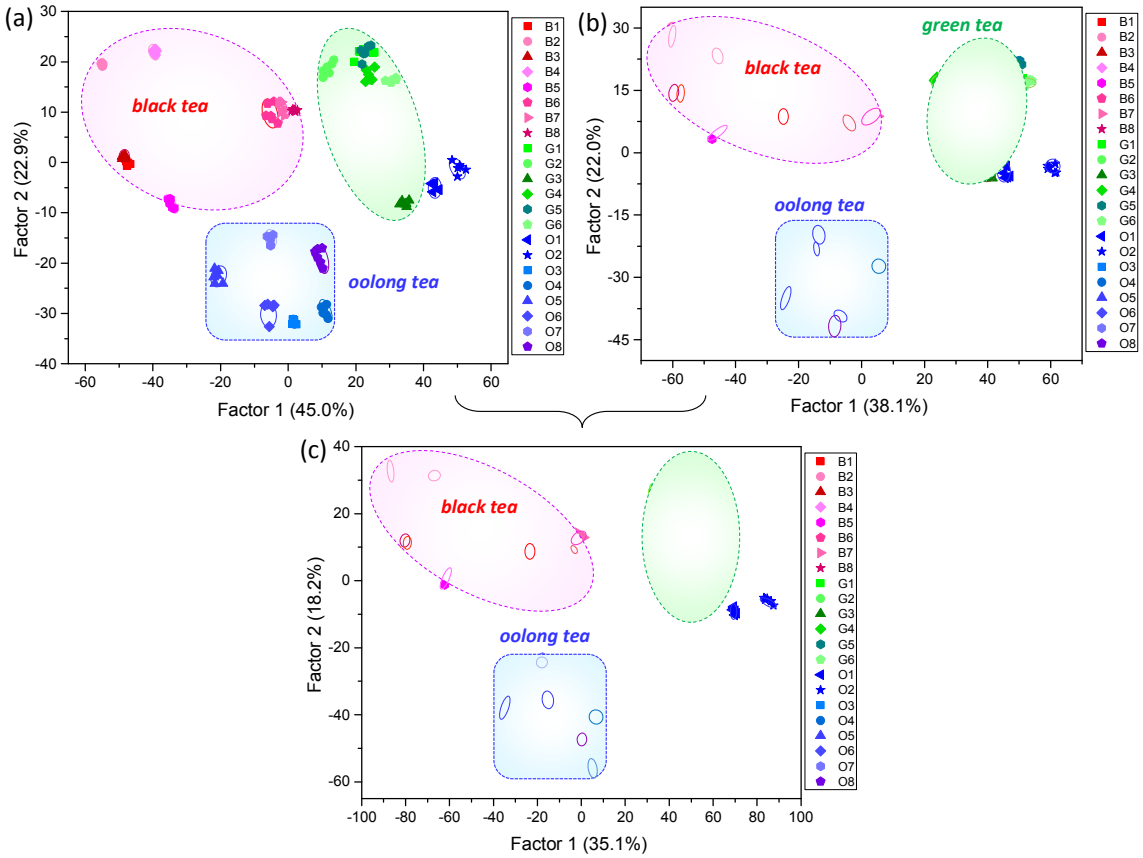

Figure 6. 2D canonical score plot for the first two factors obtained with an array of (a) PPE/CB[8] tongue (1.2 μM/9.0 μM, at pH 3, 7 and 13, buffered); (b) PPE tongue (1.2 μM, at pH pH 3, 7 and 13, buffered) and (c) combined tongue of the PPE/CB[8] tongue and the PPE-only-tongue treated with 22 kinds of teas with 95% confidence ellipses. Each point represents the response pattern for a single analyte to the array.

The 2D plots of the first two canonical scores obtained by the PPE/CB[8] tongue and the simple PPE-tongue for all teas - convert the training matrix 2 × (9 factors × 22 teas × 6 replicates) into canonical scores according to their shortest Mahalanobis distances (Figure 6, Table S4-5). Both tongues discriminate 85 of 88 unknown samples, representing an accuracy of 96% (Table 2). The two arrays have similar power in discrimination but show somewhat different, complementary

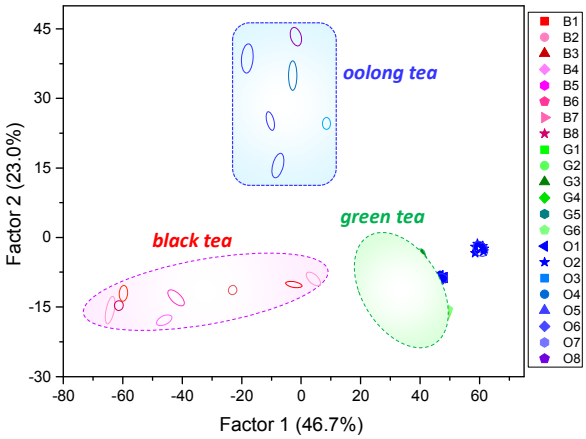

Figure 7. 2D canonical score plot for the optimized tongue obtained by an array of seven elements (**P3**/CB[8] (pH 7), **P1**/CB[8] (pH 13), **P2**/CB[8] (pH 13), **P1** (pH 3), **P2** (pH 3), **P3** (pH 3) and **P2** (pH 13).

selectivity. The complex tongue discriminates oolong teas better, while the PPE-tongue itself is better at discriminating black and green teas. Although the PPE/CB[8] tongue shows excellent discrimination of the small key compounds in tea, the PPE tongue alone is also very powerful, because it displays strong discriminative power for xanthine-type structures (caffeine, theobromine and theophylline). After combining the two tongues, the result looks similar to the result gathered from the simple PPE tongue, but with improved discrimination results (Figure 6c). The combined tongue identifies 87 of 88 unknown samples, improving the accuracy to a 99%. Starting from this 18-element tongue, we performed a three-stage pruning process, using principal component analysis (PCA, Figure S14) to reduce the number of elements without losing discriminative power. A seven-element array (Figure 3, purple circles) identifies all of the 22 teas (Figure 7). The oolong teas O1 and O2 localize in all score plots, regardless of the employed array quite close to green teas. We inspected the leaves of all teas and find that oolong tea leaves have an appearance that is similar to that of black teas. The leaves of O1, O2 however resemble those of green teas and show a similar light appearance (Figure S15), whereas the

leaves of O3-O8 are much darker. It seems that O1 and O2 were fermented much less, rendering them more similar to the green teas.

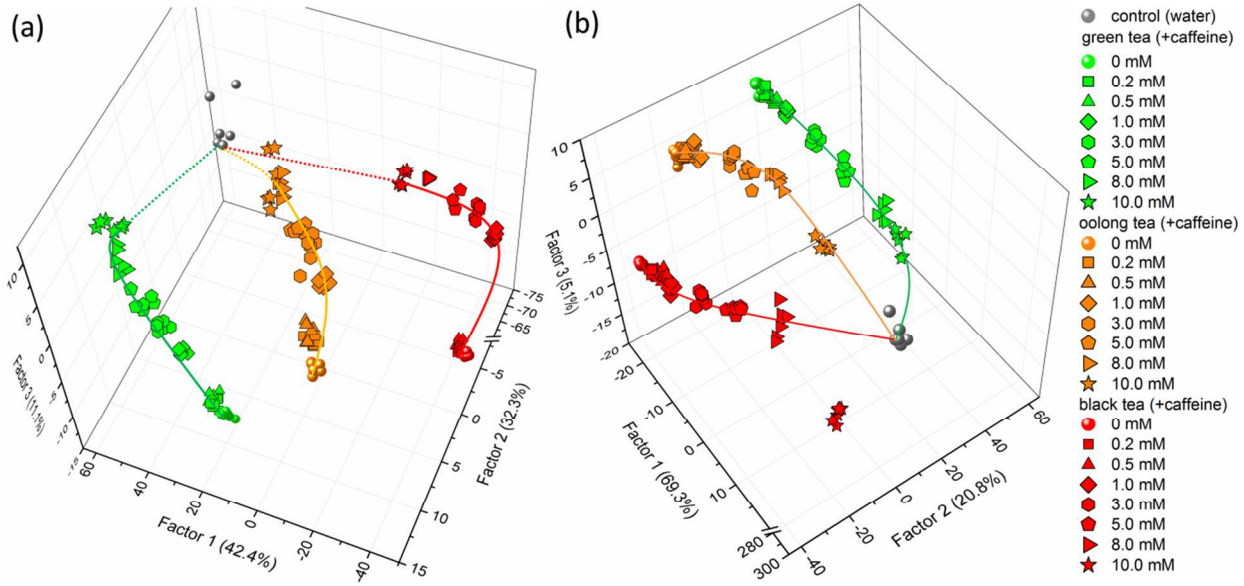

Figure 8. 3D canonical score plot obtained with an array of (a) PPE/CB[8] (1.2 µM/9.0 µM) and (b) PPE-only-tongue (1.2 µM) treated with different concentrations of caffeine (0-10 mM) in three kinds of tea infusions.

Caffeine-determination in teas. Based on the successful discrimination of teas with such a sensor array, we carried out a semi-quantitative assay to identify caffeine at various concentrations (from 0.2 mM to 10 mM) in three different tea infusions employing the complex tongue. The fluorescence modulation data were recorded and an LDA with canonical scores was calculated (training matrix, 6 factors × 8 concentrations ×6 replicates). The first three canonical factors represent 86% of the total variation. The jackknifed classification matrix with cross-validation reveals 91% accuracy (Table S6). As shown in Figure 8a, the concentration is almost linearly mapped in the LDA plot, and added caffeine could be discriminated and also scaled with concentration in the presence of different teas. By spiking caffeine in tea, the fluorescence intensity gradually increases with increasing caffeine concentration (Figure S10), giving insights

into the detection mechanism. CB[8] has a large cavity, which allows the encapsulation of caffeine; competitive binding between caffeine and CB[8] displaces the PPEs from the cavity and restores fluorescence. We can readily observe this using the simple PPE-tongue (Figure 8b, Figure S13 and Table S9), which shows that different concentration (> 3 mM) of added caffeine could also be discriminated. We find that the complex tongue is a bit more sensitive, but over all the simple PPE-based array is useful.

CONCLUSIONS

We have created a library consisting of positively charged PPEs complexed with CB[8] at different pH values. This array discriminates tea-based amino acids and caffeine-types by a displacement array. When CB[8] is omitted, with PPEs alone, caffeine, theobromine and theophylline in tea infusions are also discriminated. Both the PPE and PPE/CB[8] array generate exquisitely sensitive patterns for teas on the basis of differential fluorescence quenching and order tea samples with respect to brand, price, quality grades and geographic origins. A combined tongue of both arrays is even more powerful; 99% of all of the investigated teas are discriminated. PCA based culling reveals that a seven-element tongue suffices to discriminate the teas. Over all, the fairly simple PPE-based sensor arrays do an excellent job for quality control and differentiation of teas. So in some ways it is not absolutely necessary to employ additional supramolecular binders such as CB[8], but an effective pruned tongue contains both simple PPEs but also CB[8]-complexed elements, giving testament to the function of the commercially (!) available adjuvant CB[8]. Over all, the simple environmentally friendly setup makes these sensor arrays attractive for applicative tasks in quality control and the detection and discrimination of fraud/fake teas. On a more fundamental level, this contribution shows that teasing out of information from very simple arrays should be re-framed as an emergent

phenomenon, in which almost trivially constructed arrays discriminate almost any analyte. This concept-particularly when executed with water soluble conjugated polymers such as the PPEs seems to be universally applicable as long as it is not necessary to identify and quantify trace components. Our recent contributions support this notion.

ASSOCIATED CONTENT

Supporting Information

The Supporting Information is available free of charge on the ACS Publication website at DOI: General information, synthetic details and analytical data for **P1-P3**, complex titrations and determination of K_{SV} constants, additional screening and LDA data (PDF).

AUTHOR INFORMATION

Corresponding Author

*E-mail: uwe.bunz@oci.uni-heidelberg.de

Author Contribution

The paper was written through contributions of all authors. All authors have given approval to the final version of the paper. # These authors contribute equally.

Notes

The authors declare no competing financial interest.

ACKNOWLEDGEMENTS

The authors thank Shaoxiong Zhang (Fujian Agriculture and Forestry University, Fujian, China), Haoran Chen and Gaozhan Xie (Ruprecht-Karls-Universität Heidelberg, Heidelberg, Germany)

for their assistance with sample collection and technical advice. B. W. is grateful to the CSC (Chinese Scholarship Council) for a fellowship.

REFERENCES

1. Ye, N.; Zhang, L.; Gu, X., Discrimination of Green Teas from Different Geographical Origins by Using HS-SPME/GC–MS and Pattern Recognition Methods. *Food Anal Methods* **2012,** *5*, 856-860.

2. Baldermann, S.; Yang, Z.; Katsuno, T.; Tu, V. A.; Mase, N.; Nakamura, Y.; Watanabe, N., Discrimination of Green, Oolong, and Black Teas by GC-MS Analysis of Characteristic Volatile Flavor Compounds. *Am. J. Anal. Chem.* **2014,** *5*, 620-632.

3. Chen, Q.; Zhao, J.; Fang, C. H.; Wang, D., Feasibility Study on Identification of Green, Black and Oolong Teas Using Near-Infrared Reflectance Spectroscopy Based on Support Vector Machine (SVM). *Spectrochim. Acta, Part A* **2007,** *66*, 568-574.

4. He, Y.; Li, X.; Deng, X., Discrimination of Varieties of Tea Using Near Infrared Spectroscopy by Principal Component Analysis and BP Model. *J. Food Eng.* **2007,** *79*, 1238-1242.

5. Yu, H.; Wang, J., Discrimination of LongJing Green-Tea Grade by Electronic Nose. *Sens. Actuators, B* **2007,** *122*, 134-140.

6. Ivarsson, P.; Holmin, S.; Höjer, N.-E.; Krantz-Rülcker, C.; Winquist, F., Discrimination of Tea by Means of a Voltammetric Electronic Tongue and Different Applied Waveforms. *Sens. Actuators, B* **2001,** *76*, 449-454.

7. Yu, H.; Wang, Y.; Wang, J., Identification of Tea Storage Times by Linear Discrimination Analysis and Back-Propagation Neural Network Techniques Based on the Eigenvalues of Principal Components Analysis of E-Nose Sensor Signals. *Sensors* **2009,** *9*, 8073-8082.

8. Li, J.; Fu, B.; Huo, D.; Hou, C.; Yang, M.; Shen, C.; Luo, H.; Yang, P., Discrimination of Chinese Teas According to Major Amino Acid Composition by a Colorimetric IDA Sensor. *Sens. Actuators, B* **2017,** *240*, 770-778.

9. Han, J.; Bender, M.; Seehafer, K.; Bunz, U. H. F., Identification of White Wines by using Two Oppositely Charged Poly(p-phenyleneethynylene)s Individually and in Complex. *Angew. Chem. Int. Ed.* **2016,** *55*, 7689-7692.

10. Han, J.; Ma, C.; Wang, B.; Bender, M.; Bojanowski, M.; Hergert, M.; Seehafer, K.; Herrmann, A.; Bunz, U. H. F., A Hypothesis-Free Sensor Array Discriminates Whiskies for Brand, Age, and Taste. *Chem.* **2017,** *2*, 817-824.

11. Wang, B.; Han, J.; Ma, C.; Bender, M.; Seehafer, K.; Herrmann, A.; Bunz, U. H. F. A Simple Optoelectronic Tongue Discriminates Amino Acids. *Chem. Eur. J.* **2017,** *23*, 12471-12474.

12. Han, J.; Wang, B.; Bender, M.; Seehafer, K.; Bunz, U. H. F., Poly(p-phenyleneethynylene)-Based Tongues Discriminate Fruit Juices. *Analyst* **2017,** *142*, 537-543.

13. Miranda, O. R.; You, C.-C.; Phillips, R.; Kim, I.-B.; Ghosh, P. S.; Bunz, U. H. F.; Rotello, V. M., Array-Based Sensing of Proteins Using Conjugated Polymers. *J. Am. Chem. Soc.* **2007,** *129*, 9856-9857.

14. Bunz, U. H. F.; Rotello, V. M., Gold Nanoparticle–Fluorophore Complexes: Sensitive and Discerning "Noses" for Biosystems Sensing. *Angew. Chem. Int. Ed.* **2010,** *49*, 3268-3279.

15. Han, J.; Wang, B.; Bender, M.; Kushida, S.; Seehafer, K.; Bunz, U. H. F., Poly(aryleneethynylene) Tongue That Identifies Nonsteroidal Anti-Inflammatory Drugs in Water: A Test Case for Combating Counterfeit Drugs. *ACS Appl. Mater. Interf.* **2017,** *9*, 790-797.

16. Le, N. D. B.; Yesilbag Tonga, G.; Mout, R.; Kim, S.-T.; Wille, M. E.; Rana, S.; Dunphy, K. A.; Jerry, D. J.; Yazdani, M.; Ramanathan, R.; Rotello, C. M.; Rotello, V. M., Cancer Cell Discrimination Using Host–Guest "Doubled" Arrays. *J. Am. Chem. Soc.* **2017,** *139*, 8008-8012.

17. Liu, J.; Lan, Y.; Yu, Z.; Tan, C. S. Y.; Parker, R. M.; Abell, C.; Scherman, O. A., Cucurbit[n]uril-Based Microcapsules Self-Assembled within Microfluidic Droplets: A Versatile Approach for Supramolecular Architectures and Materials. *Acc. Chem. Res.* **2017,** *50*, 208-217.

18. de Vink, P. J.; Briels, J. M.; Schrader, T.; Milroy, L.-G.; Brunsveld, L.; Ottmann, C., A Binary Bivalent Supramolecular Assembly Platform Based on Cucurbit[8]uril and Dimeric Adapter Protein 14-3-3. *Angew. Chem. Int. Ed.* **2017,** *56*, 8998-9002.

19. Ghale, G.; Nau, W. M., Dynamically Analyte-Responsive Macrocyclic Host–Fluorophore Systems. *Acc. Chem. Res.* **2014,** *47*, 2150-2159.

20. Masson, E.; Ling, X.; Joseph, R.; Kyeremeh-Mensah, L.; Lu, X., Cucurbituril Chemistry: a Tale of Supramolecular Success. *RSC Adv.* **2012,** *2*, 1213-1247.

21. Dsouza, R. N.; Pischel, U.; Nau, W. M., Fluorescent Dyes and Their Supramolecular Host/Guest Complexes with Macrocycles in Aqueous Solution. *Chem. Rev.* **2011,** *111*, 7941-7980.

22. Barrow, S. J.; Kasera, S.; Rowland, M. J.; del Barrio, J.; Scherman, O. A., Cucurbituril-Based Molecular Recognition. *Chem. Rev.* **2015,** *115*, 12320-12406.

23. You, L.; Zha, D.; Anslyn, E. V., Recent Advances in Supramolecular Analytical Chemistry Using Optical Sensing. *Chem. Rev.* **2015,** *115*, 7840-7892.

24. Wu, J.; Kwon, B.; Liu, W.; Anslyn, E. V.; Wang, P.; Kim, J. S., Chromogenic/Fluorogenic Ensemble Chemosensing Systems. *Chem. Rev.* **2015,** *115*, 7893-7943.

25. Freudenberg, J.; Hinkel, F.; Jänsch, D.; Bunz, U. H. F., Chemical Tongues and Noses Based upon Conjugated Polymers. *Top. Curr. Chem* **2017,** *375*, 67.

26. Bunz, U. H. F.; Seehafer, K.; Bender, M.; Porz, M., Poly(aryleneethynylene)s (PAE) as Paradigmatic Sensor Cores. *Chem. Soc. Rev.* **2015,** *44*, 4322-4336.

27. Stewart, S.; Ivy, M. A.; Anslyn, E. V., The Use of Principal Component Analysis and Discriminant Analysis in Differential Sensing Routines. *Chem. Soc. Rev.* **2014,** *43*, 70-84.

28. Aryal, G. H.; Huang, L.; Hunter, K. W., Highly Fluorescent Cucurbit[8]uril-Perylenemonoimide Host-guest Complexes as Efficient Fluorescent Probes for N-terminal Phenylalanine. *RSC Adv.* **2016,** *6*, 82566-82570.

29. Gurbuz, S.; Idris, M.; Tuncel, D., Cucurbituril-Based Supramolecular Engineered Nanostructured Materials. *Org. Biomol. Chem* **2015,** *13*, 330-347.

30. Hung, Y.-T.; Chen, P.-C.; Chen, R. L. C.; Cheng, T.-J., Sequential Determination of Tannin and Total Amino Acid Contents in Tea for Taste Assessment by a Fluorescent Flow-Injection Analytical System. *Food Chem.* **2010,** *118*, 876-881.

31. Liang, Y.; Lu, J.; Zhang, L.; Wu, S.; Wu, Y., Estimation of Black Tea Quality by Analysis of Chemical Composition and Colour Difference of Tea Infusions. *Food Chem.* **2003,** *80*, 283-290.

32. Tan, F.; Tan, C.; Zhao, A.; Li, M., Simultaneous Determination of Free Amino Acid Content in Tea Infusions by Using High-Performance Liquid Chromatography with Fluorescence

Detection Coupled with Alternating Penalty Trilinear Decomposition Algorithm. *J. Agric. Food Chem.* **2011,** *59*, 10839-10847.

33. Horanni, R.; Engelhardt, U. H., Determination of Amino Acids in White, Green, Black, Oolong, Pu-erh Teas and Tea Products. *J. Food Compos. Anal.* **2013,** *31*, 94-100.

34. Sereshti, H.; Khosraviani, M.; Samadi, S.; Amini-Fazl, M. S., Simultaneous Determination of Theophylline, Theobromine and Caffeine in Different Tea Beverages by Graphene-Oxide Based Ultrasonic-Assisted Dispersive Micro Solid-phase Extraction Combined with HPLC-UV. *RSC Adv.* **2014,** *4*, 47114-47120.

TOC-Graphic