ABSTRACT: Molecularly imprinted polymers (MIPs) are synthetic receptors having specific cavities intended for a template molecule with a retention mechanism that depends on molecular recognition of the targeted constituent. They were initially established for the detection of minor molecules including drugs, pesticides, or pollutants. One of the most remarkable areas where MIPs have potential utilization is in food analysis, especially in terms of volatile compounds which are found in very low concentrations in foods but play a crucial role for consumer preference and acceptance. In recent years, these polymers have been used extensively for sensing volatile organic and off-odor compounds in terms of food quality for selective high-extraction purposes. This review first summarizes the basic principles and production processes of MIPs. Second, their recent applications in the separation, identification, and quantification of volatile and off-odor compounds in food samples are elucidated.

1. INTRODUCTION
Food safety is directly related to nutritional quality and human health. Accurate evaluation of analytes, such as the freshness of raw materials and the nutritional value of processed foods, food additives, microbial toxins, and antibiotic residues, is crucial for food safety. That is why the food industry is constantly developing effective analytical methods and technologies to ensure food safety and food quality. One of these innovations, molecular imprinting, is a technology that enables synthesis with highly selective sites on target molecules. Research in this technology has rapidly expanded in recent years due to its potential applications in various sectors including pharmaceutical, chemical, engineering, materials science, and biotech industries. In addition, one of the areas where this technique shows remarkable potential is food analysis. Molecular imprinted polymers (MIPs) have high selectivity and high loading capacity effectively minimizing complex food matrix effects; thus, they can be used as a sorbent in sample preparation to improve recoveries and detection limits. Molecular imprinted solid-phase extractions (MISPEs) have been successfully utilized to solve various problems in food processing and food analysis including common pesticide residues, drug residues, mycotoxins, toxic substances, such as toxic metal ions, additives/preservatives, and their components. In addition, the MISPE technique has also been used in some food samples in recent years for the purpose of separation and removal of volatiles and off-odorous compounds.

2. MOLECULAR IMPRINTED POLYMERS
Molecular imprinting technology was first put forward by Wulf and Sarhan in 1972. Later, this technology spread with the efforts of Mosbach and colleagues in the 1980s. Three different techniques are employed to arrange MIPs as covalent, semicovalent, and noncovalent methods. The covalent technique ensures the formation of homogeneous binding sites based on the high stability of the template and monomer, but division of the covalent bonds between the monomer and the template is a significant restriction as it is a very difficult situation. In the semicovalent approach, the template is covalently bonded with the monomer, but reconnection is the result of the noncovalent interactions. On the other hand, the noncovalent method relies on the establishment of fairly weak noncovalent interactions (such as hydrogen bonding, dipole–dipole bonds, hydrophobic and electrostatic interactions, and van der Waals forces) between the functional monomers and the template molecule before polymerization. This technique is simple, and due to the accessibility of various monomers that can interact with almost any template, it is the most widely used method for the application of MIPs. However, this approach has some disadvantages. Because the
template–monomer interactions are governed by the equilibrium process, a large amount of monomer is used to change the equilibrium when forming the template–monomer complex. An excess of free monomers is randomly added to the polymeric matrix, resulting in heterogeneous or non-selective binding sites. Despite its disadvantages, this method is still the preferred method for preparing molecularly imprinted polymers, as the noncovalent methodology is easy to carry out and removal of the template can only be accomplished by solvent extraction. This methodology was found to be more versatile, and the printing step was quite similar to the recognition pattern observed in nature.7

MIPs have high selectivity, affinity, and stability and can easily be prepared. They are resistant to harsh chemical environments and high temperatures and pressures without loss of activity compared to biological receptors. These polymers can be preserved for a long time without losing affinity for the target analyte. Five different components must be considered for the production of MIPs, which are the template, functional monomer, cross-linker, solvent, and initiator.9 In general, the type of functional monomer is determined based on the template and its functionality. The cross-linker provides 90% of the polymerizable groups defining the chemistry of the polymer, while in the synthesis of the polymers, the solvent plays an important role8 and is responsible for the establishment of pores in the polymer. For successful imprinting, the template must be soluble in a solvent but the solvent should not compete with the monomer in terms of an interface with the template.7 The process of the molecularly imprinted polymer is depicted schematically in Figure 1.

![Figure 1. Schematic representation of the polymerization of an acetophenone-MIP.7 Reprinted with permission from ref 9. Copyright 2022 Cukurova University/Nurten Cengiz.](https://doi.org/10.1021/acsomega.1c07288)

As can seen in Figure 1, acetophenone, which causes odor defects in water and food samples, has been used as a template, methyl methacrylate as a functional monomer, ethylene glycol dimethacrylate as a cross-linker, and acetonitrile as a solvent. The functional monomer is selected according to the structure of the template. The obtained polymer was designed to be used in food products, and the reason for selection of ethylene glycol dimethacrylate was the lower ratio of swelling of this cross-linker. MIP for acetophenone was obtained by a noncovalent and bulk polymerization method, which is a widely used synthesis method.9 Although this polymerization method is widely used in MIP synthesis, it has expectedly some drawbacks. The molecular diffusion is limited in this method due to weak noncovalent bonding forces, often requiring additional functional monomers to strengthen the interaction strength.3

The use of MIPs as sensors to detect the presence of contaminants in food has attracted great interest from many researchers who have given special importance to these materials as analytical instruments for assessing food safety. Research on MIPs has been a thriving field with a wide range of applications in the manufacture, processing, analysis, and quality control of foodstuff. MIPs provide some benefits such as high selectivity, sensitivity, and portability as well as a small sample requirement.14–20

3. USE OF MISPE IN FOOD FIELDS

Molecularly imprinted solid-phase extractions are widely used in separation, enrichment, pretreatment, and detection.10 The notable advantage of MISPEs is its target-selective affinity compared to conventional SPE adsorbents. Thus, it eliminates the matrix effect and ensures that the analysis is not affected by changes in the matrix composition in different samples. Hence, the MISPE technique has a robust and reproducible structure.10

In recent years, there has been more research focusing on MIPs as an adsorbant in solid-phase extraction (SPE) to create MISPE10 (Table 1). To date, a number of methodologies have been used, such as bulk polymerization, suspension polymerization, precipitation polymerization, swelling polymerization, and surface-imprinted polymerization by radical polymerization on porous silica.1a,2b,7 Despite some disadvantages, many researchers frequently use the bulk polymerization method because it necessitates simpler devices and the reaction parameters can easily be controlled.

MISPE was first used by Sellergen in 1994, and then different modes were developed by many researchers as off-line and online.11 In the online mode, the MISPE column is connected to a device and the concentration, separation, and detection processes are automatically performed, while off-line MISPE can be considered as similar to a typical SPE.11

As seen in Table 1, MISPE has been used extensively in the food industry for the analysis of different components in recent years. The bulk polymerization technique has extensively been employed in the polymer synthesis of MISPEs followed by precipitation, interference, and suspension polymerization techniques in foods (Table 1). Off-line mode has been utilized more widely because it is simple and easy in MISPE applications in foods; however, the online mode has been preferred in recent years due to the significant time advantage in clean up, separation, and detection stages.14–17 The MISPE technique has mostly been used in the off-line mode for the determination of compounds such as pesticides, phenolics, and phthalates in foodstuff including olive oils, meats, beverages, fruits, vegetables, etc. (Table 1).

4. USE OF MISPE FOR VOLATILE AND OFF-ODOR COMPONENTS

Volatile compounds possess remarkable significance in the flavor properties of foods, general quality, as well as consumer preference and acceptance. Volatile compounds consist of numerous chemical groups with low perception thresholds and directly affect food quality.12–14 MIPs are an essential detection method applied for the selective detection of volatile organic compounds (VOCs).15 These polymers can be used for the analysis of volatile compounds and in the enrichment or
| analyte (target molecule) | template | food sample | preparation method | linear range | MISPE mode | analytical system | ref |
|---------------------------|----------|-------------|--------------------|--------------|------------|-------------------|-----|
| dibutyl phthalate (DBP), diethyl phthalate (DEP), butyl benzyl phthalate (BBP), dimethyl phthalate | dibutyl phthalate | water, wine | precipitation polymerization | 10−500 μg/L | off-line | HPLC-ESI-MS | 17a |
| methidathion | methidathion | olive oil | thermal polymerization | 0.1−9 mg/L | online | MISPE-HPLC-UV | 17b |
| dimethoate | dimethoate | olive oil | interfer polymerization | 8−500 mg/L | off-line | HPLC-DAD | 17c |
| tert-buthylazine | tert-buthylazine | olive oil | interfer polymerization | 0.01−0.07 mg/L | off-line | HPLC-DAD | 17d |
| florfenicol | florfenicol | chicken, fish, honey | bulk and precipitation polymerization | 5−50 μg/mL | off-line | HPLC | 17e |
| olaquindox | olaqueindox | chicken | bulk polymerization | 20−200 mg/L | online | MISPE-HPLC | 17f |
| catechin | catechin | green tea | bulk polymerization | 1−200 μg/L | off-line | HPLC | 17g |
| dibutyl phthalate | dibutyl phthalate | soy milk | bulk polymerization | 0.005−0.1 mg/L | off-line | GC-MS | 17h |
| tetracycline (TC), chlortetracycline (CTC), oxytetracycline (OTC), doxycycline (DOX) | tetracycline | lobster, duck, honey, egg | precipitation polymerization | online | MISPE-HPLC | 17i |
| rutin, naringin, quercetin | rutin, quercetin | white wine, red wine, orange juice, tea | bulk polymerization | 2.5−25 μg/mL | off-line | HPLC | 17j |
| chloramphenicol | thiampenicol | milk | precipitation polymerization | 0.1−2 ng/mL | off-line | HPLC-MS/MS | 17k |
| metronidazole, dimetridazole, ipronidazole, ornidazole, tinidazole, carnidazole | 2-methyl-5-nitroimidazole | honey | bulk polymerization | 1−500 μg/kg | online | MISPE-HPLC-MS | 17l |
| simazine | simetryne | corn | precipitation polymerization | 0.2−0.8 μg/mL | online | MISPE-HPLC | 17m |
| benzylpenicillin | benzylpenicillin | milk | bulk polymerization | 0.5−10 mg/kg | off-line | LC-MS/MS | 17n |
| quercetin | quercetin | nettle | bulk polymerization | 6−24 μg/mL | off-line | UPLC | 17o |
| fenarimol | fenarimol | apple, banana, tomato | precipitation polymerization | online | HPLC | 17p |
| fenvalerate | fenvalerate | rice, wheat, beans | bulk polymerization | 0.01−5 mg/kg | online | MISPE-GC | 17q |
| dimethomorph | dimethomorph | ginseng | precipitation polymerization | | |

**Table 1. Molecular Imprinted Polymers for the Molecular Imprinted Solid-Phase Extractions in Food Samples**
| analyte template | food sample | preparation method | linear range | analytical system | ref |
|------------------|-------------|-------------------|--------------|-------------------|----|
| α-pinene, limonene, eucalyptol, β-pinene, terpinene, estragole vanillin | fresh and dried rosemary (*Rosmarinus officinalis* L.), basil (*Ocimum basilicum*), sage (*Salvia officinalis*) | spin coating | <20–1200 Hz | QCM | 19a |
| 3-carene hexanal | bread, milk powder, biscuit, chocolate | | | | |
| 3-carene hexanal | mango | | | | |
| 2,5-dimethyl-4-hydroxy-3(2H)-furanone furanone | mango | | | | |
| 4-ethylphenol furfural | mango | | | | |
| fluoroquinolones vanillin, ethyl vanillin, maltol, ethyl malto | milk | | | | |
| limonene 4-nitrophenol, 2,4-dinitroaniline formaldehyde, acetaldehyde, propionaldehyde, butyraldehyde furfural | carbonated beverage, energy beverage, orange juice, coffee, tea, wine | | | | |
| α-terpinyl acetate β-pinene | cardamom | | | | |
| formic acid, formaldehyde, acetaldehyde, propionaldehyde, butyraldehyde furfural | water | | | | |
| | | | | | |
| 4-ethylguaiacol, furfural | red wine | bulk polymerization | 0.25–20 mg/L | GC-FID and GC-IT/MS | 19i |
| ethylene furan furfural | banana, pear, orange | drop coating | 1–7 ppm | QCM | 19i |
| vanillin, ethyl vanillin, maltol, ethyl malto | canned tuna | | | | |
| limonene 4-nitrophenol, 2,4-dinitroaniline formic acid, acetaldehyde, propionaldehyde, butyraldehyde furfural | | | | | |
| α-terpinyl acetate β-pinene | | | | | |

*ACS Omega* http://pubs.acs.org/journal/acsodf

https://doi.org/10.1021/acsomega.1c07288

*ACS Omega* 2022, 7, 15258–15266

ACS Omega

Mini-Review
selective separation of aroma profiles in the food industry as a preisolation technique such as extraction of the solid phase for the current chromatographic investigation of flavors. There have been numerous studies related to MIPs and foodstuff, but a limited number of studies have been carried out on food volatile compounds, especially on wines, water, herbs, fruits, and vegetables. Some of these studies are summarized in Table 2.

4.1. Use of MISPE for Volatile Compounds. Volatile compounds have low molecular weight, and they are in gas form at room temperature. The detection and identification of volatiles in foods has been a popular study field of great interest. Traditional techniques including gas chromatography-mass spectrometry (GC-MS) for the analysis of volatiles have high sensitivity and selectivity, but they are costly. Thus, the demand for low-cost devices for the detection of volatile organic compounds is on an increasing trend. MIPs play an increasingly important role for the detection of VOCs. The most basic property of these polymers is the biomimetic molecular recognition function. MIPs provide an outstanding prospect to considerably improve VOC detection and a series of other applications. MIP applications for volatile compounds in food samples are shown in Table 2 that mainly concentrates on wines, water, herbs, fruits, and vegetables.

Detection of plant VOCs can be used for determining harvest time and follow pests and diseases in agriculture. MIPs are designed to adsorb these volatiles and can also function as a sensing element. The level of VOCs emitted during different stages of fruit maturity can be used to determine the ripeness levels of fruits and vegetables. Volatile and nonvolatile organic compounds with a boiling point of 40–200 °C have been reported to be detected by polymer-based quartz crystal microbalance (QCM) sensors. In a study conducted in India, a QCM sensor based on MIP was developed for the determination of 3-carene, which is an important aroma compound in mango fruit (M. indica L.). The selectivity of the MIP-modified sensor against the template analyte was checked by comparison with the NIP-coated QCM. It was also investigated whether volatile terpenes with similar structures could fit into the imprinted cavity. While the sensor could detect the 3-carene with a selectivity of 90.9%, the α-pinene, ocimen, β-caryophyllene, and Furaneol showed very weak selectivities of 2.9%, 2.6%, 2.2%, and 1.3%, respectively. The reproducibility of the sensor is 82.8%, and the reproducibility of the 3-carene compound is 93.9%. Vanillin (3-methoxy-4-hydroxybenzaldehyde) is a widely used and essential aroma component in food and cosmetic sectors due to its natural vanilla odor. Different methods are used in the analysis of this compound. One of them, chromatographic methods, has high selectivity and accuracy, but sample preparation takes time and requires complex initial procedures. Due to these drawbacks, Zhan and Yao developed a new method to improve the efficiency of this analysis for vanillin. They synthesized a PS-MIP by swelling suspension polymerization with the use of polystyrene (PS) as the “seed”. The authors elucidated that the PS-MIP showed better molecular recognition selectivity, improved adsorption capacity, and higher binding capacity in comparison with the MIP obtained by bulk polymerization.

In another study, piezoelectric quartz crystals were used as selective materials in quartz crystal microbalance sensors to detect D-limonene, which is an essential volatile compound in mangos. The authors prepared the imprinted sensor using methacrylic acid, ethylene glycol dimethacrylate, and limonene and determined the repeatability of the sensor as 98.4% and its reproducibility as 98.8%. The sensor was exposed to 300 ppm of terpene mixture vapor consisting of β-caryophyllene, α-pinene, β-pinene, γ-pinene, and limonene. The selectivity of the sensor for these compounds was 19.6%, 13.1%, 5.9%, 3.3%, and 58.2%, respectively as the limonene had the highest selectivity. This finding indicates that the template protects its selective structure against limonene better than other compounds.

α-Pinene and β-pinene are responsible for the typical odor in plants, and they are generally utilized as flavoring agents and spices in the food industry. Thus, it is important to study the freshness, usefulness, and shelf life of plants. Humaira et al. successfully developed a QCM molecular imprinted sensor modified with chitosan/α-pinene by employing the spin-coating method. In order to determine the selectivity of the sensor, the QCM modified with polymer chitosan was verified with another analyte such as ethanol, acetone, isoamyl alcohol, and n-amyl alcohol. The chitosan/α-pinene-based QCM sensor with a heating process showed high selectivity and sensitivity toward α-pinene. It was emphasized that the imprinting influence of the MIP process was successfully improved using α-pinene and chitosan polymer as the template.

Debabhuti et al. developed a QCM sensor with olive oil (OLVQCM) to detect β-pinene, which is an important VOC in Indian cardamom. It was found that hydrophobic vegetable oil containing monounsaturated fatty acids from olives was appropriate for the binding of β-pinene via noncovalent bonds. The sensor showed high sensitivity to β-pinene (R² = 0.99; 0.31 Hz/mg L⁻¹). The limit of detection (LOD) and limit of quantification (LOQ) were reported as 5.6 and 18.6 mg L⁻¹, respectively. The sensor was effectively selective toward β-pinene in cardamom in the presence of other dominant VOCs.

In a study on grass carp fillets, an MIP composite-based QCM gas sensor that is more selective, sensitive, and easy to use at room temperature and portable for the detection in humid conditions greatly increased the hexanal detection efficiency as compared to the SPME-GC-MS method. It was reported that this hydrophobic sensor could offer some new ideas for the development of highly sensitive and selective gas sensors for the quality assessment of agricultural products and human health assessment.

Methyl pyrazines, which are among the main flavor compounds in various seeds and grains, can be formed as a result of food processing, such as roasting and drying. Cruz et al. synthesized an MIP by photopolymerization using 2,3,5-trimethylpyrazine (3MP) and 2,5-dimethylpyrazine (DMP) as the template, methyl methacrylate-based monomer, and cross-linker with ethylene glycol dimethacrylate. They reported that the synthesized polymers showed selectivity for their respective templates.

4.2. Use of MISPE in Off-Odor Compounds. The organoleptic properties determined by the presence of the volatile compounds are some of the most crucial parameters for the quality and acceptance of the products by consumers. Hence, some MIP studies have been carried out for off-odor compounds in food samples such as wines, water, herbs, fruits, and vegetables (Table 2).

MIP studies with volatile compounds have been mostly reported for wine samples. Wine is a complex matrix with
many volatile and nonvolatile compounds. It contains low amounts of volatile phenols. These compounds contribute positively to the aroma of wine by providing spice, leather, and smoke odors in small amounts, but they result in off-odor at high concentrations.19b 4-Ethyl guaiacol (4-EG) and 4-ethyl phenol (4-EP) provide medicinal, horsey, barnyard, smoky, and animal aromas, which are undesirable odors in wine. The detection of these compounds is extremely important for wine producers to preserve wine quality and prevent economic losses.25 Dominguez-Renedo et al. developed a MIP-based electrochemical sensor for the sensitive and selective detection of 4-ethylphenol.25 They used 4-ethylphenol as the template and pyrrole as the monomer with electropolymerization. The MIP/GCE sensor showed acceptable detection (0.2 μM, α = β = 0.05) and repeatability (3.0%) for the range of 0.2–34.8 μM.

The detection of furanic compounds in fermented beverages is very important due to their effects on food flavor and their toxic and carcinogenic effects on humans. Pesavento et al. developed an SPR-optical fiber-MIP sensor for the detection of furfural compound in wine.20b They synthesized MIP using divinylbenzene (DVB), methacrylic acid (MAA), 2-furaldehyde (2-FAL), and 2,20-azobisisobutyronitrile (AIBN). They determined a low LOD value of 0.004 mg L−1 and underlined that the detection of furanic compounds in fermented beverages is very important because of their quality effects on the flavor and their toxic and carcinogenic effects on human health.

Detection of furan in foods such as canned tuna and tap water is difficult due to its very high volatility. Hashemi-Moghammad et al. synthesized a new MIP fiber using a furan compound with a new technique and studied the first MIP-based HS-SPME (synthesized pyrrole-imprinted monolithic fiber).20a Since the furan-imprinted polymers cannot be obtained efficiently due to the evaporation of furan during the polymerization stage, a pyrrole compound having a high boiling point but a structure similar to the furan was utilized as the template. The SPME fiber was more effective than the furan-imprinted monolithic SPME fiber for HS-SPME of furan analytes. The HS-SPME with a molecularly implanted SPME fiber showed that it is applicable to identify true samples of furan with low LOD values.

Another area of study on MIPs is water samples. Inadequate clean water supply in developing countries is a global problem affecting the health and lives of more than 1 billion people. Off-odors such as moldy and earthy that could be present in water affect its quality and consumer acceptability. Cengiz used the MISPE technique to remove the acetonophene that causes odor defects in water and rainbow trout (O. mykiss).26 Acetonophene is a simple aromatic ketone that is a colorless and viscous liquid. It was utilized as a template, while methyl methacrylate was used as a functional monomer, benzoyl peroxide as an initiator, ethylene glycol dimethacrylate as a cross-linker, and acetonitrile as a solvent. In the study, polymer synthesis was carried out using different ratios of template, functional monomer, cross-linker, and porogen. Acetonophene was obtained with a recovery of 86.5%. The synthesis of this polymer was confirmed with Fourier transform infrared (FTIR) and scanning electron microscopy (SEM) data (Figure 2). Figure 2a shows the FTIR spectra of the nonmolecularly imprinted polymers (NIP) and molecularly imprinted polymers, and Figure 2b shows the SEM image of the best MIP obtained as a result of the synthesis studies.

5. CONCLUSIONS

Molecularly imprinted polymers are effectively employed in the isolation, extraction, preconcentration, and detection of volatile and off-odor compounds in different food samples such as wine, water, olive oil, herbs, vegetables, and fruits. In the synthesis of MIPs for these compounds, some critical factors should be taken under consideration, such as solution composition, reaction temperature, time, properties of the template and monomer that improve the sorbent properties, and finally better selectivity. The MIPs significantly reduce the interference from complex matrices and efficiently improve the sensitivity and selectivity of detecting various volatile and off-odor components in numerous food samples. In these studies, researchers recommend working with MIP-based quartz crystal microbalance sensors to precisely detect volatile compounds that have a low molecular weight and are gaseous at room temperature.

In recent years, there has been more research focusing on MIPs as an adsorbent in solid-phase extraction to create molecularly imprinted solid-phase extraction. Bulk polymerization followed by precipitation, interference, and suspension polymerization techniques has extensively been employed in the polymer synthesis of MISPEs in foods. Off-line mode has been utilized more widely as it is simple and easy in MISPE applications in foods, but online mode has been preferred in recent years due to the significant time advantage in the cleanup, separation, and detection stages. The MISPE technique has mostly been used in the off-line mode for the detection of compounds such as pesticides, phenolics, and phthalates in foods.

In summary, the analytical methods based on MIPs provide a relatively simple analysis and have successfully been applied...
to food volatiles and off-odor analysis with higher selectivity and concentration in recent years, and it is believed that this approach will have broader application prospects in the near future. The use of innovative and bio-based materials via different polymerization methods increasing the ease of controlled adsorption and desorption of target analytes and active substances will be preferred almost in every sector. The key topic that should be taken into account forming the future of MIP synthesis is the potential use of natural polymers and green reactants.

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**Notes**

The authors declare no competing financial interest.

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Esra Capanoglu is a professor in the Food Engineering Department at Istanbul Technical University (ITU). She received her Ph.D. degree in 2008 at ITU and worked as a post-doctoral fellow in RWTH Aachen University, Germany, for 2 years. During her Ph.D. studies, she worked in the laboratories of Plant Research International (PRI), The Netherlands, for 6 months and in the IPK Leibniz Institute, Gatersleben, Germany, for another 6 months with a DAAD scholarship. She works on antioxidants and phenolic compounds in foods and their in vitro bioaccessibility/bioavailability. She also focuses on the effect of processing and matrix as well as encapsulation on these compounds. She has published two books, several chapters, and more than 150 papers in peer-reviewed journals and has been participating in several international and national projects. She is an Associate Editor for *ACS Omega* and an Editorial Advisory Board Member of the *Journal of Agricultural and Food Chemistry*, *Journal of Berry Research*, eFOOD, *Frontiers in Nutrition*, *Turkish Journal of Agriculture and Forestry*, and several others.

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**ACKNOWLEDGMENTS**

Dr. Nurten Kurt thanks TUBITAK (Grant no. 1002, project no. 119O604) for a scholarship. We also thank Prof. Dr. Muharrem Keskin from Hatay Mustafa Kemal University, Turkey for his outstanding editing and proof reading.

**REFERENCES**

(1) (a) Huang, C.; Wang, H.; Ma, S.; Bo, C.; Ou, J.; Gong, B. Recent Application of Molecular Imprinting Technique in Food Safety. *J. Chromatogr. A* 2021, 1657, 462579. (b) Villa, C. C.; Sánchez, L. T.; Valencia, G. A.; Ahmed, S.; Gutiérrez, T. J. Moleculary imprinted polymers for food applications: A review. *Trends Food Sci. Technol.* 2021, 111, 642–669.

(2) (a) Leibl, N.; Haupt, K.; Gonzato, C.; Duma, L. Molecularily implanted polymers for chemical sensing: A tutorial review. *Chem. Sensors* 2021, 9 (6), 123. (b) Jin, Y. Z.; Jin, Y. Z.; Piao, J. Y.; Jin, Y. S.; Xuan, Y. H. Application and Development of Molecularly Imprinted Polymer to Solid Phase Extraction. *Adv. Mater. Res.* 2013, 781–784, 1359–1365.

(3) Jin, Y.; Xuan, Y. H.; Jin, Y. S.; Row, K. H. Multi-Spe of Caffeine and Catechin Compounds from Green Tea by Caffeine and (+) Catechin MIPs. *J. Liq. Chromatogr. Relat. Technol.* 2011, 34 (15), 1604–1616.
(4) Wullf, G.; Sarhan, A. The Use of Polymers with Enzyme-Analogous Structures for the Resolution of Racemates. Angew. Chem., Int. Ed. Engl. 1972, 11 (4), 341–344.

(5) Andersson, L.; Sellergren, B.; Mosbach, K. Imprinting of Amino Acid Derivatives in Macroporous Polymers. Tetrahedron Lett. 1984, 25 (45), 5211–5214.

(6) Cowen, T.; Stefanucci, E.; Piletska, E.; Marrazza, G.; Canforotta, F.; Piletsky, S. A. Synthetic Mechanism of Molecular Imprinting at the Solid Phase. Macromolecules 2020, 53 (4), 1435–1442.

(7) Freitag, R. Molecularly Imprinted Polymers: A New Dimension in Analytical Bioseparation. Synthetic Polymers for Biotechnology and Medicine; CRC Press, 2002; Vol. 7, pp 142–170.

(8) Iuga, C.; Ortiz, E.; Noreña, L. Interaction between Volatile Organic Compounds and Functional Monomers in Molecularly Imprinted Materials. TechConnect Briefs 2011, 3, 777–780.

(9) Cengiz, N. Removal of Some Volatiles that Cause Odor Defects in Waters and Fish by Molecular Printed Solid Phase Extraction (MISPE) Method. Ph.D. Thesis, Cukurova University, Institute of Science, 2022; p 152.

(10) Wang, Q.; Liu, H.; Deng, Z.; Bu, J.; Li, T.; Yang, Y.; Zhong, S. A Critical Review of Molecularly Imprinted Solid Phase Extraction Technology. J. Polym. Res. 2021, 28 (10), 401.

(11) Yi, L.; Fang, R.; Chen, G. H. Molecularly Imprinted Solid-Phase Extraction in the Analysis of Genotoxic Chemicals. J. Chromatogr. Sci. 2013, 51 (7), 608–618.

(12) Selli, S.; Kilic Buyukkurt, O. Factors affecting on the release of aroma compounds Gida J. Food 2020, 204–216.

(13) Keskin, M.; Guclu, G.; Sekeri, Y. E.; Soysal, Y.; Selli, S.; Kelebek, H. Comparative Assessment of Volatile and Phenolic Profiles of Fresh Black Carrot (Daucus Carota L.) and Powders Prepared by Three Drying Methods. Sci. Hortic. 2021, 287 (May), 110256.

(14) Keser, D.; Guclu, G.; Kelebek, H.; Keskin, M.; Soysal, Y.; Sekeri, Y. E.; Arslan, A.; Selli, S. Characterization of Aroma and Phenolic Composition of Carrot (Daucus Carota 'Nantes') Powders Obtained from Intermittent Microwave Drying Using GC–MS and LC–MS/MS. Food Bioprod. Process. 2020, 119, 350–359.

(15) Debabutti, N.; Mukherjee, S.; Neogi, S.; Sharma, P.; Sk, U. H.; Maiti, S.; Sarkar, M. P.; Tudu, B.; Bhattacharyya, N.; Bandypadhyay, R. A Study of Vegetable Oil Modified QCM Sensor to Detect β-Pinen in Indian Cardamom. Talanta 2022, 236, 122837.

(16) Dela Cruz, E. O.; Muguruma, H.; Jose, W. I.; Pedersen, H. Molecular Imprinting of Methyl Pyrazines. Anal. Lett. 1999, 32 (5), 841–854.

(17) (a) Bariela-Alonso, M. C.; Otero-Lavandeira, N.; Bermejo-Rodriguez, A. Solid Phase Extraction Using Molecular Imprinted Polymers for Phthalate Determination in Water and Wine Samples by HPLC-ESI-MS. Microchem. J. 2017, 132, 233–237. (b) Bokas, L.; Ben Ouiji, N.; Moczko, E.; Istamboulie, G.; Pinene in Indian Cardamom. Maiti, S.; Sarkar, M. P.; Tudu, B.; Bhattacharyya, N.; Bandypadhyay, R. A. Molecularly Imprinted Solid Phase Extraction and Determination of Fenvalerate in Food Samples. J. Chromatogr. A 2014, 2016, 1017–1018, 89–100. (g) Khan, S.; Bhatia, T.; Trivedi, P.; Satyanarayana, G. N. V.; Mantrad, K.; Saxena, P. N.; Mudiam, M. K. R.; Roy, S. K. Selective Solid-Phase Extraction Using Molecularly Imprinted Polymer as a Sorbent for the Analysis of Fenarimol in Food Samples. Food Chem. 2016, 199, 870–875. (b) Nazhadali, A.; Feizy, J.; Beheshti, H. R. A Molecularly Imprinted Polymer for the Selective Extraction and Determination of Fenvalerate from Food Samples Using High-Performance Liquid Chromatography. Food Anal. Methods 2015, 8 (5), 1225–1237. (i) Xu, X.; Liang, S.; Meng, X.; Zhang, M.; Chen, Y.; Zhao, D.; Li, Y. A Molecularly Imprinted Polymer for the Selective Solid-Phase Extraction of Dimethion from Ginseng Samples. J. Chromatogr. B: Anal. Technol. Biomed. Life Sci. 2015, 988, 182–186.

(18) (a) Iqbal, N.; Mustafa, G.; Rehman, A.; Biedermann, A.; Najafi, B.; Bierzeizert, P. A.; Dickert, F. L. QCM-Arrays for Sensing Terpenes in Fresh and Dried Herbs via Bio-Mimetic MIP Layers. Sensors 2010, 10 (7), 6361–6376. (b) Ning, F.; Peng, H.; Dong, L.; Zhang, Z.; Li, J.; Chen, L.; Xiong, H. Preparation and Characterization of Superparamagnetic Molecularly Imprinted Polymers for Selective Adsorption and Separation of Vanillin in Food Samples. J. Agric. Food Chem. 2014, 62 (46), 11138–11145. (c) Ghatak, B.; Ali, S. B.; Prasad, A.; Ghosh, A.; Sharma, P.; Tudu, B.; Pramanik, P.; Bandyopadhyay, R. Application of Polymethacrylic Acid Imprinted Quartz Crystal Microbalance Sensor for Detection of 3-Carene in Mango. IEEE Sens. J. 2018, 18 (7), 2697–2704. (d) Chen, W.; Wang, Z.; Gu, S.; Wang, J. Detection of Hexanal in Humid Circumstances Using Hydrophobic Molecularly Imprinted Polymers Composite. Sensors Actuators, B Chem. 2019, 291, 141–147. (e) Ghatak, B.; Banerjee, S.; Ali, S. B.; Das, N.; Tudu, B.; Pramanik, P.; Mukherji, S.; Bandyopadhyay, R. Development of a Low-Cost Portable Aroma Sensing System for Identifying Artificially Ripened Mango. Sensors Actuators, A Phys. 2021, 331, 112964. (f) Ghatak, B.; Naskar, H.; Ali, S. B.; Tudu, B.; Pramanik, P.; Mukherji, S.; Bandyopadhyay, R. Development of Furaneol Imprinted Polymer Based QCM Sensor for Discrimination of Artificially and Naturally Ripened Mango. 2019 IEEE International Symposium on Olfaction and Electronic Nose (ISOEN), Fukuoka, Japan; IEEE, 2019; pp 1–3. (g) García, D.;
Gomez-Caballero, A.; Guerreiro, A.; Goicoeia, M. A.; Barrio, R. J. Molecularly Imprinted Polymers as a Tool for the Study of the 4-Ethylphenol Metabolic Pathway in Red Wines. J. Chromatogr. A 2015, 1410, 164–172. (h) Zheng, H. B.; Mo, J. Z.; Zhang, Y.; Gao, Q.; Ding, J.; Yu, Q. W.; Feng, Y. Q. Facile Synthesis of Magnetic Molecularly Imprinted Polymers and Its Application in Magnetic Solid Phase Extraction for Fluoroquinolones in Milk Samples. J. Chromatogr. A 2014, 1329, 17–23. (i) Teixeira, R.; Dopico-García, S.; Andrade, P. B.; Valentão, P.; López-Vilariño, J. M.; González-Rodríguez, V.; Cela-Perez, C.; Silva, L. R. Volatile Phenols Depletion in Red Wine Using Molecular Imprinted Polymers. J. Food Sci. Technol. 2015, 52 (12), 7735–7746. (j) Tolentino, M. A. K. P.; Albano, D. R. B.; Sevilla, F. B. Piezoelectric Sensor for Ethylene Based on Silver(1)/Polymer Composite. Sensors Actuators, B. Chem. 2018, 254, 299–306. (20) (a) Hashemi-Moghaddam, H.; Ahmadifard, M. Novel Molecularly-Imprinted Solid-Phase Microextraction Fiber Coupled with Gas Chromatography for Analysis of Furan. Talanta 2016, 150, 148–154. (b) Pesavento, M.; Zeni, L.; De Maria, L.; Alberti, G.; Cennamo, N. SPR-Optical Fiber-Molecularly Imprinted Polymer Sensor for the Detection of Furfural in Wine. Biosensors 2021, 11 (3), 72. (c) Fu, X.; Zhu, D.; Huang, L.; Yan, X.; Liu, S.; Wang, C. Superparamagnetic Core-Shell Dummy Template Molecularly Imprinted Polymer for Magnetic Solid-Phase Extraction of Food Additives Prior to the Determination by HPLC. Microchem. J. 2019, 150 (June), 104169. (d) Hawari, H. F.; Samsudin, N. M.; Ahmad, M. N.; Md Shakaﬁ, A. Y.; Ghanı, S. A.; Wahab, Y.; Hashıım, U. Recognition of Limonene Volatile Using Interdigitated Electrode Molecularly Imprinted Polymer Sensor. 2012 3rd International Conference on Intelligent Systems, Modelling and Simulation (ISMS), Kota Kinabalu, Malaysia; IEEE, 2012; pp 723–726. (e) Masque, N.; Marce, R. M.; Borruıl, F.; Cormaç, P. A. G.; Sherrington, D. C. Synthesis and Evaluation of a Molecularly Imprinted Polymer for Selective On-Line Solid-Phase Extraction of 4-Nitrophenol from Environmental Water. Anal. Chem. 2000, 72 (17), 4122–4126. (f) He, J.; Liu, J.; Liu, Y.; Liyin, Z.; Wu, X.; Song, G.; Hou, Y.; Wang, R.; Zhao, W.; Sun, H. Trace Carbonyl Analysis in Water Samples by Integrating Magnetic Molecular Imprinting and Capillary Electrophoresis. RSC Adv. 2021, 11 (52), 32841–32851. (g) Fang, S.; Liu, Y.; He, J.; Zhang, L.; Liyin, Z.; Wu, X.; Sun, H.; Lai, J. Determination of Aldehydes in Water Samples by Coupling Magnetism-Reinforced Molecular Imprinting Monolith Microextraction and Non-Aqueuous Capillary Electrophoresis. J. Chromatogr. A 2020, 1632, 461602. (h) Cennamo, N.; Zeni, L.; Pesavento, M.; Marchetti, S.; Marleța, V.; Baglio, S.; Grazianı, S.; Pistorıo, A.; Andò, B. A Novel Sensing Methodology to Detect Furfural in Water, Exploiting MIPs and Inkjet-Printed Optical Waveguides. IEEE Trans. Instrum. Meas. 2019, 68 (5), 1582–1589. (i) Debabhutı, N.; Neogi, S.; Mukherjeı, S.; Dhar, A.; Sharma, P.; Vekariya, R. L.; Sarkar, M. P.; Tudu, B.; Bhattacharyya, N.; Bandypadhyay, R.; Muddassı, M. Development of QCM Sensor to Detect α-Terpinył Acetate in Cardamom. Sensors Actuators, A Phys. 2021, 319, 112521. (21) Bhattacharyya Banerjeı, M.; Pradhan, S.; Banerjeı Roy, R.; Tudu, B.; Das, D. K.; Bandypadhyay, R.; Pramanık, P. Detection of Benzene and Volatile Aromatic Compounds by Molecularly Imprinted Polymer-Coated Quartz Crystal Microbalance Sensor. IEEE Sens. J. 2019, 19 (3), 885–892. (22) Zhang, Y.; Yao, X. Preparation of Molecularly Imprinted Polymer for Vanillin via Seed Swelling and Suspension Polymerization. Polym. Sci. - Ser. B 2014, 56 (4), 538–545. (23) Ghatak, B.; Ali, S. B.; Naskar, H.; Tudu, B.; Pramanık, P.; Mukherjeı, S.; Bandypadhyay, R. Selective and Sensitive Detection of Limonene in Mango Using Molecularly Imprinted Polymer Based Quartz Crystal Microbalance Sensor. ISOEN 2019 - 18th Int. Symp. Olfaction Electron. Nose, Proc. 2019, 1–3. (24) Humairah, N. A.; Fadlinusa, F.; Histhiningtyas, K. A.; Fattyadı, I. A.; Roto, R.; Kusumamıtma, A.; Triyana, K. Molecular Imprinting Polymer-Based QCM Sensor for Detection of α-Pinene. Key Eng. Mater. 2020, 840, 418–423.