Journal of Chromatographic Science, 2018, 1–14
doi: 10.1093/chromsci/bmy032
Article

Article

Recent Modifications and Validation of QuEChERS-dSPE Coupled to LC–MS and GC–MS Instruments for Determination of Pesticide/ Agrochemical Residues in Fruits and Vegetables: Review

Abubakar Lawal[1,2], Richard Chee Seng Wong[1,*], Guan Huat Tan[1], Lukman Bola Abdulra'uf[3], and Ali Mohamed Ali Alsharif[1]

[1]Department of Chemistry, University of Malaya, Kuala Lumpur 50603, Malaysia, [2]Department of Pure and Industrial Chemistry, Umaru Musa Yar'adua University, P.M.B. 2218 Katsina, Nigeria, and [3]Department of Chemistry, College of Pure and Applied Sciences, Kwara State University Malete, P.M.B. 1530 Ilorin, Nigeria

[*]Author to whom correspondence should be addressed. Email: richard@um.edu.my

Received 14 September 2016; Revised 12 January 2018; Editorial Decision 19 March 2018

Abstract

Fruits and vegetables constitute a major type of food consumed daily apart from whole grains. Unfortunately, the residual deposits of pesticides in these products are becoming a major health concern for human consumption. Consequently, the outcome of the long-term accumulation of pesticide residues has posed many health issues to both humans and animals in the environment. However, the residues have previously been determined using conventionally known techniques, which include liquid–liquid extraction, solid-phase extraction (SPE) and the recently used liquid-phase microextraction techniques. Despite the positive technological effects of these methods, their limitations include; time-consuming, operational difficulty, use of toxic organic solvents, low selective property and expensive extraction setups, with shorter lifespan of instrumental performances. Thus, the potential and maximum use of these methods for pesticides residue determination has resulted in the urgent need for better techniques that will overcome the highlighted drawbacks. Alternatively, attention has been drawn recently towards the use of quick, easy, cheap, effective, rugged and safe technique (QuEChERS) coupled with dispersive solid-phase extraction (dSPE) to overcome the setback challenges experienced by the previous technologies. Conclusively, the reviewed QuEChERS-dSPE techniques and the recent cleanup modifications justifiably prove to be reliable for routine determination and monitoring the concentration levels of pesticide residues using advanced instruments such as high-performance liquid chromatography, liquid chromatography–mass spectrometry and gas chromatography–mass spectrometry.

Introduction

The increase in population and improved health quality of life have tremendously led to demands for higher quality and quantity of food materials (1). Agriculture is one of the major practices in most countries across the globe due to its significant economic impacts on the countries' survival and gross domestic products (2). Food materials such as vegetables and fruits constitute the major type of food consumed daily apart from whole grains (3). Fertilizers are used for growing fruits and vegetables, and protected with effective pesticides such as insecticides, herbicides and fungicides. The pesticides are used for eliminating

© The Author(s) 2018. Published by Oxford University Press. All rights reserved. For Permissions, please email: journals.permissions@oup.com

Downloaded from https://academic.oup.com/chromsci/advance-article-abstract/doi/10.1093/chromsci/bmy032/4980918
by Serials Section, Dixson Library user
on 24 April 2018

or destroying insects, weeds and other parasites that affect fruits and vegetables during cultivation, transportation and storage (4).

Unfortunately, the residue of pesticides having a higher solubility, molecular weight, half-life ($t_{1/2}$) and toxicity level (lower LD_{50} or LC_{50}) with low vapor pressure periodically accumulates and render themselves persistent in the environmental water and moistened soil (5–7). Therefore, these endanger and cause many illnesses and adverse environmental impacts to humans and livestock (8, 9). For instance, there have been many health risk concerns associated with the continuous use of the triazole fungicides, carbamates, pyrethroids, organochlorine (OCP) and organophosphorus (OP) pesticides for controlling pests for the production and preservation of fruits and vegetables (10). Consequently, the recent health reports of these pesticides have resulted in many countries legislating the usage due to their high amount of residues in the food materials (11).

As a matter of fact, many health implications of pesticide usage have been documented which include; disorderliness of reproductive system (12), birth defects (13), diabetes (14), risk of cancers in both children and adults (15), diseases of the central nervous system such as Alzheimer's, Parkinson's and amyotrophic lateral sclerosis, and cardiovascular diseases such as coronary artery and atherosclerosis as well as respiratory troubles such as chronic obstructive pulmonary disease and asthma (16). Therefore, the problems caused by the continuous use of pesticides leads to developing tools or methods for determining the chemicals as well as efficient management practices to enforce regulations towards controlling quality and distribution of vegetables and fruits, which falls below their pesticides' maximum residue limits (17).

Unfortunately, one of the most significant challenges in developing efficient methods for pesticides extraction in a sample of fruits and vegetables is due to their wide range of chemical properties that include; acidity, basicity and neutral (18). Also, the analyzed matrices are of different kinds such as polar, non-polar, waxy and fatty (19). Based on these reasons, food safety analysts are compelled to look for better methods that can be used more efficiently for determining multi-class and multi-residue pesticides in vegetable and fruit samples (20).

In this regard, there are numerous reported methods, which resulted in active and good operational flexibilities for pesticides extraction in a sample of fruits and vegetables. These techniques include; supercritical fluid extraction (21), stir bar sorptive extraction (22), solid-phase extraction (SPE) (23), liquid–liquid extraction (LLE) (24), homogeneous liquid–liquid microextraction (25) and liquid-phase microextraction (26–29).

Despite the positive technological effects of the above techniques, their limitations exhibited include; time-consuming, operational difficulty, use of toxic organic solvents, with the lower selective property, expensive extraction setups and performance decline within a short period (30). Thus, the potential and maximum use of these methods has resulted in the urgent need for better techniques that will overcome the highlighted drawbacks.

Alternatively, attention has been drawn recently towards the use of simple glassware (19), which would provide quick, easy, cheap, effective, rugged and safe technique (QuEChERS) couple to dSPE to overcome the setback challenges of the previous techniques for pesticides determination in fruits and vegetables (31). Subsequently, it is essential to quantify the level of the pesticides in the samples for food consumption and environmental safety.

Although, the earlier or previous analysis of pesticide in samples of food were predominantly carried out using the laboratory instruments. These tools include; thin layer chromatography with semi-quantitative detection, gas–liquid chromatography (GLC or GC) with packed columns and selective quantitative detections (32), GC–atomic emission detector (33), HPLC (34), etc. Recently, different types of extraction methods have been developed and further improved to enhance the precision and accuracy such as relative recoveries (RRs), limits of detection (LOD) and limits of quantitation (LOQ) of the analytes. Resultantly, these give rise to more technical options for analysis of food samples.

Notwithstanding, the use of QuEChERS extraction and cleanup techniques since it was pioneered in 2003 has led to the publication of more than 700 articles to date, which relate to the recoveries of pesticides residue from a sample of vegetables and fruits. However, these articles are based on the overviewed of the literature search engines, which include; Google Search/Scholar, Elsevier Sci-Verse and Sci-Finder (35). Along the years, series of modifications had been carried out to improve the technique. Unfortunately, a review article specifically on the recent modifications involving the use of the QuEChERS-dSPE method for pesticides determination in fruits and vegetables have not been published. Even though, some review articles were published earlier on the sample treatment (QuEChERS) and cleanups techniques for pesticides determination in various food matrices. Some of the most recent articles include an overview for pesticides determination in fruits and fruits juice samples (36), and review article on the residue of pesticides in cereals, baby foods, nutraceutical foods and related processed consumers product (37). However, these reviews discussed mainly on the traditional QuEChERS-dSPE method for pesticides analysis in the food matrices. Moreover, these reviews did not discuss more about the most recent modifications of sample treatment (QuEChERS) and cleanups techniques.

Therefore, a review article on recently modified QuEChERS extraction and cleanup techniques for analysis of pesticides residue in fruits and vegetables will justifiably contribute coherently to the vast knowledge of QuEChERS extraction and cleanup modifications. Also, validated results of the crucial parameters for each of the reviewed methods such as LOD, LOQ and RRs will be compared with one another. Then, these will serve as a reference guide for future studies that include routine determination and monitoring the concentration levels of pesticides in fruit and vegetable samples using advanced instruments. These instruments include high-performance liquid chromatography (HPLC), liquid chromatography–mass spectrometry (LC–MS) and GC–MS.

SPE

Solid-phase extraction is a developed technique gradually from the LLE method that is made up of many kinds of sorbent materials such as polymeric solids and porous carbon. The materials could also exist as particles of carbon nanostructures, e.g., nanodymonds, nanotubes, nanohorns, nanocones, etc. (38). Meanwhile, the simple SPE was miniaturized by devices that include; coated fibers, membranes and stirrers. These were transformed into a cartridge known as conventional SPE. On the other hand, dSPE is used as an alternative and modified form of the conventional SPE, which was initially suggested as a method used for cleaning matrix substances by adding a small quantity (~50 mg) of the sorbent material into the extraction sample without conditioning it (39). The dSPE step involves the addition of acetonitrile usually as the extracting solvent (buffering at pH 5–5.5). However, the major characteristics feature of acetonitrile over the use of other extraction solvents such as acetone and ethyl acetate is that it is highly compatible with GC and very applicable in the reverse-phase of LC (39). Also, it is very suitable for extracting polar and non-polar analytes (40).

Downloaded from https://academic.oup.com/chromsci/advance-article-abstract/doi/10.1093/chromsci/bmy032/4980918
by Serials Section, Dixson Library user
on 24 April 2018

Unfortunately, the limited property of the solvent is that it is not suitable for the extraction of highly lipophilic materials such as fats, waxes and pigments (39). Afterwards, extraction salt will be added to a small (weighed) sample size in a centrifuge tube before the tube undergoes series of vortexing (shaking) and centrifugation. Subsequently, partitioned phases will occur after centrifugation at different levels depending on their densities. Notably, the base-sensitivity and stability of pesticides can be improved if octa-dodecyl bonded silica (C_{18}), primary secondary amine (PSA) and graphitized carbon black (GCB) in dSPE are used further to cleanup interferences of the extracted analytes in the organic phase (41).

Conversely, the most essential property of C_{18} as a sorbent material for the cleanup purpose is its excellent ability to remove the non-polar interferences such as lipids and fats (42). This property helps to improve the detection of analytes such as pesticide residues in the extracts of complex (sample) matrices without significant adverse effects on their responses (43). Meanwhile, PSA aids to eliminate sugar molecules, polar, organic and fatty acids but the recent report shows that PSA is sometimes not capable of removing excessive interferences in a complex sample of fruits and vegetables (44). Besides, GCB helps to take-off pigments such as chlorophyll and steroids in the analyte solutions. Unfortunately, the limitary use of GCB during the dSPE cleanup of QuEChERS extract is that it circumstantially eliminate 50% pesticides of the planar aromatic group such as hexachlorobenzene, thiabendazole and cyprodinil fungicides (45). Moreover, reliable and efficient dSPE cleanup methodology can also be achieved, if the exact estimated amount of salts is added to the homogenized sample. This is because of their crucial roles; magnesium sulfate ($MgSO_4$) absorbs water molecules that are mixed with analytes in the organic phase, and sodium chloride (NaCl) moves analytes to the organic phase, and it further helps to separate the organic phase from the aqueous phase (containing carbohydrates and sugars) (40, 42).

QuEChERS-dSPE

The QuEChERS-dSPE is a modified/developed feature of dSPE, which was initiated by Anastassiades *et al.* (39) for determination of pesticide residues. Thus, successfulness of the method is due to its flexibility, high efficiency and easy identification of analytes (46). Moreover, the technique provides more acceptable extraction cleanups of analyte interferences to yield excellent results after chromatographic instrumentation (47). Comparatively, the developed method is simpler, with less time, less labor and less consumption of organic solvent than the traditional or conventional SPE method. Also, multiple SPE analyses will be carried out to capture a similar amount of residues in a single QuEChERS-dSPE analysis (48).

Nevertheless, in the year 2007, QuEChERS-dSPE technique was regarded as one of the best alternative methods endorsed by the Association of Official Analytical Chemists (AOAC) International for determining residue of multi-pesticides in vegetables and fruits (49). Furthermore, the technique continues to gain popularity through various modifications by developing appropriate methodological kits for either QuEChERS extraction or dSPE cleanups (50).

However, the most commonly employed kits for QuEChERS-dSPE methods are those developed (Figure 1) officially by the European EN 15662 and AOAC official 2007.01. Although, these kits are used based on the nature and type of food sample. For example, there are special kits meant for general food samples, the samples with extremely colored extracts, the samples with waxes or fats extracts, and the samples with fats and pigment extracts (40).

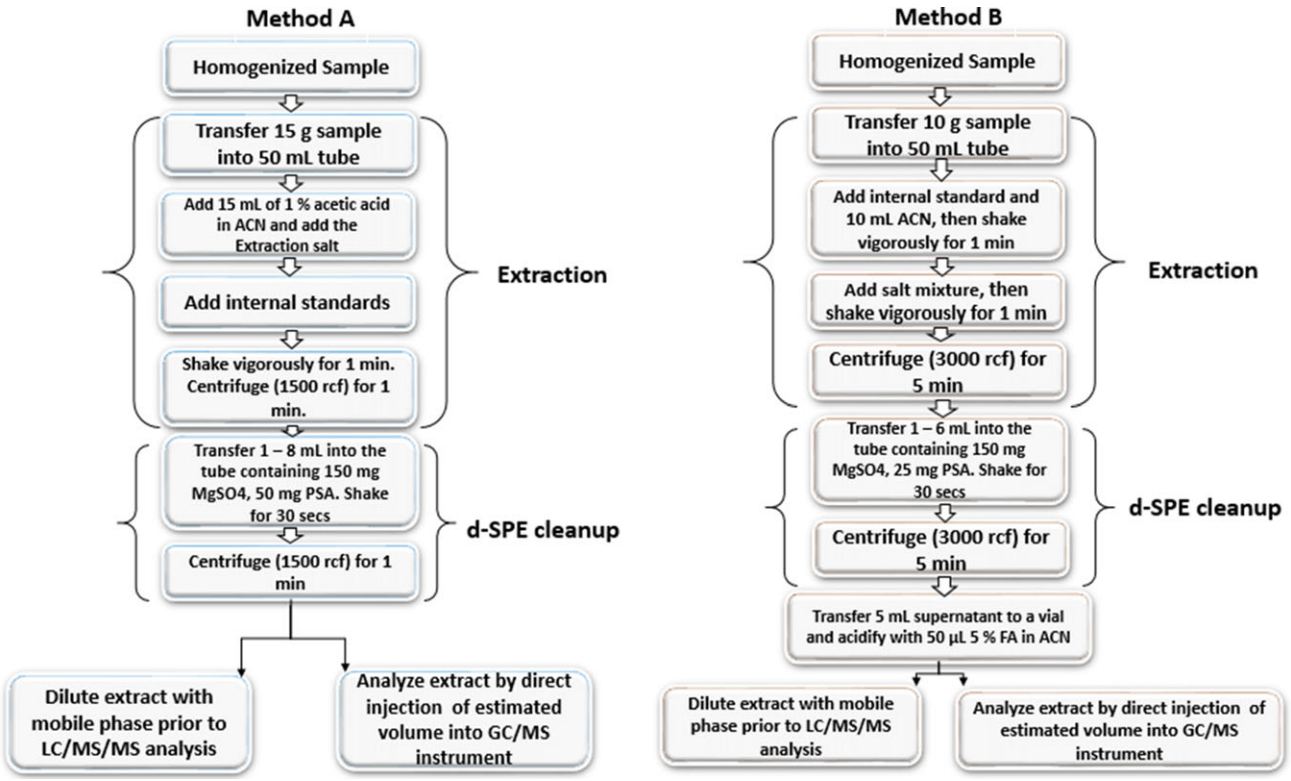


Figure 1. Schematic procedures for sample preparation using AOAC (Method A) and European EN 15662 (Method B) QuEChERS-dSPE methods (43).

Downloaded from https://academic.oup.com/chromsci/advance-article-abstract/doi/10.1093/chromsci/bmy032/4980918
by Serials Section, Dixson Library user
on 24 April 2018

The QuEChERS-dSPE technique and modifications for pesticides determination in vegetables and fruits

Over the years, research interests have been increasing in the traditional and modified form of QuEChERS-dSPE (sample preparations) method for the determination of pesticides residue in fruits and vegetables. It is based on the use of acetonitrile (as extractant), salts (for partitioning), sorbent materials (for cleanups) and technical modifications (51). Therefore, the results of the reviewed sample treatment and cleanups methods were compared with the guidelines recommendation of the European Commission, SANTE-11813 (52). Then, the methods were categorized less effective, effective, more effective and most effective. It is based on the results that show the RR enhancements, good RSD, low LOD and LOQ of the reviewed methods. However, the categorization shows the advantages of using each of the modified technique for determining residues of pesticides in the analyzed samples. Furthermore, the reviewed results are tabulated (Tables I–IV) and the RRs (%) results are illustrated (Figure 2). Meanwhile, the continuous application of organic and bio-pesticides in agricultural practices leads to close monitoring of their residual levels in the sample of fruits and vegetables (53).

In this regard, Romero-González *et al.* (54) reported the use of QuEChERS methods for analysis of 14 commonly used bio-pesticides in vegetable and fruit samples. These samples include cucumber, orange, pepper, strawberry and tomato, purchased in Spanish supermarkets (Almeria). The 50-mL conical test tube contained 10 g of each blended sample and 10 mL acetonitrile with 1% acetic acid (v/v). The tube was shaken for 1 min before adding 1 g of sodium acetate (NaOAc) and 4 g anhydrous $MgSO_4$. Centrifugation was carried out on the tube for 5 min at 5,000 rpm after shaking the tube for 1 min. The 2-mL autosampler vial containing 1 mL of the resulting supernatant was introduced into UPLC/QQQ–MS/MS for analysis. However, the technique is categorized effective when compared with other reviewed methods based on the validated results provided; LODs (≤3 μg/kg), LOQs (≤10 μg/kg), RSD (≤28%) and average RRs (70–112%). The method shows its potential applicability in the determination of bio-pesticides to a great variety of vegetables and fruits.

The health implication of cyazofamid (agrochemical) was recently documented and shown to cause respiratory problems (55). Thus, Ultra QuEChERS (extraction kits) was employed for the determination of cyazofamid and its metabolic compound of 4-chloro-5-*p*-tolylimidazole-2-carbonitrile (CCIM) in samples of apple, cabbage, mandarin, green pepper and potato (56). The samples were procured randomly from the markets (Republic of Korea) and homogenized individually. Then, 10 mL acetonitrile was transferred to a centrifuge tube (50-mL) containing 10 g of the blended sample (spiked with 10–100 μg/kg analyte standards). About 10 min was sufficient to agitate the tube at 250 rpm before the addition of the extraction kits. The tube was shaken for 2 min before subjecting it to 5 min centrifugation at 3,500 rpm. The resulting 1 mL of supernatant was transferred to 2-mL centrifuge tube containing dSPE cleanup salts, and the tube was centrifuged (15,000 rpm) for 2 min. Then, 400 μL supernatant was mixed with the 50 μL solution mixture (1% formic acid in acetonitrile) to mash-up the matrix. The mixture was analyzed with LC–MS/MS instrument. Thus, the method is categorized effective and proved to be quick, robust, sensitive and selective in comparison with other reviewed methods based on the obtained results of LOQs (2–5 μg/kg) and RRs (75.1–105.1%). The method is potentially applicable to the analysis of cyazofamid and CCIM in diverse food materials.

Recently, a study shows that the pesticide residues in Colombian (Bogota) cultivated tomatoes have not been extensively characterized (57). Based on the reason mentioned, Arias *et al.* (57) monitored 24 pesticides belonging to the class of fungicides and insecticides using the salts and adsorbent of QuEChERS-dSPE (Restek Q-Sep kits) for the extraction and cleanup of the analytes. In this method, a 50-mL centrifuge tube containing 10 g of homogenized samples was shaken vigorously for 1 min after adding a 15-mL mixture of 1% acetic acid in acetonitrile. Then, 1 g NaOAc and 6 g anhydrous $MgSO_4$ were added to the mixture of the centrifuge tube and was shaken for another 1 min before centrifugation at 4,500 rpm for 5 min. Subsequently, 10 mL supernatant, 150 mg anhydrous $MgSO_4$ and 25 mg PSA collectively, were introduced into a 15-mL centrifuge tube. The mixture was centrifuged for 2 min at the rate of 4,500 rpm after being shaken for 30 s. Then, a 0.22-μm filter was employed to filter the supernatant before injection into the UHPLC–LCMS-2020 instrument. Thus, the applied method is categorized effective based on the provided results; RRs (71.3–112.3%), LODs (1–200 μg/kg) and LOQs (10–800 μg/kg) as compared with other reviewed methods. However, the technique could be utilized in an optimum condition to provide excellent results in other food materials apart from fruits and vegetables.

Notwithstanding, the high usage of fungicides and insecticides during cultivation or storage of fresh fruit and vegetables has become a major concern that requires analytical attention (58). Bilehal *et al.* (59) studied five pesticides (fungicides and insecticides) in Indian fruit and vegetable samples of pomegranate and mango using the QuEChERS-dSPE method. The 15-g of each blended sample was extracted with 15 mL acetonitrile after addition of 10 g anhydrous sodium sulfate (Na_2SO_4) and centrifuged (2,000 rpm) for 3 min. Then, the dSPE salt (25 mg PSA) was used to cleanup 1 mL supernatant (aliquot) in a 10-mL centrifuge tube. The resulting extract was slightly evaporated (at 50°C) to dryness using a stream of nitrogen flow and filtered through the 0.2-μm membrane. Finally, a reversed-phase ultra-performance liquid chromatography (RP–UPLC) was used to analyze the filtrate. The obtained results of RRs (87.0–96.0%) and RSD (0.8–20.5%) proved to be simple, rapid but it is categorized less effective when compared with other reviewed methods.

Moreover, Carneiro *et al.* (60) have demonstrated the use of QuEChERS technique for the determination of 128 pesticides in banana samples. The samples were collected from the pesticide-free areas of Brazil (Minas-Gerais); the extraction occurs in a 50 mL centrifuge tube containing 10 g of homogenized sample, which was spiked with estimated analytes' standard solutions. Then, 15 mL acetonitrile was mixed with the tube's content, followed by the addition of 1 g NaOAc and 4 g anhydrous $MgSO_4$. The mixture was shaken for 1 min and agitated for 9 min at 4,000 rpm. Then, dSPE was carried out on the obtained supernatant in a 50-mL centrifuge tube which contained 1.5 g anhydrous $MgSO_4$. The tube was shaken for 1 min, centrifuged (4,000 rpm) for 9 min and the resulting supernatant was introduced into a 2-mL autosampler vial before undergoing UHPLC–MS/MS analysis. The simple modified technique is categorized more effective as compared with other methods reviewed because it provided excellent validated results; RRs (70–120%), LODs (≤5 μg/kg), LOQs (≤10 μg/kg) and RSD (≤20%). These results demonstrated the feasibility and applicability of the method for the routine analysis of pesticide residues and other contaminants in samples containing a large quantity of water.

In a similar and modified QuEChERS technique, Jadhav *et al.* (61) reported the use of 10 mL ethyl acetate (EtOAc) containing 1%

Downloaded from https://academic.oup.com/chromsci/advance-article-abstract/doi/10.1093/chromsci/bmy032/4980918
by Serials Section, Dixson Library user
on 24 April 2018

Table I. The summary of QuEChERS method for extraction of pesticides/agrochemicals residue in homogenized fruit and vegetable samples

Samples	Analyte	Mass of sample (g)	Volume of extract solvent	Acetic acetate buffer	Extraction salts	Internal standard	Shaking time	Centrifuge speed	Centrifuge time	Ref
Cucumber, orange, pepper, strawberry and tomato	14 Bio-pesticides	10	10 ml ACN	1 g NaOAc	4 g Anhydrous $MgSO_4$	nr	1 min	5,000 rpm	5 min	(54)
Apple, cabbage, green pepper, mandarin and potato	Cyazofamid and CCIM	10	10 mL ACN	nr	"Ultra-kits" (anhydrous $MgSO_4$ and NaCl)	nr	2 min	3,500 rpm	5 min	(56)
Tomatoes	Fungicides and insecticides	10	15 mL ACN	1 g NaOAc	Restek Q-Sep kits (1 g NaOAc and 6 g anhydrous $MgSO_4$)	nr	1 min	4,500 rpm	5 min	(57)
Pomegranate and mango	5 Fungicides and insecticides	15	15 mL ACN	nr	10 g Anhydrous Na_2SO_4	nr	nr	2,000 rpm	3 min	(59)
Bananas	128 Kinds of pesticides	10	15 mL ACN	1 g NaOAc	4 g Anhydrous $MgSO_4$	nr	1 min	4,000 rpm	9 min	(60)
Bitter gourd, capsicum, curry leaves, drumstick, grape, mango and okra	20 Agrochemicals	10	10 mL EtOAc	0.5 g NaOAc	10 g Anhydrous Na_2SO_4	nr	2 min	5,000 rpm	5 min	(61)
Tomatoes	109 Pesticides	15	15 mL ACN	1.5 g NaOAc	6 g Anhydrous $MgSO_4$	nr	1 min	5,000 rpm	1 min	(63)
Cucumber and potato	ETU	10	5 mL Alkaline ACN	nr	4 g Anhydrous $MgSO_4$ plus 1 g NaCl	nr	2 min	3,800 rpm	5 min	(65)
Potatoes and pears	Quaternary ammonium pesticides of CQ and MQ	5	3.5 mL ACN	nr	3 g Anhydrous $MgSO_4$	35 mL TPP	1 min	6,000 ×*g*	10 min	(67)
Apples, spinaches, strawberries and tomatoes	SDHI fungicides	15	15 mL ACN	1.5 g NaOAc	6 g Anhydrous $MgSO_4$	150 µL TPP	1 min	2,200 *g*	5 min	(69)
Strawberry, grape, celery and cabbage	16 Amide fungicides	5	9.5 mL ACN	nr	2 g NaCl	nr	1 min	5,000 rpm	3 min	(71)
Garland chrysanthemum, lettuce leaves and leek	70 Pesticides	10	10 mL ACN	nr	NaCl (1 g) and $MgSO_4$ (4 g)	nr	2 min	3,800 rpm	5 min	(72)
Apples, bananas, celeries, eggplants, grapes, leeks, papayas and tomatoes	Glufosinate pesticide	10	10 mL Methanol	nr	nr	nr	2 min	4,000 rpm	5 min	(75)
Pear and orange	16 Post-harvest fungicides	10	10 mL ACN	1 g TCD	4 g anhydrous $MgSO_4$ and 1 g NaCl	DHC	4 min	3,500 rpm	5 min	(77)
Kiwi fruit and Juice	33 Pesticides	10	10 mL ACN	nr	4 g anhydrous $MgSO_4$ and 1 g NaCl	nr	1 min	3,800 rpm	5 min	(78)
Apples, cucumbers, oranges and tomatoes	101 Pesticides residues	10	10 mL ACN	nr	4 g anhydrous $MgSO_4$ and 1 g NaCl	nr	1.5 min	5,000 rpm	5 min	(81)
Cucumber, grapes, pears and tomatoes	11 Pesticides	2	2 mL Acetonitrile	nr	nr	100 ng/g TPP	1 min	nr	nr	(82)
Cabbage, cauliflower, cucumber, dragon fruit, grape, rambutan and watermelon	8 Carbamate pesticides	7	10 mL 1% acetic acid in ACN (v/v)	0.4 g NaOAc	2 g anhydrous $MgSO_4$	nr	1 min	4,000 rpm	10 min	(83)
Banana, apple and tomato	Fenarimol fungicides	10	10 mL ACN	nr	"Ultra-kits" (anhydrous $MgSO_4$ and NaCl)	nr	nr	nr	nr	(86)
Celery, garlic, ginger, leek, onion and shallot	38 Organochlorine, organophosphorus and pyrethroid pesticides	25	50 mL ACN	nr	7 g NaCl	50 µL HEI-B (3 µg/mL)	nr	nr	nr	(87)

EtOAc, ethyl acetate; NaOAc, sodium acetate; CCIM, 4-chloro-5-*p*-tolylimidazole-2-carbonitrile; SDHI, succinate dehydrogenase inhibitor; TPP, tryphenyl phosphate; CQ, chlormequat, MQ, mepiquat; ETU, ethylenethiourea; ACN, acetonitrile; nr, not recorded; Ref, references; HEI-B, heptachlor epoxide isomer B; DHC, disodium hydrogen citrate; TCD, trisodium citrate dihydrate.

Downloaded from https://academic.oup.com/chromsci/advance-article-abstract/doi/10.1093/chromsci/bmy032/4980918
by Serials Section, Dixson Library user
on 24 April 2018

Table II. The application summary of dSPE cleanup salts used after QuEChERS extraction

Sample	Analytes	Extraction volume	Cleanup salts	Shaking time	Centrifuge speed	Centrifuge time	References
Cucumber, orange, pepper, strawberry and tomato	14 Organic-pesticides	nr	nr	nr	nr	nr	(54)
Apple, cabbage, green pepper, mandarin and potato	Cyazofamid and CCIM	1 mL into 2-mL centrifuge tube	Cleanup kits	nr	15,000 rpm	2 min	(56)
Tomatoes	Fungicides and insecticides	10 mL into 15-mL centrifuge tube	Restek Q-Sep kits (150 mg $MgSO_4$ and 25 mg PSA)	30 s	4,500 rpm	2 min	(57)
Pomegranate and mango	5 fungicides and insecticides	1 mL into 10-mL centrifuge tube	25 mg PSA	nr	nr	nr	(59)
Bananas	128 Kinds of pesticides	nr	1.5 g Anhydrous $MgSO_4$	1 min	4,000 rpm	9 min	(60)
Bitter gourd, capsicum, curry leaves, drumstick, grape, mango and okra	20 Agrochemicals	5 mL into 10-mL centrifuge tube	25 mg PSA	30 s	nr	nr	(61)
Tomatoes	109 Pesticides	4 mL into 15-mL centrifuge tube	$MgSO_4$ (0.6 g) and PSA (0.2 g)	1 min	5,000 rpm	1min	(63)
Cucumber and potato	ETU	1 mL into 2-mL centrifuge tube	$MgSO_4$ (100 mg) and PSA (50 mg)	1 min	nr	5 min	(65)
Potatoes and pears	Quaternary ammonium pesticides of CQ and MQ	1 mL into 2-mL centrifuge tube	125 mg Anhydrous $MgSO_4$, 25 mg GCB and 25 mg sorbent PSA	60 s	13,300 ×*g*	10 min	(67)
Apples, spinaches, strawberries and tomatoes	SDHI fungicides	1 mL into 2-mL centrifuge tube	150 mg Anhydrous $MgSO_4$ and other dSPE salts	1 min	2,200 g	5 min	(69)

GCB, graphitized carbon black; PSA, primary secondary amine; dSPE, dispersive solid-phase extraction.

acetic acid as an extraction solvent for determination of some agrochemicals in 10 g (homogenized) sample of Indian fruits and vegetables. The samples include bitter gourd, capsicum, curry leaves, drumstick, grape, mango and okra, respectively. Then, 10 g anhydrous Na_2SO_4 and 0.5 g NaOAc was added to a 50-mL centrifuge tube containing each of the samples. The tube was vortexed for 2 min and centrifuged (5,000 rpm) for 5 min. The 5-mL supernatants underwent dSPE cleanup with 25 mg PSA in a 10-mL centrifuge tube and shaken for 30 s before centrifugation. The 2-mL of the cleaned extract was transferred into 10-mL test tube containing 10 µL of 10% diethylene glycol (DEG), and the mixture was evaporated to dryness at 35°C under the flow of nitrogen stream. Then, methanol was added to dissolve the obtained residue (1:1). The solution was mixed with 2 mL ammonium formate (20 mM in H_2O), ultrasonicated for 1 min, vortexed for 30 s, followed by 5 min centrifugation (10,000 rpm). The extracted aliquot was filtered through 0.2-µm pores of Nylon-66 filter before analysis with LC–MS/MS instrument. The results obtained by this method are satisfactory with RRs (70–120%), low RSD (<20%) and LOQs (0.2–1 µg/kg). The method is categorized more effective when compared with other reviewed methods. It could be potentially applicable as a standard regulatory tool for the routine analysis of agrochemical residues (basic or acidic compounds) in fruits and vegetables.

The fact that Turkey is ranked fourth worldwide in tomatoes cultivation. Unfortunately, there is no record of pesticides residue determination in the product (62). Hence, Golge and Kabak (63) have carried out the determination of 109 residues of pesticide in tomatoes cultivated in the areas of Antalya and Mersin (Turkey). The QuEChERS method was employed in which 15 g out of the blended 1 kg (representative) sample was placed in 50-mL centrifuge tube. The 15-mL acetonitrile/acetic acid (99:1 v/v) was added and shaken until the solvent was uniformly mixed followed by addition of NaOAc (1.5 g) and $MgSO_4$ (6 g) before the tube was vortexed for 1 min and centrifuged (5,000 rpm). The dSPE was carried out on the supernatant (4 mL) after it was mixed with PSA (0.2 g) and $MgSO_4$ (0.6 g) in 15-mL centrifuge tube. Then, 1 min was, respectively, used to vortex and centrifuged the tube's mixture at 5,000 rpm. Finally, the resulting supernatant was analyzed using the LC–MS/MS instrument. The developed method yielded satisfactory results with RRs (77.1–113.2%), LODs (0.5–10.8 µg/kg), LOQs (1.3–30.4 µg/kg) and RSD (<20%). Thus, the technique is categorized effective when compared with other reviewed methods. The method could be potentially applicable to the analysis of other fruit and vegetable samples with high water content.

In addition, the recent recommendatory report shows that the determination of ethylenethiourea (ETU) (precursor of highly effective ethylenebisdithio-carbamate fungicides) in food materials is highly demanding because it has been known to cause thyroid cancer (64). Thus, Zhou *et al.* (65) reported the use of the QuEChERS-dSPE technique for the extraction of ETU in samples of cucumber and potato. A 10-g of the homogenized sample was transferred into a 50-mL centrifuge tube, and the sample was spiked with ETU standard solution before adding 5 mL alkaline acetonitrile (containing 1% ammonia monohydrate). The mixture was vortexed for 2 min, followed by centrifugation (3,800 rpm) for 5 min. The extraction process was repeated on the same tube, and the resulting supernatants were transferred into another 50-mL centrifuge tube containing 4 g anhydrous $MgSO_4$ and 1 g NaCl. The mixture was vortexed for 1 min before centrifugation for 5 min. The 1-mL supernatant was introduced into a 2-mL centrifuge tube containing $MgSO_4$ (100 mg) and PSA (50 mg). The tube was shaken for 1 min before centrifugation for 5 min. Finally, the supernatant obtained was

Downloaded from https://academic.oup.com/chromsci/advance-article-abstract/doi/10.1093/chromsci/bmy032/4980918
by Serials Section, Dixson Library user
on 24 April 2018

Table III. The summary of modified forms of sorbent materials replacing dSPE cleanup salts used after QuEChERS extraction

Sample	Analytes	Extraction volume	Sorbent materials	Shaking time	Centrifuge speed	Centrifuge time	Ref
Strawberry, grape, celery, and cabbage	16 Amide fungicides	1 mL into 50-mL volumetric-tube	10 mg MWCNTs	1 min	9,000 rpm	3 min	(71)
Garland chrysanthemum, lettuce leaves and leek	70 Pesticides	1 mL into 2-mL centrifuge tube	MWCNTs (10 mg) and $MgSO_4$ (150 mg)	1 min	10,000 rpm	3 min	(72)
Apples, bananas, celeries, eggplants, grapes, leeks, papayas and tomatoes	Glufosinate pesticide	1 mL into 2-mL centrifuge tube	5 mg MWCNTs	1 min	10,000 rpm	1 min	(75)
Pear and orange	16 Post-harvest fungicides	5 mL into 15-mL centrifuge tube	MWCNTs, PSA, yttria-stabilized zirconium dioxide and anhydrous $MgSO_4$	30 s	3,500 rpm	5 min	(77)
Kiwi fruit and Juice	33 Pesticides	1 mL into 2-mL centrifuge tube	m-PFC	nr	nr	nr	(78)
Apples, cucumbers, oranges and tomatoes	101 Pesticides residues	1 mL into 2-mL centrifuge tube	MNPs (40 mg), PSA (50 mg), GCB (10 mg) and anhydrous $MgSO_4$ (100 mg)	1 min	nr	nr	(81)
Cucumber, grapes, pears and tomatoes	11 Pesticides	0.8 mL mL into 1.5-mL vial	1840 mg MNPs and 0.1 g $MgSO_4$	1 min	nr	nr	(82)
Cabbage, cauliflower, cucumber, dragon fruit, grape, rambutan and watermelon	8 Carbamate pesticides	7 mL into 15-mL centrifuge tube	CTAB-modified zeolite NaY	2 min	nr	nr	(83)
Banana, apple and tomato	Fenarimol fungicides	1 mL into SPE cartridge	MIP in SPE cartridge	nr	nr	nr	(86)
celery, garlic, ginger, leek, onion and shallot	38 Organochlorine, organophosphorus and pyrethroid pesticides	10 mL	Absorbent cotton, 0.1 g GCB, Na_2SO_4 and 3 g florisil liquid	nr	nr	nr	(87)

MWCNTs, multi-walled carbon nanotubes; MNPs, magnetic nanoparticles; CTAB, cetyl-trimethyl-ammonium bromide; MIP, molecular imprinted polymer; m-PFC, multi-plug filtration cleanup.

analyzed with LC–MS/MS instrument after filtration (0.22-μm pore). Thus, the success of the used method includes; simplicity, sensitivity, rapidity, manageability of organic solvent and effectively categorized as compared with other methods reviewed. This is because the method resulted in low LODs (0.025–0.15 μg/kg), LOQs (0.1–0.5 μg/kg) and RSD (<18%) with good RRs (60–110%).

Furthermore, a slight modification of the QuEChERS-dSPE method was employed for the determination of quaternary ammonium pesticides. It was based on the environmental concerns, which shows that the high residues of such compounds can cause disruption of endocrine glands and could affect the reproductive system in animals (66). The modified technique was documented by Gao *et al.* (67) documented the modified technique for the determination of chlormequat and mepiquat pesticides; 5 g for each of the homogenized samples of potatoes and pears were weighed and then transferred into a 50-mL centrifuge tube, respectively. It was then vortexed for 30 s after the addition of 3.5 mL acetonitrile and 35 μL of the internal standard triphenyl phosphate (TPP). Then, the tube was centrifuged (6,000 ×*g*) for 10 min after adding 3 g anhydrous $MgSO_4$ and vortexed for 1 min. The dSPE was carried out on the 1-mL of the supernatant in the 2-mL centrifuge tube containing 125 mg anhydrous $MgSO_4$, 25 mg GCB and 25 mg sorbent of PSA. A minute was enough to shake the tube before centrifugation (13,300 ×*g*) for 10 min. The extract was filtered through 0.22-μm pore membrane before the LC–MS/MS analysis. The results obtained [RRs (83.4–119.4%), LOQs (70–700 μg/kg), RSD (<7.0%) and LODs (21–210 μg/kg)] categorically proved to be more effective and sensitive, easy, quick and economical when compared with other reviewed methods for the routine analysis of CQ and MQ in fruits and vegetables.

The method was employed further to determine succinate dehydrogenase inhibitor (SDHI) fungicides. These pesticides are well-known to be active against diseases affecting fruits and vegetables, but recent studies revealed severe ecological effects in amphibians by inducing embryonic malformations (68). However, the continuous application of the newly introduced SDHI fungicides in food crops inspired Abad-Fuentes *et al.* (69) to use the modified QuEChERS method for determining the fungicides, pioneeringly. The analytes (Isopyrazam, Penthiopyrad and Penflufen) residues in Spanish samples of vegetables and fruits were determined; A 15 g of the homogenized sample was mixed with 150 μL (50 μg/mL TPP), 6 g anhydrous $MgSO_4$ and 1.5 g NaOAc in a 50-mL centrifuge tube. Then, 15 mL acetonitrile/acetic acid (99:1% v/v) was added to the tube and vortexed for 1 min followed by 5 min centrifugation (2,200 rpm). The 1 mL resulting extract underwent further cleanup with an appropriately measured dSPE salt [PSA and C_{18}, 150 mg anhydrous $MgSO_4$ and GCB] in a 2-mL centrifuge tube. The vortexed (1 min) mixture was centrifuged (2,200 rpm) for 5 min. Finally, the supernatant was filtered through 0.22-μm Teflon paper before analyzing it with UPLC–MS/MS instrument. The resulting [LODs (0.8–2 μg/kg), LOQs (≤10 μg/kg), RRs (80–136%) and RSD

Downloaded from https://academic.oup.com/chromsci/advance-article-abstract/doi/10.1093/chromsci/bmy032/4980918
by Serials Section, Dixson Library user
on 24 April 2018

Table IV. The summary of validated results for QuEChERS extraction technique coupled with cleanups using dSPE salts and the modified sorbent materials

Sample	Analytes	RRs (%)	LODs (μg/kg)	LOQs (μg/kg)	RSD (%)	Detection	Ref
Cucumber, orange, pepper, strawberry and tomato	14 Organic-pesticides	70–112	≤3	≤10	≤28	UPLC/QQQ–MS/MS	(54)
Apple, cabbage, green pepper, mandarin and potato	Cyazofamid and CCIM	75.1–105.1	nr	2–5	nr	LC–MS/MS	(56)
Tomatoes	Fungicides and insecticides	71.3–112.3	1–200	10–800	nr	UHPLC–LCMS	(57)
Pomegranate and mango	5 Fungicides and insecticides	87.0–96.0	nr	nr	0.8–20.5	RP–UPLC	(59)
Bananas	128 Kinds of pesticides	70–120	≤5	≤10	≤20	UHPLC–LCMS/MS	(60)
Bitter gourd, capsicum, curry leaves, drumstick, grape, mango and okra	20 Agrochemicals	70–120	nr	0.2–1	<20	LC–MS/MS	(61)
Tomatoes	109 Pesticides	77.1–113.2	0.5–10.8	1.3–30.4	<20	LC–MS/MS	(63)
Cucumber and potato	ETU	60–110	0.025–0.15	0.1–0.5	<18	LC–MS/MS	(65)
Potatoes and pears	Quaternary ammonium pesticides of CQ and MQ	83.4–119.4	21–210	70–700	<7.0	LCMS/MS	(67)
Apples, spinaches, strawberries and tomatoes	SDHI fungicides	80–136	0.8–2	≤10	<20	UPLC–MS/MS	(69)
Strawberry, grape, celery and cabbage	16 Amide fungicides	72.4–98.5	≤3	≤10	<10	UHPLC–MS/MS	(71)
Garland chrysanthemum, lettuce leaves and leek	70 Pesticides	74–119	0.1–2.4	0.3–7.9	<14.2	LC–MS/MS	(72)
Apples, bananas, celeries, eggplants, grapes, leeks, papayas and tomatoes	Glufosinate pesticide	80–108	0.3–3.3	1–10	0.6–9.8	LC–MS/MS	(75)
Pear and orange	16 Post-harvest fungicides	77–120	nr	≤10	<10	LC-ESI-MS/MS	(77)
Kiwi fruit and Juice	33 Pesticides	71–120	1–4	3–10	<20	GC–MS	(78)
Apples, cucumbers, oranges and tomatoes	101 Pesticides residues	71.5–111.7	0.03–2.17	0.1–7.25	<10.5	GC–MS/MS	(81)
Cucumber, grapes, pears and tomatoes	11 Pesticides	70.3–114.1	nr	2–49.6	8.5–13.5	GC–MS	(82)
Cabbage, cauliflower, cucumber, dragon fruit, grape, rambutan and watermelon	8 Carbamate pesticides	79.5–124	4–4,000	15–5,000	0.1–15.7	HPLC	(83)
Banana, apple and tomato	Fenarimol fungicides	91.2–99.5	30–60	0.12–0.21	0.02–6.55	UPLC	(86)
celery, garlic, ginger, leek, onion and shallot	38 Organochlorine, organophosphorus and pyrethroid pesticides	62.9–130	nr	0.01–0.03	≤13.0	GC–MS	(87)

LODs, limit of detections; LOQs, limit of quantitations; RRs, relative recoveries; RSD, relative standard deviation.

(<20%)] are acceptable. Thus, this method is the most effective as compared with other reviewed methods, and it could be accepted officially for monitoring different kinds of pesticides in a variety of vegetables and fruits.

Multi-walled carbon nanotubes (MWCNTs) are a category of carbon nanotubes, which has been used recently for modification of the QuEChERS-dSPE technique. The MWCNTs is used explicitly as a reversed dSPE sorbent for cleanup of samples with a high proportion of pigments. This is because the MWCNT materials possess a large surface area and have a unique structure (70). The use of MWCNTs as a dSPE cleanup tool after QuEChERS extraction was recently reported by Wu *et al.* (71) reported the use of MWCNTs as a cleanup tool after QuEChERS extraction for the determination of 16 fungicides (amide) in fruit and vegetable samples of strawberry, grape, celery and cabbage. In this method, 5 g of homogenized sample was added to a 50-mL centrifuge tube followed by the addition of the 500 μL analyte (spiked) standard solutions. The mixture was vortexed to equilibrate for 15 s and allowed to stabilize for 1 h. Then, 9.5 mL acetonitrile was introduced into the tube and was shaken before addition of 2 g NaCl, followed by 1 min vortexing and 3 min centrifugation (5,000 rpm). The 50-mL volumetric-tube containing 1 mL supernatant was diluted to 5 mL with water to yield 20% acetonitrile. Then, the solution was mixed with acetic acid to adjusting the pH range (3–6). The mixture underwent extraction after addition of 10 mg MWCNTs, shaken for 1 min and centrifuged (9,000 rpm) for 3 min. Later-on, 10 mL acetone was introduced into the mixture after the supernatant was thrown away. Then, 2 min centrifugation (9,000 rpm) was further carried out after 1 min vortexing. At 40°C, evaporation to dryness was conducted on the resulting supernatant (5 mL) under the flow of nitrogen stream. The resulting residue was dissolved in 2.5 mL with a combined solution of acetonitrile/H_2O (20:80 v/v) and 0.1% methanoic acid. Finally, filtration using 0.22-μm pore membrane filter was carried out on the resulting solution, and the 10-μL of the filtrate was analyzed with UHPLC–MS/MS instrument. Likewise, the use of MWCNTs sorbent material for sample cleanup has more advantages compared with PSA because it successfully provided lower LOQs (≤10 μg/kg), LODs (≤3 μg/kg) and RSD (<10%) as well as acceptable RRs (72.4–98.5%). Thus, the method is categorically less effective as compared with other methods reviewed.

In another study, Han *et al.* (72) documented the use of MWCNTs for determination of 70 residues of pesticides in

Downloaded from https://academic.oup.com/chromsci/advance-article-abstract/doi/10.1093/chromsci/bmy032/4980918
by Serials Section, Dixson Library user
on 24 April 2018

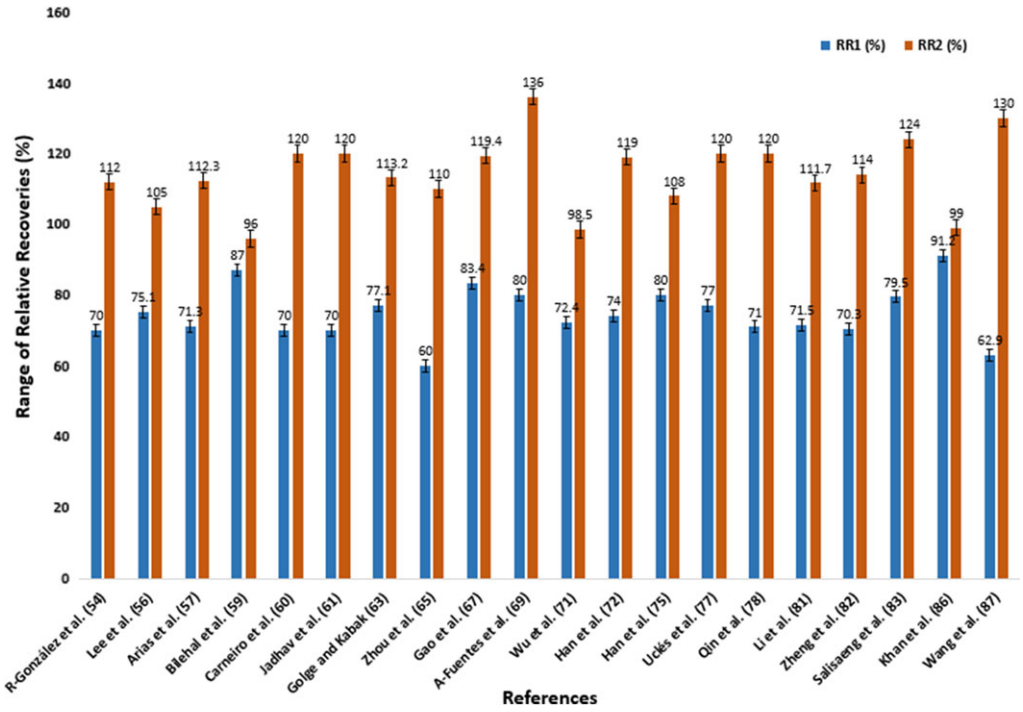


Figure 2. Graphical presentation of percentage relative recoveries (RRs) ranging from RR1 to RR2.

vegetable samples of garland chrysanthemum, lettuce leaves, and leek. The 50-mL of centrifuge tube containing each homogenized sample (10 g) was mixed with 10 mL acetonitrile, and the mixture was shaken for 2 min. The tube was centrifuged (3,800 rpm) for 5 min followed by the addition of NaCl (1 g) and $MgSO_4$ (4 g). The mixture was shaken for 1 min, and 1 mL of the supernatant was poured into a 2-mL centrifuge tube containing anhydrous $MgSO_4$ (150 mg) and 10 mg of the MWCNTs sorbent. Then, the tube was vortexed for 1 min and subjected to 3 min centrifugation (10,000 rpm). Finally, 0.22-µm filter (Nylon-syringe) was used to filter 1 mL of the supernatant before LC–MS/MS analysis. The modified method is categorized more effective when compared with other reviewed methods. The method provided lower LOQs (0.3–7.9 µg/kg), and LODs (0.1–2.4 µg/kg) at RSD (<14.2%), with acceptable RRs (74–119%) and could be used for routinely determination of pesticides in fruits and vegetables.

Glufosinate is a non-selective, broad spectrum and post-emergence herbicide known to inhibits the synthesis of enzyme glutamine which causes health-related issues (73). Therefore, a newly modified QuEChERS technique (QuPPe) developed by the reference laboratories of the European Union (74) based on the use of methanol and the sorbent of MWCNTs as extracting solvent and cleanup material respectively, for the highly polar pesticides. The method was employed by Han *et al.* (75) for extraction of glufosinate pesticide in 10 g homogenized sample of apples, bananas, celeries, eggplants, grapes, leeks, papayas and tomatoes purchased in the local market (Beijing, China). The homogenized samples were individually transferred into 50-mL centrifuge tube, and 10 mL of methanol was introduced into the tube and vortexed for 2 min. The tube was centrifuged for 5 min at 4,000 rpm. Then, 1 mL of the resulting supernatant was transferred to a 2-mL centrifuge tube containing 5 mg of MWCNTs. The vial tube was vortexed (1 min) before centrifugation (10,000 rpm) for 1 min, and the resulting supernatant was filtered through 0.22-µm membrane and the filtrate was analyzed with LC–MS/MS instrument. Thus, the method is categorized effective and can be used efficiently for monitoring glufosinate routinely in vegetables and fruits because of its accuracy, sensitivity and reliability. These help to provide acceptable results of LOQs (1–10 µg/kg), LODs (0.3–3.3 µg/kg) and RRs (80–108%) at RSD (0.6–9.8%).

Another study shows that the blue and green molds (fungi) cause many types of diseases to citrus fruits during transportation or storage. This resulted in high rates of continuous usage of post-harvest fungicides such as Imazalil (76), Based on this fact, Uclés *et al.* (77) employed the recent cleanup material replacing dSPE with sorbent mixtures that include yttria-stabilized zirconium dioxide and MWCNTs for determination of 16 commonly use post-harvest fungicides in pear and orange samples. Each sample was homogenized, and 10 g of it was mixed with acetonitrile (10 mL) in an automatic axial-extractor and shaken for 4 min. The extract was mixed with 1 g each of trisodium citrate dihydrate and NaCl, 4 g anhydrous $MgSO_4$ and 0.5 g disodium hydrogen citrate sesquihydrate in a 50-mL centrifuge tube. The tube was placed in the automatic axial-extractor and shake for another 4 min before 5 min centrifugation (3,500 rpm). Then, 5 mL of the acquired supernatant was introduced to a 15-mL centrifuge tube containing MWCNTs (50 mg), PSA (125 mg), yttria-stabilized zirconium dioxide (175 g) and anhydrous $MgSO_4$ (750 mg). The mixture was centrifuged (3,500 rpm) for 5 min after it was vortexed for 30 s. Finally, the resulting supernatant was diluted with a known amount of acetonitrile/H_2O mixture before spiking it with 10 µL dimethate-d6 (2.5 µg/mL) to obtain 0.05 mg/kg standard. Then, 5 µL (aliquot) was injected for analysis using LC-ESI-MS/MS instrument. The results [RRs (77–120%), LOQs (≤10 µg/kg) and RSD (<10%)] obtained from the developed technique proved satisfactory. Thus, the method is reliable, accurate, easy, quick and categorized more effective when compared with

Downloaded from https://academic.oup.com/chromsci/advance-article-abstract/doi/10.1093/chromsci/bmy032/4980918
by Serials Section, Dixson Library user
on 24 April 2018

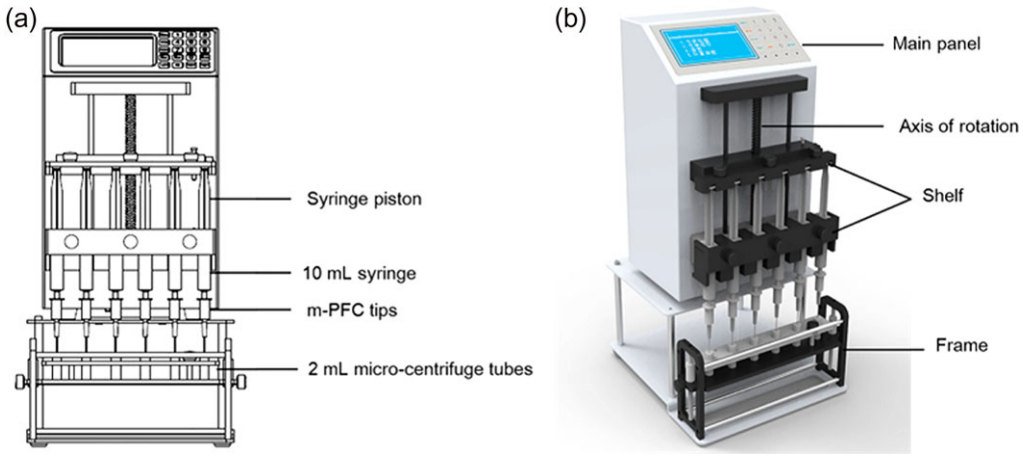


Figure 3. Diagram of the m-PFC equipment (a) and its mechanically automated components (b) reprinted with the permission of Qin *et al.* (78).

other reviewed methods. The advanced cleanup technique can be used as a sorbent material for broader analysis of pesticides residue fruits and vegetables.

Furthermore, Qin *et al.* (78) additionally showed the application of MWCNTs sorbent (replacing dSPE) cleanup material advanceable for removal of sample matrix interferents using a multi-plug filtration cleanup (m-PFC). Thus, m-PFC is made up of a column composing of sorbent materials including MWCNTs, $MgSO_4$ and PSA (79). The technique was used to determine the pesticides residue in kiwi fruit and juice samples purchased (Beijing, China). Firstly, the 10-mL acetonitrile was transferred into a 50-mL centrifuge tube containing 10 g of the ground sample or juice sample. The tube was vortexed for 1 min before introducing 1 g of NaCl and 4 g anhydrous $MgSO_4$. Meanwhile, the 3-g NaCl was added to the juice sample. Water-bath containing ice was used for cooling each tube before shaking it for 1 and 5 min centrifugation (3,800 rpm). Then, for each sample, the m-PFC procedure was carried out on the 1 mL of the collected supernatants, which were contained in a 2-mL microcentrifuge tubes separately, and placed in the automatic equipment. The 10-mL syringes were attached to the m-PFC tips, and their needles were directly placed inside the 2-mL microcentrifuge tubes. Notably, the setup involves three cycles of automated pulling and pushing the extracted samples through the m-PFC (sorbent) tips at 6 and 8 mL/min, respectively. It is done with the aid of a piston, which was automatically controlled by the equipment (Figure 3). Finally, the cleaned aliquots were filtered through a 0.22-μm membrane after removing the needles before GC/MS analysis. In fact, the technique provided good and acceptable results of LOQs (3–10 μg/kg), LODs (1–4 μg/kg), RRs (71–120%) and RSD (<20%). Accordingly, the automated method is categorized more effective when compared with other reviewed methods. It can be used in a wider approach for analysis and monitoring of pesticides. Moreover, it has shown to be easier, robust, less laborious and less time-consuming as it does not require an additional step for centrifugation.

Another developmental technical modification of a QuEChERS-dSPE technique was the use of magnetic nanoparticles (MNPs) to replace the commonly used dSPE cleanup salt/kit was. This is because of the good surface area, adsorption, mechanical, magnetic and optical properties of the magnetic nanoparticles (80). In fact, Li *et al.* (81) reported the use of modified QuEChERS coupled with MNPs of $Fe_3O_{4(s)}$ (Figure 4) as cleanup material for the

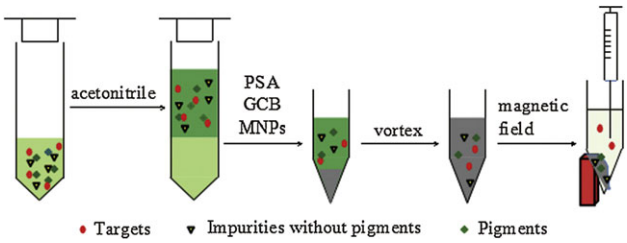


Figure 4. Modified QuEChERS-dSPE procedure replaced by magnetic nanoparticles of iron oxide reprinted with permission of Li et al. (81).

determination of 101 pesticides residues in a sample of apples, cucumbers, oranges and tomatoes. The analyzed samples were purchased from Tai'ans supermarket (China). Methodologically, the 50-mL centrifuge tube containing 10 g homogenized sample was spiked with the standard analyte solutions before the addition of 10 mL acetonitrile. The tube was agitated for 30 s before adding 4 g anhydrous $MgSO_4$ and 1 g NaCl. The tube was shaken for 1.5 min and centrifuged (5,000 rpm) for 5 min. The 1-mL supernatant was introduced into 2-mL centrifuge tube containing MNPs (40 mg), PSA (50 mg), GCB (10 mg) and anhydrous $MgSO_4$ (100 mg) and the mixture was vortexed for 1 min. A magnet was used externally during the collection of the extracted analytes. Then, the collected supernatant was transferred to 1.5-mL Eppendorf-vial before GC–MS/MS analysis. Thus, the method categorically proves to be effective as compared with other reviewed methods. It successfully meets the requirements for multi-residue determination of pesticides in fruits and vegetables based on the good results obtained; RSD (<10.5%) for LODs (0.03–2.17 μg/kg), LOQs (0.1–7.25 μg/kg) and RRs (71.5–111.7%). The technique could be applied broadly for analysis of various analytes in the other food samples.

Similarly, Zheng *et al.* (82) recently documented the use of MNPs adsorbent in one-step QuEChERS extraction method for determination of 11 residues of pesticides in juice and pomace samples obtained from blended and squeezed cucumber. The 2-g of a pesticide-free (blank) sample of cucumber was transferred into a 10-mL centrifuge tube. Then, another 2 g sample was transferred into another 10-mL centrifuge tube. The 0.1-μg/mL of TPP and analyte standard solutions were, respectively, added to the centrifuge tubes for calibration and validation. Then, each tube was treated

Downloaded from https://academic.oup.com/chromsci/advance-article-abstract/doi/10.1093/chromsci/bmy032/4980918
by Serials Section, Dixson Library user
on 24 April 2018

with 2 mL acetonitrile and vigorously shaken for 1 min before the addition of 1,840 mg MNPs adsorbent. The tube was shaken vigorously for another 1 min, and 0.8 mL supernatant was collected into 1.5-mL Eppendorf-vial containing 0.1 g $MgSO_4$ after the matrix was conglomerated in the tube due to an external magnetic force. The vial was vigorously shaken and allowed to settle down for 0.5 min. The 1-µg/mL D-sorbitol (analyte-protectant) was added to the collected extract. Finally, the 1 µL of it was injected for analysis in GC–MS instrument. The modified method is also effectively categorized because it produced acceptable results [RRs (70.3–114.1%), LOQs (2–49.6 µg/kg) and RSD (8.5–13.5%)] when compared with other reviewed methods. The method may serve as an alternative when rapidness is required in place of the commonly used QuEChERS-dSPE technique for analysis of pesticide residues in vegetables and fruits.

In addition, some newly adsorbent materials have recently been reported and used as cleanup material after the QuEChERS extraction (83). These materials include Vortex-assisted dispersive micro-solid-phase extraction (VA-D-µ-SPE) based on the cetyltrimethylammonium bromide (CTAB)-modified zeolite NaY (84). Hence, the material was successfully used by Salisaeng *et al.* (83) for the extraction and cleaning interferences involved during the determination of carbamate pesticides in fruit and vegetable samples. The samples of cabbage, cauliflower, cucumber, dragon fruit, grape, rambutan and watermelon were purchased in Khon Kaen, Thailand. Each of the homogenized samples was weighed (7 g) into 50-mL centrifuge tube and 10 mL acetonitrile containing 1% acetic acid (v/v) was added. The mixture was vortexed for 1 min before 10 min centrifugation (4,000 rpm). Furthermore, 0.4 g of sodium acetate and 2 g $MgSO_4$ were, respectively, added to the mixture followed by 10 min centrifugation (4,000 rpm). The supernatant was evaporated (45°C) to dryness under the flow of nitrogen stream. The residue was dissolved in 7 mL of purified water in a 15-mL centrifuge tube, which contained the sorbent material of CTAB-modified zeolite NaY. The mixture was vortexed for 2 min after forming a suspension and filtered through 0.45-µm membrane. Finally, the absorbed analytes were eluted with 500 µL methanol, and the eluate was dried under a stream of nitrogen flow. HPLC analysis was carried out after re-dissolving the analyte residue with methanol (100 µL). However, the modified technique proved sensitive, rapid and achieved excellent extraction efficiency without an additional centrifugation step. These gives rise to low LODs (4–4,000 µg/kg), good RRs (79.5–124%), LOQs (15–5,000 µg/kg) and RSD (0.1–15.7%). Thus, this categorically proved more effective when compared with other methods reviewed. The method could be authentically used for wider analysis of carbamate pesticides in fruit and vegetable samples.

In another report, the molecularly imprinted polymer (MIP) was recently developed and could serve as a cleanup (sorbent) material for the removal of interfering chlorophyll (interference) from green vegetable and fruit samples (85). Therefore, Khan *et al.* (86) described the modified form of synthesized MIP (noncovalent) as a cleanup technique for determination of fenarimol fungicides in Indian samples of banana, apple and tomato. The 10-g of each blended sample was mixed with 10 mL acetonitrile in a 50-mL centrifuge tube and vortexed before addition of QuEChERS extraction salt (sachet), containing NaCl and anhydrous $MgSO_4$. The mixture underwent centrifugation and the supernatant obtained was transferred to SPE setup unit. Subsequently, the SPE cartridge (1 mL) used was containing 150 mg MIP, and its frit was secured on all sides before conditioning it with 10 mL acetonitrile and water (10 mL). Then, the 1-mL supernatant (eluent) resulting from the QuEChERS extraction was introduced into the cartridge at the flow rate of 0.5 mL/min and a vacuum pressure of 20 kPa. At the end of the extraction/cleanup, 5 mL acetic acid (10%) was used to elute the analyte, and it was absorbed into 1 mL ethyl acetate. Finally, the ethyl acetate was evaporated, and the residue was dissolved in 1 mL acetonitrile before UPLC analysis. The technique is categorically less effective as compared with other methods reviewed because of the results obtained; RRs (91.2–99.5%), LODs (30–60 µg/kg), LOQs (0.12–0.21 µg/kg) and RSD (0.02–6.55%).

The recent use of synthetic magnesium silicate (florisil) in column chromatography for extraction cleanups is one of the newly modified forms of QuEChERS-dSPE technique. Thus, the modified column chromatography was reported by Wang *et al.* (87), which was technically constructed by sequential occupying the glass chromatography with absorbent cotton; 0.1 g of GCB, 3 g each for florisil and anhydrous Na_2SO_4. Then, the glass was placed in an ironic stand before activating the column with 6 mL of hexane. Meanwhile, the 25-g each for the vegetable sample of celery, garlic, ginger, leek, onion and shallot were investigated quantitatively for the presence of 38 OCP, OP and pyrethroid pesticides. Each of the samples was separately homogenized and suck filtered into a glass cup containing 7 g of NaCl and 50 mL of ACN. The mixture was shaken vigorously for 2 min. Then, the solution was allowed to settle for half an hour before transferring 10 mL of the upper phase (ACN extract) into a flat bottom flask. The extract was concentrated in water using rotary evaporator bath at 40°C and 180 mPa. Subsequently, the 9-mL of acetone/hexane (2:8, v/v) was used to reconstitute the extract before transferring it into the activated column. Afterwards, the 6-mL of acetone/hexane (2:8, v/v) was added to the column. Therefore, two eluted solutions were collected in a 50-mL round bottom flask before concentrating it in the water-bath using rotary evaporator at 35°C and vacuum of 300 mPa. The analyte residue was dissolved with 50 µL of 3 µg/mL Heptachlor epoxide isomer B (internal standard) and 950 µL hexane. Finally, GC–MS analysis was carried out on 1 µL of the analyte solution. The advanced method demonstrated excellent removal of matrix interference due to the combination roles performed by florisil and GCB. This resulted to low LOQs (0.01–0.03 µg/kg), excellent RRs range (62.9–130%) at 0.1 µg/kg and RSD (≤13.0%). The technique categorically showed a better result when compared with all the other reviewed methods except the one documented by Abad-Fuentes *et al.* (69). Moreover, the method also showed better results with shorter sample preparation time when compared with the commercially employed cartridges of SPE technique. Therefore, the method could potentially be applied for routine analysis of multi-pesticide residues in complex matrices of vegetable samples. Although, the fact that toxic organic solvents were involved with high extraction time would render this method less advantage as compared with the previously reported methods.

Conclusion and recommendations

The novelty of QuEChERS-dSPE technique was documented in 2003 for pesticide residue determination in fruits and vegetables. Since then, a series of modifications using advanced techniques have been carried out by the traditionally known method. However, these techniques ensure reliable extraction/separation efficiencies towards increasing analyte recoveries as well as lowering relative standard deviation, detection and quantitation limits. This review demonstrated the qualitative aspects of the modified QuEChERS-dSPE techniques in providing excellent validation parameters such as

Downloaded from https://academic.oup.com/chromsci/advance-article-abstract/doi/10.1093/chromsci/bmy032/4980918
by Serials Section, Dixson Library user
on 24 April 2018

range of relative recoveries, quantitation and detection limits of pesticides determined in various samples of fruits and vegetables.

In conclusion, the modified preparation methods reviewed have proven to be more favorable with low consumption of organic (extractant) solvent, providing faster, more selective and higher sensitivity of pesticide analysis in the analyzed sample of vegetables and fruits when compared with the traditionally known method. Thus, the obtained results excellently show that QuEChERS-dSPE and its recent modifications are justifiably reliable methods for routine determination and monitoring of pesticide residues in samples of fruits and vegetables. Certainly, modification involving the use of CTAB-modified zeolite NaY, GCB, PSA, yttria-stabilized zirconium dioxide and florisil as cleanup materials provided the better efficiencies and analyte recoveries when compared categorically with other reviewed cleanup sorbent materials. Moreover, the application of MWCNTs provided a better result than PSA and GCB during the cleanup of high pigment samples. Also, the modified (one-step) methodology, which employs magnetic adsorbent material without centrifugation during purification of target analytes conveniently, facilitates phase separation of the sample mixtures.

Recommendatory notes include further improvement of QuEChERS and cleanup methods by determining residue of pesticides in other food samples such as the wet samples of cereals and legumes. Moreover, considering the aspects of environmental and green chemistry, it is recommended to replace the commonly used acetonitrile (extractant) in the QuEChERS-dSPE method and other modified methods that involve the use of toxic solvents such as acetone and hexane. Thus, these could alternatively be replaced with the non-toxic, green solvents such as supercritical liquid carbon dioxide, ionic liquid-based, low transition temperature mixtures (LTTMs), etc.

Funding

The research is supported by Institute of Research Management and Services (IPPP) under the grant no. PG 174-2014B, University of Malaya Kuala Lumpur, Malaysia.

References

1. Trostle, R.; *Global Agricultural Supply and Demand: Factors Contributing to the Recent Increase in Food Commodity Prices*. DIANE Publishing, Collingdale, (2010); pp. 1–30.
2. Byerlee, D., De Janvry, A., Sadoulet, E.; Agriculture for development: toward a new paradigm; *Annual Review of Resource Econmics*, (2009); 1 (1): 15–31.
3. Liu, R.H.; Health-promoting components of fruits and vegetables in the diet; *Advances in Nutrition: An International Review Journal*, (2013); 4 (3): 384–392.
4. Raven, P.H.; GM crops, the environment and sustainable food production; *Transgenic Research*, (2014); 23(6): 915–921.
5. Halfon, E., Galassi, S., Brüggemann, R., Provini, A.; Selection of priority properties to assess environmental hazard of pesticides; *Chemosphere*, (1996); 33(8): 1543–1562.
6. Hijosa-Valsero, M., Bécares, E., Fernández-Aláez, C., Fernández-Aláez, M., Mayo, R., Jiménez, J.J.; Chemical pollution in inland shallow lakes in the Mediterranean region (NW Spain): PAHs, insecticides and herbicides in water and sediments; *Science of the Total Environment*, (2016); 544: 797–810.
7. Kaur, R., Hasan, A., Iqbal, N., Alam, S., Saini, M.K., Raza, S.K.; Synthesis and surface engineering of magnetic nanoparticles for environmental cleanup and pesticide residue analysis: a review; *Journal of Separation Science*, (2014); 37(14): 1805–1825.
8. Pimentel, D.; Environmental and economic costs of the application of pesticides primarily in the United States; *Environment, Development and Sustainability*, (2005); 7(2): 229–252.
9. Kamrin, M.A.; *Pesticide Profiles: Toxicity, Environmental Impact, and Fate*. CRC Press, Boca Raton, FL, (1997).
10. Bempah, C.K., Donkor, A., Yeboah, P.O., Dubey, B., Osei-Fosu, P.; A preliminary assessment of consumer's exposure to organochlorine pesticides in fruits and vegetables and the potential health risk in Accra Metropolis, Ghana; *Food Chemistry*, (2011); 128: 1058–1065.
11. Kmellár, B., Abrankó, L., Fodor, P., Lehotay, S.J.; Routine approach to qualitatively screening 300 pesticides and quantification of those frequently detected in fruit and vegetables using liquid chromatography tandem mass spectrometry (LC–MS/MS); *Food Additives and Contaminants*, (2010); 27(10): 1415–1430.
12. Boro, S.; Factors influencing ageing and sleep disorders in women: a study of social and environmental factors; *International Journal of Interdisciplinary and Multidisciplinary Studies*, (2015); 2(8): 77–84.
13. Criswell, J.T., Shelton, K., Luper, C.; Toxicity of pesticides. Pesticide Applicator Certification Series, Oklahoma Cooperative Extension Service, *EPP-7457*. (2013).
14. Starling, A.P., Umbach, D.M., Kamel, F., Long, S., Sandler, D.P., Hoppin, J.A.; Pesticide use and incident diabetes among wives of farmers in the Agricultural Health Study; *Occupational and Environmental Medicine*, (2014); 71: 629–635.
15. Parrón, T., Requena, M., Hernández, A.F., Alarcón, R.; Environmental exposure to pesticides and cancer risk in multiple human organ systems; *Toxicology Letters*, (2014); 230(2): 157–165.
16. Mostafalou, S., Abdollahi, M.; Pesticides and human chronic diseases: evidences, mechanisms, and perspectives; *Toxicology and Applied Pharmacology*, (2013); 268(2): 157–177.
17. MCGorrin, R.J.; One hundred years of progress in food analysis; *Journal of Agricultural and Food Chemistry*, (2009); 57: 8076–8088.
18. Yang, X.J., Du, Z., Lin, A., Yuan, Q., Wan, P., Wong, C.; Simultaneous determination of neutral, basic and acidic pesticides in aquatic environmental matrices by solid-phase extraction and liquid chromatography electrospray ionization mass spectrometry; *Analytical Methods*, (2013); 5: 2083–2092.
19. Orso, D., Martins, M.L., Donato, F.F., Rizzetti, T.M., Kemmerich, M., Adaime, M.B., *et al.*; Multiresidue determination of pesticide residues in honey by modified QuEChERS method and gas chromatography with electron capture detection; *Journal of the Brazilian Chemical Society*, (2014); 25(8): 1355–1364.
20. Banerjee, K., Oulkar, D.P., Dasgupta, S., Patil, S.B., Patil, S.H., Savant, R., *et al.*; Validation and uncertainty analysis of a multi-residue method for pesticides in grapes using ethyl acetate extraction and liquid chromatography–tandem mass spectrometry; *Journal of Chromatography A*, (2007); 1173(1): 98–109.
21. Zhou, Y., Du, Z., Zhang, Y.; Simultaneous determination of 17 disperse dyes in textile by ultra-high performance supercritical fluid chromatography combined with tandem mass spectrometry; *Talanta*, (2014); 127: 108–115.
22. Deng, X., Guo, Q., Chen, X., Xue, T., Wang, H., Yao, P.; Rapid and effective sample clean-up based on magnetic multiwalled carbon nanotubes for the determination of pesticide residues in tea by gas chromatography–mass spectrometry; *Food Chemistry*, (2014); 145: 853–858.
23. Xie, J., Peng, T., Zhu, A., He, J., Chang, Q., Hu, X., *et al.*; Multi-residue analysis of veterinary drugs, pesticides and mycotoxins in dairy products by liquid chromatography–tandem mass spectrometry using low-temperature cleanup and solid phase extraction; *Journal of Chromatography B*, (2015); 1002: 19–29.
24. Radford, S.A., Hunter, R.E., Jr, Barr, D.B., Ryan, P.B.; Liquid–liquid extraction of insecticides from Juice: an Analytical Chemistry Laboratory Experiment; *Journal of Chemical Education*, (2013); 90(4): 483–486.
25. Berijani, S., Sadigh, M., Pournamdari, E.; Homogeneous liquid–liquid microextraction for determination of organophosphorus pesticides in environmental water samples prior to gas chromatography-flame photometric detection; *Journal of Chromatographic Science*, (2016); 54(6): 1061–1067.

Downloaded from https://academic.oup.com/chromsci/advance-article-abstract/doi/10.1093/chromsci/bmy032/4980918
by Serials Section, Dixson Library user
on 24 April 2018

26. Abdulra'uf, L.B., Sirhan, A.Y., Huat Tan, G.; Recent developments and applications of liquid phase microextraction in fruits and vegetables analysis; *Journal of Separation Science*, (2012); 35(24): 3540–3553.
27. Alsharif, A.M.A., Tan, G.-H., Choo, Y.-M., Lawal, A.; Efficiency of hollow fiber liquid-phase microextraction chromatography methods in the separation of organic compounds: a review; *Journal of Chromatographic Science*, (2017); 55: 378–391.
28. Alsharif, A.M.A., Tan, G.H., Choo, Y.M., Lawal, A.; Liquid phase microextraction for analysis of mycotoxins in food samples: REVIEW; *Research Journal of Chemical and Environmental Sciences*, (2015); 3(6): 5–21.
29. Lawal, A., Tan, G.H., Alsharif, A.M.A.; Recent advances in analysis of pesticides in food and drink samples using LPME techniques coupled to GC-MS and LC-MS: a review; *Journal of AOAC International*, (2016); 99(6): 1383–1394.
30. Seidi, S., Yamini, Y., Rezazadeh, M.; Electrochemically assisted solid based extraction techniques: a review; *Talanta*, (2015); 132: 339–353.
31. Grimalt, S., Dehouck, P.; Review of analytical methods for the determination of pesticide residues in grapes; *Journal of Chromatography A*, (2016); 1433: 1–23.
32. Lehotay, S.J.; New technologies applied in pesticide residue analysis. Residuos de plaguicidas Pesticide residues 96; *IV Seminario International sobre Residuos de Plaguicidas*, (1998); 96: 53.
33. Cook, J., Engel, M., Wylie, P., Quimby, B.; Multiresidue screening of pesticides in foods using retention time locking, GC-AED, database search, and GC/MS identification; *Journal of AOAC International*, (1998); 82(2): 313–326.
34. Aulakh, J., Malik, A., Kaur, V., Schmitt-Kopplin, P.; A review on solid phase micro extraction-high performance liquid chromatography (SPME-HPLC) analysis of pesticides; *Critical Reviews in Analytical Chemistry*, (2005); 35(1): 71–85.
35. Bruzzoniti, M.C., Checchini, L., De Carlo, R.M., Orlandini, S., Rivoira, L., Del Bubba, M.; QuEChERS sample preparation for the determination of pesticides and other organic residues in environmental matrices: a critical review; *Analytical and Bioanalytical Chemistry*, (2014); 406(17): 4089–5116.
36. Fernandes, V.C., Domingues, V.F., Delerue-Matos, C., Mateus, N.; Determination of pesticides in fruit and fruit juices by chromatographic methods. An overview; *Journal of Chromatographic Science*, (2011); 49 (9): 715–730.
37. Raina-Fulton, R.; New trends in pesticide residue analysis in cereals, nutraceuticals, baby foods, and related processed consumer products; *Journal of AOAC International*, (2015); 98(5): 1163–1170.
38. Valcarcel, M., Cárdenas, S., Simonet, B., Moliner-Martinez, Y., Lucena, R.; Carbon nanostructures as sorbent materials in analytical processes; *TrAC, Trends in Analytical Chemistry*, (2008); 27(1): 34–43.
39. Anastassiades, M., Lehotay, S.J., Štajnbaher, D., Schenck, F.J.; Fast and easy multiresidue method employing acetonitrile extraction/partitioning and "dispersive solid-phase extraction" for the determination of pesticide residues in produce; *Journal of AOAC International*, (2003); 86(2): 412–431.
40. RESTEK. (2015). QuEChERS Methodology: AOAC Method., U.S.A. www.restek.com/pdfs/805-01-002.pdf (accessed March 15, 2016).
41. Biziuk, M., Stocka, J.; Multiresidue methods for determination of currently used pesticides in fruits and vegetables using QuEChERS technique; *International Journal of Environmental Science and Development*, (2015); 6(1): 18–22.
42. Aranzana, M.S.C.; Dispersive solid-phase (Micro) extraction. In *Encyclopedia of Analytical Chemistry*. John Wiley & Sons, Ltd, Spain, (2010); pp. 1–11.
43. Waters.; (2011). QuEChERS Procedure for Multi-residue Pesticide Analysis. https://www.waters.com/webassets/cms/library/docs/720003643en.pdf. (accessed July 25, 2016).
44. Zhao, P., Wang, L., Zhou, L., Zhang, F., Kang, S., Pan, C.; Multi-walled carbon nanotubes as alternative reversed-dispersive solid phase extraction materials in pesticide multi-residue analysis with QuEChERS method; *Journal of Chromatography A*, (2012); 1225: 17–25.
45. Łozowicka, B., Rutkowska, E., Jankowska, M.; Influence of QuEChERS modifications on recovery and matrix effect during the multi-residue pesticide analysis in soil by GC/MS/MS and GC/ECD/NPD; *Environmental Science and Pollution Research*, (2017); 24(8): 7124–7138.
46. Johnson, Y.S.; Determination of polycyclic aromatic hydrocarbons in edible seafood by QuEChERS-based extraction and gas chromatography tandem mass spectrometry; *Journal of Food Science*, (2012); 77(7): 131–137.
47. Petrarca, M.H., Fernandes, J.O., Godoy, H.T., Cunha, S.C.; Multiclass pesticide analysis in fruit-based baby food: a comparative study of sample preparation techniques previous to gas chromatography–mass spectrometry; *Food Chemistry*, (2016); 212: 528–536.
48. Liu, Y., Zhong, D., Shen, D., Mo, R., Tang, F.; Determination of four insecticides in bamboo shoot by QuEChERS-MSPD combined with LC–MS/MS; *Food Science and Technology Research*, (2014); 20(3): 563–569.
49. Lehotay, S.J., Tully, J., Garca, A.V., Contreras, M., Mol, H., Heinke, V., *et al.*; Determination of pesticide residues in foods by acetonitrile extraction and partitioning with magnesium sulfate: collaborative study; *Journal of AOAC International*, (2007); 90(2): 485–520.
50. Oshita, D., Jardim, I.C.; Evaluation of dispersive and cartridge SPE clean-up procedures using the modified QuEChERS method for the analysis of pesticides in strawberries; *Analytical Methods*, (2015); 7(3): 982–989.
51. Rizzetti, T.M., Kemmerich, M., Martins, M.L., Prestes, O.D., Adaime, M.B., Zanella, R.; Optimization of a QuEChERS based method by means of central composite design for pesticide multiresidue determination in orange juice by UHPLC–MS/MS; *Food Chemistry*, (2016); 196: 25–33.
52. SANTE-11813.; Guidance document on analytical quality control and method validation procedures for pesticide residues and analysis in food and feed. 21–22 November 2017 ed. EUROPEAN COMMISSION (2017), pp. 1–42.
53. Lamichhane, J.R., Dachbrodt-Saaydeh, S., Kudsk, P., Messéan, A.; Toward a reduced reliance on conventional pesticides in European agriculture; *Plant Disease*, (2016); 100(1): 10–24.
54. Romero-González, R., Plaza-Bolaños, P., Limón-Garduza, R.I., Martínez-Vidal, J.L., Frenich, A.G.; QuEChERS approach for the determination of biopesticides in organic and nonorganic vegetables and fruits by ultra-performance liquid chromatography/tandem mass spectrometry; *Journal of AOAC International*, (2014); 97(4): 1027–1033.
55. Jackson, K.L., Yin, J., Ji, P.; Sensitivity of *Phytophthora capsici* on vegetable crops in Georgia to mandipropamid, dimethomorph, and cyazofamid; *Plant disease*, (2012); 96(9): 1337–1342.
56. Lee, H., Kim, E., Lee, J.-H., Sung, J.H., Choi, H., Kim, J.-H.; Analysis of cyazofamid and its metabolite in the environmental and crop samples using LC–MS/MS; *Bulletin of Environmental Contamination and Toxicology*, (2014); 93(5): 586–590.
57. Arias, L.A., Bojacá, C.R., Ahumada, D.A., Schrevens, E.; Monitoring of pesticide residues in tomato marketed in Bogota, Colombia; *Food Control*, (2014); 35(1): 213–217.
58. López-Fernández, O., Rial-Otero, R., González-Barreiro, C., Simal-Gándara, J.; Surveillance of fungicidal dithiocarbamate residues in fruits and vegetables; *Food Chemistry*, (2012); 134(1): 366–374.
59. Bilehal, D.C., Chetti, M., Sung, D.D., Goroji, P.; Reversed-phase UPLC method for the determination of monocrotophos, thiram, carbendazim, carbaryl, and imidacloprid pesticides in mango and pomegranate by QuEChERS method; *Journal of Liquid Chromatography & Related Technologies*, (2014); 37(12): 1633–1643.
60. Carneiro, R.P., Oliveira, F.A., Madureira, F.D., Silva, G., de Souza, W. R., Lopes, R.P.; Development and method validation for determination of 128 pesticides in bananas by modified QuEChERS and UHPLC–MS/MS analysis; *Food Control*, (2013); 33(2): 413–423.
61. Jadhav, M.R., Oulkar, D.P., Shabeer, T.P.A., Banerjee, K.; Quantitative screening of agrochemical residues in fruits and vegetables by buffered ethyl acetate extraction and LC–MS/MS analysis; *Journal of Agricultural and Food Chemistry*, (2015); 63(18): 4449–4456.

Downloaded from https://academic.oup.com/chromsci/advance-article-abstract/doi/10.1093/chromsci/bmy032/4980918
by Serials Section, Dixson Library user
on 24 April 2018

62. Karaağaç, S.U.; Enzyme activities and analysis of susceptibility levels in Turkish *Tuta absoluta* populations to chlorantraniliprole and metaflumizone insecticides; *Phytoparasitica*, (2015); 43(5): 693–700.
63. Golge, O., Kabak, B.; Evaluation of QuEChERS sample preparation and liquid chromatography–triple-quadrupole mass spectrometry method for the determination of 109 pesticide residues in tomatoes; *Food Chemistry*, (2015); 176: 319–332.
64. Singh, A., Srivastava, P.; In-vivo study of effects of dithiocarbamates fungicide (Mancozeb) and its metabolite ethylenethiourea (ETU) on fresh water fish Clarius batrachus; *Journal of Biology and Earth Sciences*, (2013); 3(2): B228–B235.
65. Zhou, L., Liu, X., Kang, S., Zhang, F., Pan, C.; A rapid determination method for ethylenethiourea in potato and cucumber by modified QuEChERS–High performance liquid chromatography–tandem mass spectrometry; *Food Chemistry*, (2013); 138(2): 1355–1359.
66. Hoy, J., Swanson, N., Seneff, S.; The high cost of pesticides: human and animal diseases; *Poultry, Fisheries & Wildlife Sciences*, (2015); 3(1): 1–18.
67. Gao, J., Wang, J., Zuo, M., Ma, L., Cui, Y., Yang, T., *et al*.; A highly sensitive method for simultaneous determination of the quaternary ammonium pesticides chlormequat and mepiquat in pears and potatoes by modified QuEChERS-high performance liquid chromatography–tandem mass spectrometry; *RSC Advances*, (2015); 5(8): 5895–5903.
68. Li, D., Liu, M., Yang, Y., Shi, H., Zhou, J., He, D.; Strong lethality and teratogenicity of strobilurins on *Xenopus tropicalis* embryos: basing on ten agricultural fungicides; *Environmental Pollution*, (2015); 208: 868–874.
69. Abad-Fuentes, A., Ceballos-Alcantarilla, E., Mercader, J.V., Agulló, C., Abad-Somovilla, A., Esteve-Turrillas, F.A.; Determination of succinate-dehydrogenase-inhibitor fungicide residues in fruits and vegetables by liquid chromatography–tandem mass spectrometry; *Analytical and Bioanalytical Chemistry*, (2015); 407(14): 4207–4211.
70. Lee, M.-S., Lee, S.-Y., Park, S.-J.; Preparation and characterization of multi-walled carbon nanotubes impregnated with polyethyleneimine for carbon dioxide capture; *International Journal of Hydrogen Energy*, (2015); 40(8): 3415–3421.
71. Wu, Y.-L., Chen, R.-X., Zhu, Y., Zhao, J., Yang, T.; Simultaneous determination of sixteen amide fungicides in vegetables and fruits by dispersive solid phase extraction and liquid chromatography–tandem mass spectrometry; *Journal of Chromatography B*, (2015); 989: 11–20.
72. Han, Y., Zou, N., Song, L., Li, Y., Qin, Y., Liu, S., *et al*.; Simultaneous determination of 70 pesticide residues in leek, leaf lettuce and garland chrysanthemum using modified QuEChERS method with multi-walled carbon nanotubes as reversed-dispersive solid-phase extraction materials; *Journal of Chromatography B*, (2015); 1005: 56–64.
73. Rojano-Delgado, A., Priego-Capote, F., De Prado, R., De Castro, M.L.; Qualitative/quantitative strategy for the determination of glufosinate and metabolites in plants; *Analytical and Bioanalytical Chemistry*, (2014); 406(2): 611–620.
74. Anastassiades, M., Kolberg, D.I., Eichhorn, E., Benkenstein, A., Lukačević, S., Mack, D., *et al*.; Quick method for the analysis of numerous highly polar pesticides in foods of plant origin via LC–MS/MS involving simultaneous extraction with methanol (QuPPe-Method); *EU Reference Laboratories for Residues of Pesticides*, (2015); 9: 1–60.
75. Han, Y., Song, L., Zhao, P., Li, Y., Zou, N., Qin, Y., *et al*.; Residue determination of glufosinate in plant origin foods using modified Quick Polar Pesticides (QuPPe) method and liquid chromatography coupled with tandem mass spectrometry; *Food Chemistry*, (2016); 197: 730–736.
76. Altieri, G., Di Renzo, G.C., Genovese, F., Calandra, M., Strano, M.C.; A new method for the postharvest application of imazalil fungicide to citrus fruit; *Biosystems Engineering*, (2013); 115(4): 434–443.
77. Uclés, A., López, S.H., Hernando, M.D., Rosal, R., Ferrer, C., Fernández-Alba, A.R.; Application of zirconium dioxide nanoparticle sorbent for the clean-up step in post-harvest pesticide residue analysis; *Talanta*, (2015); 144: 51–61.
78. Qin, Y., Zhang, J., He, Y., Han, Y., Zou, N., Li, Y., *et al*.; Automated multiplug filtration cleanup for pesticide residue analyses in Kiwi fruit (*Actinidia chinensis*) and Kiwi juice by gas chromatography–mass spectrometry; *Journal of Agricultural and Food Chemistry*, (2016); 64(31): 6082–6090.
79. Zhao, P., Fan, S., Yu, C., Zhang, J., Pan, C.; Multiplug filtration clean-up with multiwalled carbon nanotubes in the analysis of pesticide residues using LC–ESI-MS/MS; *Journal of Separation Science*, (2013); 36(20): 3379–3386.
80. Latham, A.H., Williams, M.E.; Controlling transport and chemical functionality of magnetic nanoparticles; *Accounts of Chemical Research*, (2008); 41(3): 411–420.
81. Li, Y.-F., Qiao, L.-Q., Li, F.-W., Ding, Y., Yang, Z.-J., Wang, M.-L.; Determination of multiple pesticides in fruits and vegetables using a modified quick, easy, cheap, effective, rugged and safe method with magnetic nanoparticles and gas chromatography tandem mass spectrometry; *Journal of Chromatography A*, (2014); 1361: 77–87.
82. Zheng, H.-B., Ding, J., Zheng, S.-J., Yu, Q.-W., Yuan, B.-F., Feng, Y.-Q.; Magnetic "one-step" quick, easy, cheap, effective, rugged and safe method for the fast determination of pesticide residues in freshly squeezed juice; *Journal of Chromatography A*, (2015); 1398: 1–10.
83. Salisaeng, P., Arnnok, P., Patdhanagul, N., Burakham, R.; Vortex-assisted dispersive micro-solid phase extraction using CTAB-modified zeolite NaY sorbent coupled with HPLC for determination of carbamate insecticides; *Journal of Agricultural and Food Chemistry*, (2016); 64(10): 2145–2152.
84. Patdhanagul, N., Srithanratana, T., Rangsriwatananon, K., Hengrasmee, S.; Ethylene adsorption on cationic surfactant modified zeolite NaY; *Microporous and Mesoporous Materials*, (2010); 131(1): 97–102.
85. Batlokwa, B.S., Mokgadi, J., Majors, R., Turner, C., Torto, N.; A novel molecularly imprinted polymer for the selective removal of chlorophyll from heavily pigmented green plant extracts prior to instrumental analysis; *Journal of Chemistry*, (2013); 2013: 1–4.
86. Khan, S., Bhatia, T., Trivedi, P., Satyanarayana, G., Mandrah, K., Saxena, P.N., *et al*.; Selective solid-phase extraction using molecularly imprinted polymer as a sorbent for the analysis of fenarimol in food samples; *Food Chemistry*, (2016); 199: 870–875.
87. Wang, X., Qi, P., Wang, X., Zhang, Q., Wang, Z., Xu, X., *et al*.; An efficient cleanup method coupled with gas chromatography and mass spectrometry for multi-pesticides residue analysis in complex plant matrices; *Journal of Separation Science*, (2017); 40: 2438–2450.

Downloaded from https://academic.oup.com/chromsci/advance-article-abstract/doi/10.1093/chromsci/bmy032/4980918
by Serials Section, Dixson Library user
on 24 April 2018