Development of analytical methodologies for multiresidue pesticide analysis in agri-food products from Colombia

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DEVELOPMENT OF ANALYTICAL METHODOLOGIES FOR MULTIRESIDUE PESTICIDE ANALYSIS IN AGRI-FOOD PRODUCTS FROM COLOMBIA

MEMORIA PARA LA OBTENCIÓN DEL GRADO DE DOCTORA

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D. JAVIER HERNÁNDEZ BORGES, PROFESOR TITULAR DE QUÍMICA ANALÍTICA DEL DEPARTAMENTO DE QUÍMICA DE LA UNIVERSIDAD DE LA LAGUNA (ESPAÑA), Y D. MIGUEL ÁNGEL GONZÁLEZ CURBELO, PROFESOR TITULAR DEL DEPARTAMENTO DE CIENCIAS BÁSICAS DE LA UNIVERSIDAD EAN (COLOMBIA),

INFORMAN:

Que Dña. Diana Angélica Varela Martínez, Licenciada en Química por la Universidad Pedagógica Nacional de Colombia, ha realizado bajo nuestra dirección los trabajos conducentes a la realización de su Tesis Doctoral titulada DEVELOPMENT OF ANALYTICAL METHODOLOGIES FOR MULTIRESIDUE PESTICIDE ANALYSIS IN AGRI-FOOD PRODUCTS FROM COLOMBIA.

Revisado el trabajo, autorizamos su presentación bajo la modalidad por compendio de publicaciones para que se pueda proceder a su lectura y defensa pública, y optar al grado de Doctora en Química con Mención Internacional por esta Universidad.

Y para que así conste, firmamos el presente en San Cristóbal de La Laguna, a 18 de diciembre de 2020.

Fdo: Dr. Javier Hernández Borges
(Director y tutor)

Fdo: Dr. Miguel Ángel González Curbelo
(Co-director)

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Poder reconocer nuestras raíces, nuestro pasado y hacer una construcción de la vida a partir de las experiencias es un verdadero valor. Saber que construimos y evolucionamos nos hace grandes. Tener la capacidad de hacerlo con amor y sabiduría, de ser mensajeros de experiencias y transmitir la belleza del pensamiento nos convierte en maestros.

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De corazón, gracias.

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Being able to recognize our roots, our past and construct life based on experiences is a true value. Knowing that we build and evolve makes us great. Having the ability to do it with love and wisdom, to be messengers of experiences and transmit the beauty of our thoughts makes us masters.

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From my heart, thank you.

Diana.

A mis padres
A mis hermanos

TABLE OF CONTENTS

TABLE OF CONTENTS

Table of contents

CHAPTER I

INTRODUCTION

I.- INTRODUCTION

I.1.- Generalities of Colombia

Colombia is located in the northwest of South America, in the tropics. With an area of 1,141,748 km^2 as continental territory and 988,000 km^2 as maritime territory, it is the fourth largest country of South America and the twenty-sixth largest country in the world [1]. It limits to the north with Panama, to the east with Venezuela and Brazil and to the south with Ecuador and Peru [2]. It is divided in 32 departments and a capital district, Bogotá, located in the centre of the country [3].

According to the National Population and Housing Census conducted by the National Administrative Department of Statistics (DANE), in 2018, Colombia has a population of around 48.3 million people. Most of it, 85.2 %, is white or mestizo -the conjugation of indigenous, European and African roots- while Afro descendants, Raizal and Palenquera, constitute 9.4 %, and indigenous people 3.9 % [4, 5]. In this last sense, it is important to highlight, that there are more than 80 indigenous groups in the Colombian territory, and they represent an important cultural diversity that has greatly contributed to the development of the country.

The characteristics of the Colombian relief creates a variety of climates throughout the territory. The different mountain ranges, depending on their height, originate the aforementioned regions and climatic subregions, which influence vegetation and fauna. As an example, and as a result of the tropical location of the territory and uniform sun radiation, temperatures may vary between 0 and 38 °C in extreme cases [6].

Colombia is a country with abundant water resources, represented in a good number of swamps, dams, lakes, lagoons, reservoirs, and groundwater. It is divided into five distinct regions, Caribbean, Pacific, Amazonia, Orinoquia and Andea, and, within them, rivers are born. In particular, it is estimated that Colombia is the seventeenth country with the highest water wealth in the world [7]. Examples of such wealthiness are the swamps Zapatoca, which are one of the largest inland wetlands of Colombia with fresh water. It has an extension between 30,000 and 40,000 ha in summer and 70,000 ha in autumn and winter [8]. The Tota and the Fuquene lagoons, in the Cundinamarca and Boyacá departments, respectively, are the most extensive, while the largest is Santa Marta swamp with an approximate area of 3,487 km^2, of which 730 km^2 correspond to the body of water [9-10]. Regarding runoff waters, part of the Amazon River is also born in the country, while the Magdalena river, is another important water source that flows 1,528 km from the mountains, from the department of Huila to the Caribbean Sea [11].

Concerning oceanic waters, which also influence greatly the climate of the country, they are constituted by the Caribbean Sea to the north and the Pacific Ocean to the west, which bath the continental territory for approximately 1,600 km of coast in the first case, and with 1,300 km in the second [12].

Apart from the previously commented issues, the richness of Colombia is also its biodiversity. In fact, it is the second country in the world in terms of biodiversity [13]. Currently, 1,889 birds, 4,000 orchids, 2,000 marine fish, 3,000 butterflies and 1,239 macro-fungi species can be found, being the first country in the world with the highest variety of amphibians (15 %), crocodiles (25 %) and turtles (30 %) and the second with the highest number of butterfly species [14, 15]. These figures report the richness of the flora and fauna of this country, which is also currently being investigated in order to report new species.

I.2.- Agricultural production in Colombia: tropical fruits

Natural and geographical strengths of Colombia, hand in hand with ancestral agricultural knowledge, and technological advances, have historically contributed to its economic and social development. In fact, agriculture currently contributes to the economic development of the country as the main source of income [16]. Indeed, Colombia is known as a farming country, up to the point that it is one of the seven countries in the world identified by the Food and Agriculture Organization (FAO) of the

United Nations with agricultural potential to become a world pantry facing the growing demand for food, which by 2030 will increase by at least a 50 % [17].

The agricultural production of the country is very diverse. According to the National Agricultural Survey carried out in 2019, the total agricultural production was 63,247,863 t: 66.7 % corresponds to agro-industrial and agri-food products (coffee, oil palm, sugar cane, cocoa, soy and cotton), 10.6 % to fruits (avocado, banana, peach, feijoa, strawberry, guava, lemon, lulo, mandarin, mango, apple, passion fruit, blackberry and gulupa), 10.1 % to tubers and plantains (cassava, potato and "cooking bananas"), 7.0 % to cereals (rice, barley, corn and wheat), 4.8 % to vegetables and legumes (pea, onion, beans, carrot and tomato) and 0.7 % to forest plantations (pine, cypress, eucalyptus, alder and cedar) [18, 19]. In 2019, the total land use was 50,102,269 ha, distributed in livestock use (77.9 %), forests (10.3 %), agriculture (9.2 %) and other uses (2.6 %) [18].

Colombia currently cultivates a variety of exotic agri-food products, including tropical fruits (i.e. pineapple, papaya, mango, avocado, Tahiti lemon, and passion fruit), which have become known worldwide for being a healthy and exquisite food source. Some of those exotic species are mainly cultivated and produced in the Colombian territory (i.e. granadilla, soursop, tree tomato, lulo, mangostino and uchuva), thanks to the variety of climates, water sources, geographic position as wells as culinary tastes. Among them, the so-called minor tropical fruits, which were not initially relevant for human consumption, can also be found (i.e. rose apple/pomarrosa, starfruit/carambola, papayuela, yoyomo, gulupa, guanbana, cherimoya, among others), since they were later discovered to have a high commercial value as a result of their organoleptic characteristics and nutritional properties. Such tropical fruit market (which represents a cultivated area of 505,164 ha) is constantly increasing and offers Colombia the possibility of its expansion and consolidation [18]. In fact, during the last four decades, the area for fruit plantations has experienced a constant growth, which is clearly reflected in the decrease of the areas dedicated to non-marketable crops and, in general, to the rest of the agri-food products, except that of coffee [20]. Table I.1 shows the variety of tropical fruits cultivated in the different regions of the country, and which include those exotic and minor tropical fruits that have an export potential.

Table I.1.- Fruits cultivated in Colombia according to the regions [19].

Regions	Production
Andean	Curuba, soursop, blackberry, pineapple, strawberry, avocado, cape gooseberry, papayuela, custard apple, guava, passion fruit, feijoa, lulo, orange, tangerine, tree tomato, apple, banana, pear, granadilla, melon, watermelon, yoyomo, uchuva guanabana, cherimoya and pitahaya, among others.
Caribbean	Anon, sapote costeño, loquat, tamarind, cashew, corozo, mango, and banana.
Orinoquia	Orange, lemon, and tangerine. In some sectors soursop is grown.
Pacific	Borojó, almirajo, loquat fruit, and chontaduro.
Amazonian	Race, starfruit/carambola, copoazú, amazon anón, cocona, camu camu, maraco, pineapple, rose apple/pomarrosa, gulupa and amazon lulo.

Colombia is as an important world producer of exotic tropical fruits, especially minor tropical fruits (see Figure I.1). This is the case of gulupa and granadilla, which have had a representative role in international markets since 2019, becoming one of the main sources of income for fruit exports in the country.

Figure I.1.- Photograph of some of the tropical fruits analyzed in this PhD Thesis.

Gulupa (*Passiflora pinnatistipula*) is a tropical fruit native to South America, depending on its degree of maturity, can be green, yellow or purple in colour and round to slightly oblong in shape. The pulp consists of oval black seeds, covered with aril of yellow to orange colour; its flavour is slightly acidic and very juicy [22]. Among its nutritional benefits, its high content of calcium, phosphorus, ascorbic acid stands out, in addition to its health benefits as an aid to the cardiovascular system and the regulation of blood pressure levels [23]. In Colombia, it began to be cultivated in the Department of Amazonas and presents a good profitability since its production begins after eight months from sowing. In Amazonas, approximately 2,000 ha are cultivated nowadays with a production of 25,000 t [24]. It is also currently cultivated in the departments of Antioquia, Boyacá, Quindío and Cauca, in approximately 8,109 ha [25]. Its exports have reported a remarkable growth, especially to the Netherlands and the United Kingdom in more than an 85 % between 2008 and 2018. In fact, it has already become the fourth best-selling fruit in the country [24].

Rose apple/pomarrosa (*Syzygium malaccense*) is a tropical fruit native to Malaysia, but it is present in some countries in South America and Central America, including Colombia. The fruit is oblong in shape and green, yellow or red depending on the degree of maturation and the variety, while the pulp is white. Its flavour is sweet and very juicy since approximately 85% of its weight is water [24]. Among its nutritional benefits, its high content of fibre, potassium, phosphorus, calcium, and vitamin B1, B2 and B6 stand out. In addition, it is also used to prevent diseases such as constipation and asthma [24]. In Colombia, it is grown mainly in the departments of Antioquia and Boyacá, as well as in the Amazonian region [25]. Rose apple/pomarrosa has been exported increasingly, especially to the United States, Europe and the United Kingdom, but it also has a significant local consumption [26].

Yoyomo (*Spondias purpurea*) is a fruit native to South America. The fruit is a drupe generally yellow, orange or purple red in colour, and it has an ovoid shape approximately 3 cm long by 1.5 cm wide. Its pulp is yellow, and it has stone, a lot of fibre and a sweet and sour taste. Among its benefits, it has a low caloric content, and it is used in healthy diets [27]. In Colombia, it is grown mainly in the department of Boyacá, which contributes with a 74 % of the total production. Moreover, this crop has grown by 55 % throughout the country in the last five years and it has been considerably exported to China [28, 29].

Another minor tropical fruit that has found an important place in the Colombian market is starfruit/carambola (*Averrhoa carambola*), a native species of tropical Asia. It is a star-shaped fruit as it has five ellipsoidal or ovoid longitudinal prominences in cross section, which is slightly acidic, juicy and crispy [30]. Among its nutritional benefits, its high content of calcium, phosphorus, iron, carotenoids, proteins and fibre stands out [30]. It is grown in the lower tropics of the country, where there is medium to high rainfall. The departments of Valle del Cauca, Córdoba, Antioquia, Quindío, Tolima, Meta, and the Caribbean areas are the most prominent in the production of this fruit, focused on small crops and a reduced market niche [31]. Its exports are mainly directed to the United States and Canada [32].

Papayuela (*Vasconcellea pubescens*), a species native to north western countries of South America, grows up to 3.5 m tall, has a thick stem at the base and tapers at the top. It has a lobed denture leaf of 20 to 26 cm long. It grows at a height of 1,800-2,800 m and at a temperature of 12 to 18 °C. Its vegetative period is 18 months [33]. Its colour can be white, yellow, pink or orange, depending on the maturation stage. It has a high-water content, it is very aromatic, and has a sweet flavour resembling that of pineapple [34]. Among its nutritional benefits, its high content of iron, vitamin A, ascorbic acid stand out. [34]. The departments where the crops of this fruit predominate are the Llanos Orientales, Córdoba, Valle del Cauca and Quindío [35]. The largest exports are to Europe and the Netherlands [36].

Cherimoya (*Annona cherimola Miller*) is one of the most appreciated fruits within tropical fruits and is part of the Colombian identity. It is native to the Equatorial and Peruvian Andes. Its flavour is sweet, and the pulp is white. It has oval-shaped seeds of black colour. The tree is slow-growing, and it is mature when it reaches approximately 8 m in height. It presents an exuberant foliage and sometimes a branched habit [37,38]. Among its nutritional benefits, its high content of carbohydrates, phosphorus, calcium and vitamin B2 is notorius. [39]. It is grown especially in the departments of Boyacá, Antioquia, Nariño and Santander since it requires a not very humid climate [40]. The main destinations for the export of this fruit are Europe (mainly Spain and the Netherlands), the United States and South America (especially Panama) [41].

Concerning the latest export sales of the country (reported in December 2019), agricultural products, food and beverages represented 626.7 million USD and showed a growth of 11.5 %, compared to the same period in 2018. Figure I.2 represents the percentage contribution of sales of tropical fruits that were exported [42]. Compared to 2018 figures, exotic and tropical fruits increased by a 6 % in 2019; such offer of fruits included uchuva, granadilla, soursop, gulupa, passion fruit, pitahaya, tree tomato, cape gooseberry, custard apple, curuba and lulo, which are being exported to different countries of the world, mainly the Netherlands, United Kingdom, Belgium and Canada as shown in Figure I.3 [43].

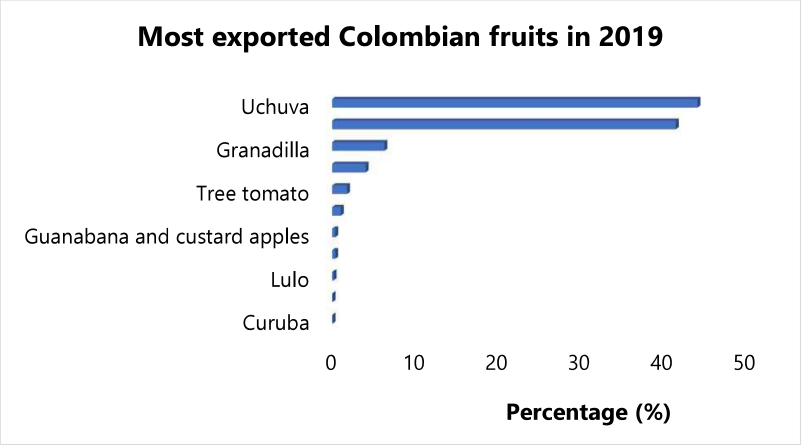


Figure I.2.- Exports of Colombian tropical fruits (including minor tropical fruits) during 2019 [42].

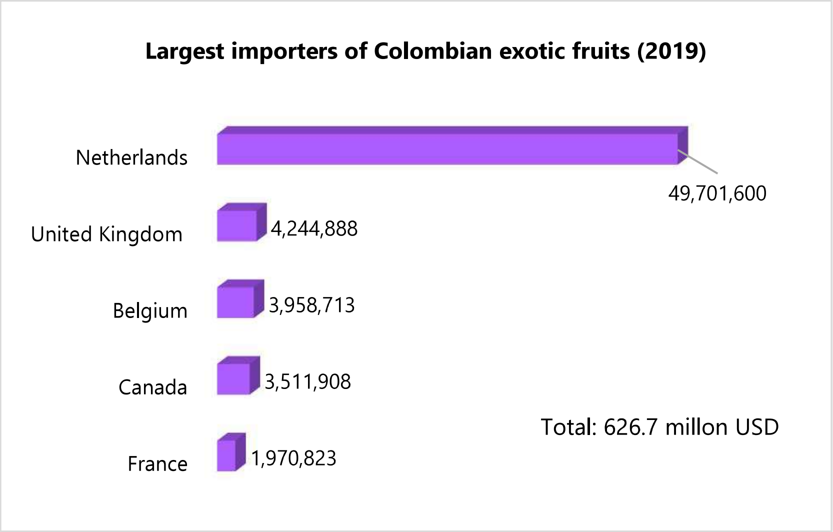


Figure I.3.- Main countries and export sales of Colombian tropical fruits (including minor tropical fruits) during 2019 [43].

The highest growth in tropical fruit exports in 2019, in terms of economic income, has been those of cape gooseberry, gulupa and granadilla with sales of 32.8, 30.8 and 4.6 million dollars, respectively. The first two represent an increase of 8 % compared to 2018, while granadilla registered a growth of 22 %. Hass avocado is another fruit that has grown its export volumes by approximately 50 %, and similarly, though not so highly apparent, sales of pineapple, pitahaya and papaya are also gaining ground in premium fruit markets of different countries of South America, and are also reaching eastern markets like Japan [43, 44].

The goal of Colombia as an agricultural country is to continue positioning itself as producer and exporter of exotic and tropical fruits worldwide, to expand the cultivation area, and to continue conquering different international markets.

I.3.- Pesticides

Agricultural production systems seek to increase production yields, but bringing some problems such as erosion, loss of soil fertility and certain pests. To mitigate this last issue, the use of pesticides has been the preferred option since they are simple and effective to use, but they cause an imbalance in the ecosystems, the loss of natural regulation, the resistance of some pests and the birth of others as well as the contamination of the environment [45].

The use of pesticides in the environment must take place under specific, controlled, and approved conditions following national and international standards and applying the so-called *good agricultural practices*. This concept applies to the use of pesticides to control pests and, in turn, seeks not to exert side effects on the environment from the residues that remain in it. However, when these good agricultural practices and established conditions are not followed, there are surely harmful effects on the environment and on those exposed species [46].

According to the "International Code of Conduct for the Distribution and Use of Pesticides" adopted by the FAO in 2003, a pesticide is defined as "*any substance intended to prevent, destroy, attract, repel or combat any pest, including unwanted species of plants or animals, during the production, storage, transport, distribution and processing of food, agricultural products or animal feed, or that can be administered to animals to combat ectoparasites. The term includes substances intended to be used as plant growth regulators, defoliants, desiccants, agents to reduce fruit density or germination inhibitors, and substances applied to crops before or after harvest to protect the product against deterioration during storage and transport. The term does not normally include fertilizers, nutrients of plant or animal origin, food additives or medications for animals"* [47, 48]. Therefore, the purpose of pesticides is to destroy certain living organisms [49].

The use of chemicals for pest eradication is probably as old as agriculture. In the times of the Romans and the Greeks, burned sulphur was used as a fumigant. In the 16th century, certain heavy metals were applied while at the beginning of the 19th century, Europe began to use compounds with mercury, copper, lead or ground tobacco (i.e. nicotine is a well-known pesticide), among others. These were called the first generation of pesticides (basically insecticides), very persistent in the environment but little effective [50, 51].

In the 20th century, with the extensions of crops and large-scale production, and with the growth in the demand due to the increase in the world population, new forms of pesticide production began to be explored. The development of pesticide synthesis arose mainly from the two World Wars, due to the need to look for new sources of chemical products. Agriculture appeared afterwards as the ideal market for them. Such synthetic pesticides are known as their second generation -which were mainly insecticides- [52], most effective for the eradication of pests, but highly contaminating. The first synthesized compound was 1,1,1-trichloro-2,2-bis (4-chlorophenyl)ethane (DDT). Its insecticidal properties, which were explained by Paul Müller in 1939, was used during the Second World War to protect the soldiers of the mosquito that transmits malaria. In 1945 its commercialization, including that of other organochlorine pesticides (OCPs), spread to the rest of the world when the United States allowed it, which was seen as an advance to continue searching for more selective substances with a pesticide activity [53]. At that time, many consumers and most policy makers were not aware of the potential health risk of using pesticides. During the 1960s, routine analysis of pesticide residues in different agri-food and environmental matrices emerged as a result of the risks to the environment and human health, but such methods had also to adapt to the continuous introduction of pesticides in the market.

Glyphosate, probably the pesticide best sold ever, was also introduced in the 1970s and the 1980s, which also witnessed the introduction of wide number of pesticides families, i.e. triazoles, imidazoles, pyrimidines, dicarboximide, etc. or new generation of others like the third of pyrethroids. Those new pesticides were more selective, less harmful than previous ones, but they were not free of problems related with resistance. In the 1990s other new families also appeared (i.e. triazolopyrimidine, spinosyn, strobilurin, azolone, etc.) and were even improved later on [53].

Nowadays, pesticides are probably the chemical compounds most studied from an environmental point of view. Many governments around the globe have set strict regulations for their commercialization and use, while they are constantly analysing food products in order to check if they are being correctly applied, in particular, to ensure food safety.

Current classification of pesticides is quite complex and can be developed according to their specific function, toxicity, specific action, chemical family, etc. As an example, the United States Environmental Protection Agency (EPA) classifies pesticides according to their specific function -which is nowadays a wide use classification- as algaecides (to eliminate algae and/or to slow down their proliferation), antimicrobials (to control germs and microbes), disinfectants (to control germs and microbes), nematicides (to control or eliminate pests on plants), fungicides (to eliminate fungal problems such as mould and rust), herbicides (to remove or inhibit the growth of unwanted plants), insecticides (to remove and control insects), growth regulators (to interrupt the growth and reproduction of insects), rodenticides (to remove rodents) and preservatives for wood (which are resistant to insects, fungi and other pests) [54].

On the other hand, the World Health Organization (WHO) classifies them according to their toxicity (see Table I.2), in particular, according to the average lethal dose (LD_{50} in mg/kg) and the average lethal concentration (LC_{50}) present in organisms and in relation to their body weight [55, 56].

From a commercial point of view, they are classified according to their final destination in pesticides for household, phytosanitary, livestock, environmental, food industry and personal hygiene use [57].

According to their presentation or method of use, they are classified in gases or liquefied gases, fumigants and aerosols, powders with a particle diameter less than 50 μm, solids and preparations in the form of tablets, liquids or baits [58].

Table I.2.- WHO recommended classification of pesticides by hazard [55].

Class		LD$_{50}$ for rats (mg/kg body weight)	
		Oral	Dermal
Ia	Extremely hazardous	<5	<50
Ib	Highly hazardous	5-50	50-200
II	Moderately hazardous	50-200	200-2,000
III	Slightly hazardous	Over 2,000	Over 2,000
U	Unlikely to present acuate hazard	5,000 or higher	

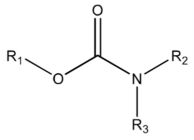
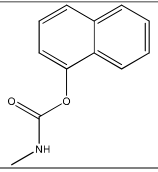
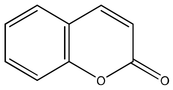
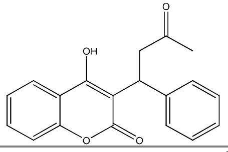
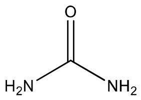
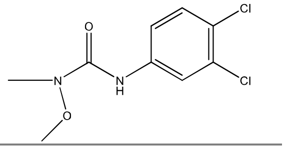
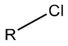
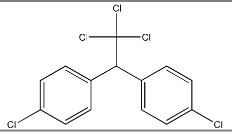
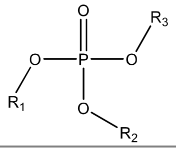
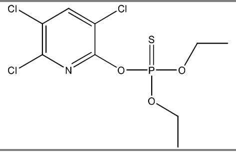
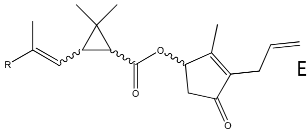
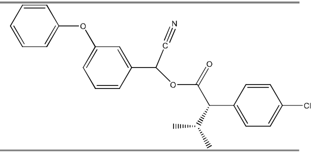
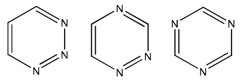
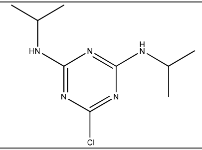
When a more specific categorization is required, pesticides are classified according to their chemical composition (see Table I.3 for some examples) into: inorganic compounds (arsenicals, mercury derivates), carbamates, coumarin derivatives, urea derivatives, dinitro compounds, OCPs, organophosphorus pesticides (OPPs), organonitrogen pesticides (ONPs), organometallics, pyrethroids, thiocarbamates, triazines, botanical compounds (rotenone, nicotine), among others also previously commented [59].

I.3.1.- Pesticides consumption and uses in Colombia

As previously commented, Colombia stands out for its agricultural activity, being one of the main pillars of its economy. The eastern region is the one with the most important agricultural activity followed by the Pacific, Central, Atlantic and Orinoco-Amazon regions [60]. Like in any country around the world, the use of pesticides is a common practice.

During the 1970s, the use of pesticides on corn, potato, rice and cotton crops were intense, and they accounted for more than 90 % of all the applied pesticides. In the particular case of cotton, it demanded a greater consumption of pesticides, principally, OCPs like aldrin, dieldrin, endrin, heptachlor, hexachlorobenzene, toxaphene and DDT [61-62]. In 1986, the government banned the import, production, formulation, sale, handling, use and spraying of DDT in the country. The remaining material (around 160,000 t) were stored or buried in different areas of the country, under the protection the Ministry of Social Protection, along with the prohibition of import, marketing, and use of other persistent pesticides, basically, OCPs [62,63].

Table I.3.- Some representative chemical families of pesticides.

Family	General structure	Example	Structure
Carbamates		Carbaryl	
Coumarin derivatives		Warfarin	
Urea derivatives		Linuron	
OCPs		DDT	
OPPs		Chlorpyriphos	
Pyrethroids		Esfenvalerate	
Triazines		Atrazine	

Introduction

According to the Colombian Agricultural Institute, in 2015, the country achieved a production of 50.9 million litres and 24.5 million kg of pesticides [64], being herbicides the most produced in the interior of the country, basically OPPs, carbamates and pyrethroids [65]. In contrast, the import of pesticides in that same year was 43.3 million litres and 34.7 million kg. The destination of these pesticides is mainly for their application on rice, potato, flower and banana crops, though the great boom in the production of tropical and minor tropical fruits experienced in the last years has also increased such amounts, but they vary according to the growing region in order to eliminate the specific pests of each area.

During a study carried out in 2013 in different regions of Cundinamarca, Boyacá and Huila in crops of passion fruit, gulupa and granadilla, residues of pyrimethanil, tebuconazole, carbofuran, chlorothalonil, and OPPs were found [66]. In another study carried out in 2016 to identify target OPPs in tropical fruits grown and marketed in the Colombian Caribbean Region, in the department of Bolivar, pesticide residues of malathion, anzinphosmethyl, phenchlorphos, chlorpyrifos, phorate, dementon, methylsulfon and disulfoton were the most frequent [67].

However, thanks to new agricultural practices, pest control, biological controllers and the use of bio-inputs, in the last 20 years the use of pesticides has decreased by 43 %, though their application is still high [68]. Obeying to good agricultural practices and avoiding the excessive application of pesticides, Colombia has been recently developing organic or ecological agriculture. In fact, in 2016, Ministerial Resolution 0187 was issued to administer the use of the Ministry of Agriculture and Rural Development Organic Food Seal. Colombia is one of the most active countries in Latin America in applying organic agriculture together with Argentina, Brazil and Mexico in which this type of agriculture is being applied, mainly exporting its products to Europe and the United States. The products most cultivated under this modality are cereals, cocoa, coffee, tropical and exotic fruits and vegetables, with an area of approximately 34,060 ha cultivated in the country [69].

Taking these arguments into account, it is worth asking what type and amount of residues generated by the high use of pesticides is finally reaching the consumer, especially when it comes to Colombian agri-food products destined for export, and what strategies could be developed to avoid it. This is, in fact, one of the most important challenges of agriculture nowadays: the production of "pesticide-free food", guaranteeing and supplying the food of the world with a low risk to the environment and human health.

I.3.2.- Maximum residue limits

In order to protect consumers, regulatory agencies and countries have adopted measures to standardize the amounts of pesticides that should reach the consumer by establishing maximum residue limits (MRLs), which are the highest levels of a pesticide residue that are legally tolerated in food or feed when pesticides are correctly applied in accordance with good agricultural practices [70].

Globally, both the FAO and the WHO have proposed through the Codex Alimentarius Commission a list of MRLs of a wide number of pesticides in order to promote their harmonization worldwide and, therefore, to facilitate international food trade. Such proposal has acquired special importance in the international context due to its recognition within the Agreement of Sanitary and Phytosanitary Measures of the World Trade Organization [71]. In the particular case of Colombia, the country has adopted such list of MRLs as a national standard and, therefore, they should be taken as a reference when pesticides are analysed in any commodity.

Codex MRLs are obtained based on estimates made by the Joint FAO/WHO Meeting on Pesticide Residues, after the toxicological evaluation of the pesticide and its residues as well as the examination of waste data obtained in supervised trials and uses that agree with good national agricultural practices. The tests include data from supervised trials conducted at the highest recommended, authorized, or registered use concentration in the country [70]. It should be highlighted, that MRLs are not toxicological limits and that they are established considering their tolerable daily intake. The punctual consumption of a product with concentrations exceeding MRLs may not produce harm (though extremely high concentrations may produce an acute effect in some people). On the contrary, a continuous exposure may result in chronic effects [72].

MRLs are not unique for each pesticide or commodity. They generally vary from 0.01 to 10 mg/kg depending on the food product [73]. They are constantly being studied and, if required, changed, especially when vulnerable population like children is considered. In many cases, MRLs are applied to the whole commodity but, in others, only to a part of it (i.e. for avocados the seed is not considered while for bananas the whole fruit must be taken).

The Codex Alimentarius has also set the so-called extraneous MRLs which refer to compound residues that were used as pesticides but are no longer registered as such, which derive from environmental contamination (including past agricultural uses of pesticides). These residues are treated as contaminants (i.e. DDT, aldrin, endosulfan, dieldrin, etc.) and cover a wide range of residue levels present in food to account for those persistent contaminants present in the environment [73, 74].

It is important to continue developing new versatile and adaptative methodologies for the multiresidue analysis of pollutants in different agri-food matrices with appropriate levels of sensitivity, as well as a high robustness, to quantify such analytes in accordance with their corresponding MRLs, and thus, to continue improving and implementing methodological applications and to work for the preservation of food safety and the environment.

I.4.- Analytical methods for the analysis of pesticide residues in agri-foods

The successful separation and identification of the target analytes is one of the most important steps of any analytical method. For this purpose, suitable instrumentation must be available to obtain adequate limits of detection (LODs) and quantification (LOQs) in accordance with the current legislation, without prejudice to other fundamental analytical parameters such as reliability and reproducibility of the analyses. Among all the separation techniques used for pesticide residue analysis, gas chromatography (GC) and liquid chromatography (LC) are the most widely used, whereas capillary electrophoresis (CE) has been applied to a much lesser extent. In fact, the first two of them are frequently found in any analytical laboratory dedicated to the routine analysis of pesticides.

I.4.1.- Gas chromatography

GC has been, by far, the most widely used separation technique for low polar and thermally stable pesticides due to the relatively high volatility of many pesticides, the relatively low cost of the instrumentation compared to LC or CE and easy maintenance of the equipment [75,76]. It should also be highlighted that the first analytical instrumentation developments were focused on gas chromatographs and, therefore, those analyses that could be easily developed by GC were soon consolidated and improved over time, which was also the case of the analysis of many pesticides.

Conventional detectors have been widely used for many years for the analysis of specific groups of pesticides, especially since the very beginning of the technique. This is the case of the nitrogen-phosphorus detector (NPD) and the flame-photometric detector (FPD) for the analysis of OPPs and ONPs [77,78], respectively, and the electron capture detector (ECD) for OCPs [79] due to their high level of sensitivity and their selectivity that minimizes matrix interferences. The flame ionization detector (FID) has also been widely used, but less frequently, due to its nearly negligible selectivity [80]. On the contrary, GC coupled to mass spectrometry (MS) soon gained prominence in the identification and quantification of pesticides as a result of its so desired confirmation capability, apart from its higher selectivity and higher or comparable sensitivity, which are fundamental, especially when it comes to the analysis of highly complex matrices [81]. Initially, GC-MS instrumentation used single quadrupoles (Qs) that only allowed solving co-elution problems or partial overlapping through the single ion monitoring

(SIM) mode. Later on, other analysers such as ion traps (ITs), triple quadrupoles (QqQs) and time-of-flight (TOF) were introduced, followed by Q-TOF and Q-orbitrap, among others, which situated MS detection at a higher level: the highly desired tandem MS (MS/MS) [82]. These more advanced analysers provide greater structural selectivity since they perform consecutive structural fragmentations of the analytes under the multiple reaction monitoring (MRM) mode. GC-MS/MS also provides a better signal-to-noise ratio (S/N) and, therefore, it improves the sensitivity of the method and reduces the matrix effect [83]. Some examples of the application of GC-MS and GC-MS/MS for the analysis of pesticide residues in agri-food samples are compiled in Table I.4.

I.4.1.1.- Matrix effect

GC analysis of pesticide residues in agri-food matrices has some limitations since it frequently presents many interferences and the instrumental response of the analyte changes (it increases or decreases) due to the presence of matrix components. This makes it difficult to identify such analytes in a considerable percentage of cases at the desired LOQs.

The matrix effect can be defined as the change in the signal (in particular, a change in the slope of the calibration curve) when the sample matrix, or part of it, is present. Very frequently, in GC, the matrix effect is measured in the following way [84]:

Matrix effect (%)= [(slope of the matrix-matched calibration curve – slope of the calibration curve in pure solvent)/ slope of the calibration curve in pure solvent] × 100

A matrix effect of a 0 % indicates that both signals (the one of the analytes in the sample matrix and the one of the analytes in pure solvent) are the same and no observable changes occurs in the sample matrix. In this sense, matrix effect values of ± 20 % are considered acceptable in many cases and no further corrections are necessary. On the contrary, values higher than 50 % clearly indicate an important enhancement of the signal while values lower than -50 % indicate an important signal suppression [84].

Table I.4.- Some examples of the application of GC-MS and GC-MS/MS for the determination of pesticides in agri-food samples.

Number of multiclass pesticides	Matrix	Sample preparation	Matrix effect compensation	Analyser	LOQ	References
15	Fruits juice	SPME	Deuterated ISs	Q	2 µg/kg	[85]
38	Grapes	SPME	Deuterated ISs	TOF	1 µg/kg	[86]
26	Baby foods	DLLME	Non-deuterated ISs and matrix-matched calibration	Q	1 µg/kg	[87]
16	Grain, oilseed, dried fruit, and nut	SPME	Non-deuterated ISs	Q	2 µg/kg	[88]
14	Pear, grapes, lettuce, and broccoli	SPME	Non-deuterated ISs	Q	< 1 µg/kg	[89]
205	Spices	QuEChERS	Matrix-matched calibration	Q-orbitrap	2 µg/kg	[90]
100	Tomato, squash, broccoli, apple, grapes, peach, green bean, and cucumber	QuEChERS	Deuterated ISs	QqQ-IT	1 µg/kg	[91]
56	Apple, orange, carrot, tomato, and olive oil	QuEChERS	Deuterated ISs, matrix-matched calibration and PTV injector	Q	1 µg/kg	[92]
120	Tomato, red pepper, sour cherries, dried apple, black currant powder, raisins, wheat flour, rolled out, and wheat germ	QuEChERS	Non-deuterated ISs, analyte protectants and PTV injector	QqQ	1 µg/kg	[93]
182	Rice, mushroom, soybean, spinach, tomato, broccoli, grapefruit, carrot, lettuce, and cucumber	QuEChERS	Matrix-matched calibration	Q-TOF	2 µg/kg	[94]
439	Fruits and vegetables	SPE	Matrix-matched calibration	Q-TOF	1 µg/kg	[95]

SPME: Solid-phase microextraction; DLLME: Dispersive liquid-liquid microextraction; IS: Internal standard; IT: Ion trap; PTV: Programmable temperature vaporizer; Q: Single quadrupole; QqQ: Triple quadrupole; QuEChERS: Quick, easy, cheap, effective, rugged and safe; TOF: Time-of-flight.

In GC, the matrix effect is frequently caused by the masking of the active sites of the liner and column by components of the matrix. The non-masked active sites may produce peak tailing or decomposition of the target analytes. The presence of matrix components blocks such interactions (the blocking is more pronounced when the contamination of the GC system with matrix components is higher) and, as a result, a signal enhancement is frequently achieved [96]. Moreover, if such matrix effect is not properly corrected, results may be overestimated. At this point, it should also be highlighted that it is possible to use highly inert components in a GC if proper maintenance is carried out, but it is extremely difficult to keep a GC system inert at all.

Ideally, sample treatment procedures should be highly selective and avoid the coextraction of matrix components that generate important changes in the signal. In many cases, efforts are made to obtain highly clean extracts, but this may result in a decrease of the recovery values as well as in the increase of the cost and labour of the method. However, despite the efforts, matrix effect still takes place and, therefore, it should be always studied and corrected as much as possible [97]. Moreover, the effect of the repeated injections of the samples in any chromatographic or electrophoretic system should also be studied in order to clearly determine if the analytical performance is being compromised as a result of the repeated injections of other components of the samples, even at low concentrations.

In general, matrix effect cannot be eliminated. Even though, several approaches can be developed to compensate/correct it (some of them are applicable to any chromatographic or electrophoretic technique):

1.- Use of internal standards (ISs). ISs are compounds very similar to the target analytes, for which a similar extraction and chromatographic/electrophoretic behaviour is expected. They are added in a constant amount to the samples, blanks and calibration standards and, therefore, the ratio of signals (i.e. peak areas or peak heights of the analytes and ISs) is plotted *vs* the concentration of the analytes in order to obtain the calibration curves. In this way, the use of ISs not only allows to compensate the matrix effect, but also the possible losses of the analytes that take place during the whole analytical method, as well as the correction of the possible variability of the signal of the detector or the unrepeatability of the injection (less frequent nowadays since autosamplers are mostly used). One of the main drawbacks of the use of ISs relies in the difficulty of finding an IS that fits all kinds of target analytes in a multiresidue analysis. Accordingly, the more variability in the pesticide properties, the more types of ISs should be added. When MS detection is used, the problem can be quickly solved by the use of isotopically labelled standards, which are more and more frequently available, though for not every single compound. However, in many cases, their extremely high cost clearly precludes the use of them since the cost of the analysis increases highly. Besides, the introduction of ISs also increases the number of transitions of the MS, which could also end in a certain reduction of the sensitivity if too many compounds coelute, while it is true that it is less frequent with newest MS detectors. Consequently, the use of a limited, but practical, number of isotopically labelled ISs is usually the preferred choice [98].

2.- Use of analyte protectants. Analyte protectants are highly polar compounds that interact with the active sites of the gas chromatograph, decreasing the degradation and/or adsorption of co-injected analytes [99]. These compounds should not interfere with the separation and are added to the extracts and matrix-matched standards at the pre-injection stage. Many compounds have been evaluated in order to find those analyte protectants with the highest effectivity [96, 100-101]. Among them, the ones that have provided the best results have been those that contain a high number of hydroxyl groups such as shikimic acid, 3-ethoxy-1,2-propanediol, L-gulonic acid 3-lactone, and D-sorbitol [102, 103]. These compounds have a strong hydrogen bonding capability, since hydrogen bonding has been shown to be an important factor in analyte interactions with active sites [101]. In fact, pesticides with hydroxy and amino groups, such as carbamates, imidazoles and benzimidazoles, urea derivatives and several organophosphate compounds are the most susceptible type of analytes to this effect [101-106]. The use of analytes protectants provides important benefits like the improvement of the LODs as a result of the signal enhancement, easier integration of the peaks, better quantitation, less maintenance of the GC inlet and low cost [101].

3.- Matrix-matched calibration. This type of calibration involves preparing the calibration standards using the matrix extracts obtained when treating a sample free of the target analytes. The matrix itself acts as an analyte protectant and therefore it is considered as the most effective and practical strategy to reduce matrix effect. Some of the disadvantages of this method include the impossibility on many occasions of having a matrix free of the analytes of interest and the same sample as the one that is being analysed. Very frequently, to avoid such problems, some matrices are considered as representative of different commodities. For example, in the analysis of pesticides in agri-food products, limes are used as representative matrices of citrus fruits [107] and avocado for high lipid content fruits [108].

Another problem related with matrix-matched calibration is the extra labour and the cost of the preparation of the blank extracts to be used for the calibration. Besides, the method cannot effectively compensate the matrix effect when the analytical sequence consists of more than one type of food matrix. Furthermore, there is also a certain variability within the same type of food [84]. Apart from the previously mentioned issues, the accumulation of non-volatile components in the injection system as a result of the constant injection of the samples, leads to a decrease in the analytical response due to the formation of new active sites, which forces the injection liners to be changed more frequently [96].

4.- Modification of the GC injection technique. Several GC injection techniques (i.e. on-column injection, pulsed splitless, and programmable temperature vaporizer (PTV) injection) have been applied to compensate the matrix effect, in particular, to shorten the contact time of the analytes with the active sites [109-111]. Since they cannot act directly on the active sites, their effect is limited. Among them, PTV is one of the most used. In this case, the sample is injected at a temperature below or close to the boiling point of the solvent. Then, temperature is increased to evaporate the solvent and to achieve a gradual transfer of the analytes to the chromatographic column. This allows the separation of the analytes from the non-volatile components extracted from the matrix, so that they are prevented from being introduced into the column and thus avoiding the negative effects that affect the analysis and the system, in addition to obtaining better recovery values for thermally unstable analytes [96].

5.- Use of the standard addition method (SAM). In the SAM, different aliquots of sample are spiked with various amounts of the pure analyte in order to enhance the response of the analyte according to the magnitude of the response [112]. Though the SAM is easy to perform, the truth is that it requires extra efforts, in particular, a specific calibration for each sample, but it still leads to inaccuracies because the matrix effect is concentration dependent [112].

6.- Use of a modifier of the carrier gas. Very recently, it has been observed that the introduction of ethylene glycol, which acts as an analyte protectant, into the carrier gas of a GC-MS system is also able to reduce the magnitude of the matrix effect [113-114]. It can be used with matrix-matched calibration, which is highly recommended, and in combination with other analyte protectants that have a low molecular weight to avoid to interfere with the detection of the target analytes, low vapor pressure to reduce GC-MS system contamination, and a high polarity to minimize its interactions with silanol groups [113].

I.4.1.2.- Fast gas chromatography

In the last decades, chromatography has also evolved into the development of fast multiresidue analysis, achieving a better resolution and at the lowest possible cost. Advances in injection systems, internal pressure regulators, in the scanning and sensitivity of the detectors, rapid heating/cooling systems and ionization techniques have also allowed the obtaining of faster chromatographic separations. Reducing analysis time improves efficiency, laboratory capacity and especially, the implementation of standardized workflows allow the exploitation of the full potential of GC [115].

Moreover, such approaches combined with rapid sample treatment are those that are sought to achieve more and better analyses, especially in multiple residue analysis in different agri-food matrices.

Conventional GC is characterized by a duration of over 20 min, while fast GC is frequently designated as those GC separations in the 3-20 min range, those very fast in the 1-3 min range while hyper-fast separations are considered when less than 60 s are needed and ultra-fast those developed in less than 1 s [116]. The most common routes to shorten GC analyses times involve the use of micro-bore columns (≤ 0.18 mm i.d.), narrow-bore columns (≥ 0.20 and < 0.32 mm i.d.), low-pressure outlet conditions, and resistive heating.

The use of micro-bore columns is a very common and direct approach since it allows the full replication of a conventional GC method in less time. Such reduction of the i.d. reduces band broadening and increases column efficiency. It requires the use of faster temperature gradients (from 10 to 30 ºC/min) and shorter hold-up times (20-60 s), beings its main drawback its reduced sample capacity [116].

The low-pressure approach (LP-GC), also named as vacuum-outlet GC, involves the use of a short micro-drilling (0.5-1 m × 0.10 mm i.d.) column next to the injector at atmospheric conditions that connects to a short mega-bore analytical column (0.32-0.53 mm i.d.) of 5-10 m length which operates under low pressure conditions compatible with MS analysers and at higher flow rates. This technique results in improved S/N ratios and, therefore, in better LODs, as a result of the obtaining of narrower peaks caused by the increased linear velocity [117, 118]. Another advantage of LP-GC is the fact that lower elution temperatures can be achieved and, therefore, it is possible to elute thermally labile and high boiling point compounds at moderately low temperature [119]. Sample capacity is also increased. However, its separation power is highly reduced compared to conventional capillary GC.

Concerning resistive column heating, it consists on the use of an electricallyconductive solid material as heating source, in direct or close contact with the column, avoiding the use of a conventional column oven, which is also an advantage for the portability of the GC, if needed [116]. With its used, it is possible to increase and decrease the temperature along the column. High temperature programs can be used with short columns providing an important reduction of the analysis time.

The use of narrow bore columns, as the final and most used fast GC approach, also requires the use of accelerated temperature programs. However, such fact also needs a fast cooling, otherwise, the analysis time would also increase.

Finally, it should be considered that the previously mentioned fast-GC methods are also compatible with MS detection since many of the current MS systems are capable of satisfying the requirements of fast GC analyses (i.e. number of acquisition points per peak). Low-resolution mass analysers like Q have been, by far, the ones mostly used, though there is a clear trend in the use of high-resolution systems as long as they improve in their fast detection capabilities [116].

I.4.1.3.- Multidimensional gas chromatography

Another important chromatographic development is the so-called multidimensional (MD) chromatography, where a new perspective is opened in the detailed analysis of complex matrices. One of its great advantages is the multiplication of chromatographic resolution (which increases the number of analytes that could be analysed), the selectivity, sensitivity, and the information obtained on the identification of the target analytes [120].

In MD-GC, the columns can be in the same oven or in two different ones, which is a more flexible approach. Part or all of the components of the samples (depending on what is desired) are subjected to the two separations that the system has and analytes from the first column should be transferred in an orderly manner to the second column [121].

When all the eluting compounds from the first column are continuously transferred to the second, the technique is called comprehensive GC (GCxGC) and a "modulator" (usually cryogenic) is used as interface to ensure such transference, which results in a practically orthogonal system. However, compounds can also be selectively introduced in the second dimension, which is called "heart-cut MDGC (H/C MD-GC)" [122, 123]. The use of a cryogenic device in both cases reconcentrates the analytes, increases the peak capacity and concentrates trace compounds (as a result of the cryogenic trapping/focusing effect), though the transfer can also take place if the second column is kept at a lower temperature. In GCxGC, the second column is normally a short 1-2 m micro-bore column and, therefore, the peak capacity is mainly that of the first column.

If the possibility of coupling in parallel more than one detector, including those that are selective, is also considered, MD-GC becomes a powerful tool for the selective identification and detection of trace-level compounds in very complex matrices. This allows obtaining a more detailed fingerprint of such mixtures. However, one of the disadvantages of this technique is the time required for optimization and separation, as well as the complex coupling of instrumentation, which is probably why it has been used in fewer applications for the determination of pesticide residues in agri-food samples compared to conventional GC [123-131]. Among such works, it could be highlighted that of Khan *et al.* [131] who extracted 47 pesticides from tobacco using a modification of the QuEChERS method and used H/C MD-GC with an apolar column in the first dimension (VF-5MS) and a mid-polar one in the second (Rxi-624 SilMS). Recovery values were in the 70-119 % range with LOQs between 7.5 and 15 µg/kg.

I.4.2.- Liquid chromatography

The use of liquid chromatography (LC) is recommended for the analysis of high molecular weight, highly polar, and/or thermally labile compounds [132, 133]. In fact, it is a complementary separation technique to GC, also for the analysis of pesticides. This fact has allowed LC to become a widely used technique and even more with its coupling to MS. In fact, LC-MS instrumental developments have allowed it to position itself as one of the most robust and used analytical techniques in any laboratory [134]. Table I.5 shows some representative examples of the application of LC-MS/MS for the determination of pesticides in agri-food products.

The analytical methods developed for the determination of pesticide residues have mainly used reversed-phase (RP) columns and pre-columns (C_8 or C_{18}) with mobile phases mainly composed of water and methanol (MeOH) or acetonitrile (ACN), using ultraviolet (UV) or diode-array detection (DAD) as well as the MS detection systems previously mentioned. However, as in GC, HPLC coupling with MS/MS has positioned itself, despite its high cost, as the most suitable technique for the analysis of pesticides in a variety of complex matrices [134, 143].

LC, like any other technique, has also evolved towards its miniaturization in order to reduce solvent consumption and analysis time, which mainly involve the miniaturization of the columns [144, 145]. Such reduction of column i.d. has yield to the so-called capillary and nano LC (CLC and nano-LC), which have obviously led to the modification of the instrumentation [146, 147]. Though the nomenclature is not yet fully unified, it is frequently called nano-LC when capillaries with i.d. < 100 µm and flow rates of 50-800 nL/min are used and CLC when the i.d. is in the range 100–500 µm and the flow rates are 1-100 µL/min [147]. The columns can be packed, monolithic or open tubular, with a wide variety of stationary phases [148]. Such column i.d. reduction clearly decreases the analysis time and the consumption of the mobile phase, improves heat dissipation, and provides an appropriate coupling with MS. In addition, the fact that sample dilution is also decreased may also improve sensitivity [149]. However, though this fact has been demonstrated theoretically and experimentally, considering that injected volumes are in the ranges 10-60 nL and 1-50 µL (for nano-LC and CLC, respectively), the sensitivity with these techniques can be questionable for practical purposes, especially when UV-Vis detection is used, as a result of the reduction of the optical path length [146]. Both CLC and nano-LC have been mainly applied to the analysis of proteins, though a good number of applications related with the analysis of pesticides can also be found in the literature [146,148].

Table I.5.- Some representative examples of the application of LC-MS/MS approaches for the determination of pesticides in agri-food products.

Number of multiclass pesticides	Matrix	Sample preparation	Matrix effect compensation	Analyzer	LOQ	References
38	Rice, orange, apple, and spinach	QuEChERS	Deuterated ISs, analyte protectants, and matrix-matched calibration	QqQ	<1 µg/kg	[84]
42	Orange, red wine, red grapes, raisins, and wheat flour	QuEChERS	Analyte protectants and matrix-matched calibration	Q-orbitrap	5 µg/kg	[99]
25	Lupin, white mustard, soya bean, sunflower, and field bean	QuEChERS	Deuterated ISs and matrix-matched calibration	QqQ	1 µg/kg	[135]
39	Ginseng	DLLME	Matrix-matched calibration	QqQ	2 µg/kg	[136]
250	Processed fruits	QuEChERS	Non-deuterated ISs and matrix-matched calibration	QqQ	0.6-6.0 µg/kg	[137]
7	Soy	DLLME	Matrix-matched calibration	IT	<1 µg/kg	[138]
506	Honeysuckle	QuEChERS	Deuterated ISs and matrix-matched calibration	Q-orbitrap	1 µg/kg	[140]
9	Banana, cabbage, tomato, orange, and onion	DLLME	Deuterated ISs and matrix-matched calibration	QqQ	<1 µg/kg	[141]
93	Apple, lettuce, and wheat flour	QuEChERS	Matrix-matched calibration	Q-TOF	1 µg/kg	[142]

DLLME: Dispersive liquid-liquid microextraction; IS: Internal standard; IT: Ion trap; Q: Single quadrupole; QqQ: Triple quadrupole; QuEChERS: Quick, easy, cheap, effective, rugged and safe; TOF: Time-of-flight.

The reduction of the stationary phase particle diameter is also an important improvement of LC in the last years, which has also yielded the introduction of ultra-high-performance LC (UHPLC) [150]. As the particle size decreases to less than 2.5 µm, there is a significant gain in efficiency even when flow rates, or linear velocities increase. As a result, resolution and separation speed are also improved, but the backpressure is high. Furthermore, smaller particles can work at higher linear velocities, although it is necessary to use a special equipment able to resist and apply such high pressures through the column even with 5 µm particles [151, 152]. Nowadays, sub 2 µm particles are also commercialized and provide high separation power for groups with a high number of pesticides [134, 154].

Another strategy that has been introduced to improve LC performance is the introduction of core-shell particles, which have a solid core of 1.2 to 4.5 µm size surrounded by a 0.2 or 0.5 µm porous layer (shell) [155]. These particles also allow to overcome the limitations of the use of high amounts of organic solvents and long analysis time in HPLC as well as the high backpressure and frictional heating of UHPLC [156]. Both the core and the shell could be made from the same or different material. The size of the core particle, the shell thickness and the porosity in the shell are key factors determining different types of chromatographic applications. They all reduce band broadening and improve the peak efficiency, resolution and sensitivity. In fact, more and more analytical methods, also those devoted to the analysis of pesticides, are developed using this type of columns, especially those with the most reduced sizes.

I.4.2.1.- Matrix effects

In LC, the matrix effect, which mechanism is not yet fully understood, is caused by co-eluting compounds (either from the sample matrix or part of the reagents used during sample treatment) that alter the ionization process. In this case, the properties of the analytes, the nature of the matrix, the extraction process, chromatographic and MS detection conditions, the type and conditions of the ionization (since the ionization mechanism is different) as well as the matrix to analyte concentration ratio play a key role [157]. As a result, there is not a unique cause, though, it is clear that it is basically produced during the ionization process [157].

In LC, matrix effect can be evaluated following the method proposed by Matuszewski *et al.*, which is widely used nowadays, using the following equation [158]:

$$\text{Matrix effect (\%)} = (B/A)\times 100$$

where A is the peak area of the standard solution (standard in pure solvent) and B is the peak area of the matrix solution (matrix-matched standard). When the matrix effect is below 100 %, ion suppression takes place, while above 100 % a signal enhancement is observed. However, between 80 and 120 % it is considered that no matrix effect takes places or that it is negligible.

Different actions can be taken to try to overcome ion suppression or enhancement in LC-MS. One of them is to change the ionization mode. For example, from electrospray ionization (ESI) to atmospheric pressure chemical ionization (APCI) when ion suppression takes place since, with some exceptions, ion suppression is lower in APCI [159]. In recent studies, atmospheric pressure photo ionization (APPI) has also been distinguished for the efficient ionization of non-polar compounds, a lower sensitivity to matrix effects and a broad dynamic linear range of response [160, 161]. The ionization polarity can also be taken into consideration when an analyte can be ionized in either positive or negative mode, since the last of them is less subjected to ion suppression [159].

Another strategy, which can also be applicable to any technique, is to pay special attention to sample treatment in order to minimize the amount of coextracted compounds. In such case, recovery values should be studied together with the capability of the method to eliminate coextractives [162, 163]. In some cases, dilution of the sample or the final extract may also work, though this can be particularly inappropriate for trace analysis.

Apart from the previously commented issues, the composition of the mobile phase should also be considered with care, since mobile phase additives used to improve separation may also influence ionization, even the same additive and different concentrations [164].

As it also happened in GC, when matrix effect cannot be overcome, several strategies should be developed which include the use of isotopically labelled ISs, matrix-matched calibration or SAM, which have been previously commented.

An interesting approach that has also been developed, though not widely applied (probably as a result of its complexity when a good number of analytes are considered), is the "echo-peak technique", in which two consecutive injections are carried out (with a certain time between them): the injection of sample and that of a standard solution [165, 166]. In this way, since the retention times of the analytes are close enough to be affected by the matrix effect, it is compensated.

I.4.2.2.- Multidimensional liquid chromatography

MD-LC is also an important alternative to conventional LC separations when extremely complex samples, as well as a high number of compounds, need to be analysed. It can be mainly developed in two modes, either following an online or an offline approach: comprehensive LC (LCxLC) or H/C MD-LC [167-169]. Apart from them, the "stop flow mode", which stops the separation in the first column while the second column separation is running, has also been introduced [170]. In all cases, two independent separation processes take place, which means that the combination of some LC modes presents some difficulties: mobile phase immiscibility or incompatibility (i.e. normal phase, NP, and RP as well as hydrophilic interaction liquid chromatography, HILIC, and RP).

In both offline approaches, the fractions of interest that elute from the first dimension are manually collected, evaporated, reconstituted in an appropriate solvent, and injected in the second dimension. Though easier, they can be time consuming, difficult to automate and/or reproduce; sample loss can take place as well as contamination [171]. On the contrary, both online approaches offer an improved sample throughput and minimize sample loss or contamination [169].

As it also happens in GCxGC, LCxLC analysis require the adjustment of many parameters in order to accomplish a successful separation: stationary phases type, mobile phases compatibility, solvent and temperature gradients, matching of column dimensions and flow rates and volume of the transferred fraction [171].

Concerning the applications of MD-LC in the food analysis field, it has been mainly applied to food composition analysis (i.e. polyphenols, carotenoids, peptides, proteins., etc.). In the particular case of pesticide analysis in foods, few applications have been developed up to now using MD-LC, which is lesser than those already published using MD-GC [172-175], many of them dealing with the simultaneous analysis of other compounds. Among them, it is worth mentioning the work of Kittlaus *et al.* [175] in which 300 pesticides were analysed in cucumber, lemon, wheat flour, rocket, and black tea (extraction was carried out using ACN). Pesticides were separated using an HILIC column in the first dimension and a RP in the second. Due to the high elution strength of the first column, it was not possible to transfer the eluate directly to the second column and a trapping column was used to trap groups of compounds. MS/MS was used with recovery values in the 70-120 % for most analytes and LOQs of at least 0.01 mg/kg.

I.4.3.- Other separation techniques

Pesticides have also been analysed, though in a much less extent, by CE, basically capillary zone electrophoresis (CZE) when they are charged, and micellar electrokinetic chromatography (MEKC) when they are in their neutral form [176-177]. In both cases, the selectivity and resolution of their separation are directly controlled by different buffer additives (i.e. solvents, complexing agents, polymers, etc.). Among other separation modes, capillary electrochromatography (CEC) applications with packed or open tubular columns also outstands for the separations of either charged or uncharged pesticides [178, 179].

Apart from the use of conventional detectors (UV or DAD), which have been highly applied, the coupling with MS has also been developed though not as straight forward as with GC or LC, since there is not an outlet vial, nor an electrode to close the electrical circuit. Several interfaces have also been applied with success being ESI assisted with a sheath liquid the most common approach [180-182]. When MEKC is to be used, non-volatile background electrolytes should be used or the application of the partial filling technique [183, 184]. In general, the number of applications is much lower than those of GC and LC since CE-MS or CE-MS/MS have found much more important applications in the omics fields (i.e. proteomics, peptidomics, metabolomics, etc.) [185].

Another technique worth to mention for pesticide analysis is supercritical fluid chromatography (SFC) -considered as a hybrid of GC and LC- also coupled to MS [186-188], which is currently awakening in different fields as a result of the production of more robust and reliable instrumentation that have improved its reproducibility, robustness, specificity and sensitivity [189-191]. The use of supercritical fluids as mobile phases (i.e. supercritical carbon dioxide, the most common) allows fast separations of pesticides of a wide polarity due to the use of high flow rates with less or no consumption of organic solvents, which can be used as co-solvents. The use of a co-solvents modifies the density and polarity of the mobile phase and therefore, its separation power. They also block active sites on the stationary phase and inhibit adsorption, among other issues.

As also happened with CE, the hyphenation of SFC with MS is not straightforward since supercritical fluids possess much higher compressibility than liquids, which needs to be controlled at high pressure, particularly when the fluid is not anymore under the backpressure control [189]. Indeed, when the pressure is released, analytes can precipitate before entering the MS. Even though, few applications have also appeared concerning the analysis of food samples, a good number of them focused on quantification of enantiomers of a reduced number of pesticides [192-197], though others have also focused on multiresidue analysis [188, 198-201]. As examples, Table I.6 compiles some relevant works regarding the use of CE and SFC in the quantification of pesticides in different agri-food matrices using different detection systems.

Table I.6.- Some representative examples of the application of CE and SFC approaches for the determination of pesticides in agri-food products.

Number of pesticides	Matrix	Sample preparation	Calibration type	Detector	LOQ	References
CE						
7	Peach, melon, watermelon, and apricot	SPE	ISs	MS	5 μg/kg	[181]
9	Medicinal plants	DLLME	Matrix-matched calibration	DAD	2 μg/kg	[202]
3	Milk	SPE	Matrix-matched calibration and ISs	DAD	7 μg/kg	[203]
6	Peaches and nectarines	SPE	ISs	MS	1 μg/kg	[204]
SFC						
162	Dried spices	QuEChERS	Deuterated ISs and matrix-matched calibration	MS/MS	5 μg/kg	[188]
2 (enantiomers)	Tomato, cucumber, apple, grape, and soil	QuEChERS	Matrix-matched calibration	MS/MS	4 μg/kg	[192]
373	Spinach	QuEChERS	Matrix-matched calibration	MS	3 μg/kg	[199]
3	Green vegetable and rice	MSPD	Matrix-matched calibration	DAD	0.2 μg/kg	[205]
6	Tomato, cucumber, apple, peach, rice, and wheat	dSPE	Matrix-matched calibration	MS/MS	1 μg/kg	[206]

DAD: Diode-array detector; DLLME: Dispersive liquid-liquid microextraction; IS: Internal standard; MSPD: Matrix solid-phase dispersion; MS: Mass spectrometry; QuEChERS: Quick, easy, cheap, effective, rugged and safe; SPE: Solid-phase extraction.

I.4.4.- Sample preparation approaches: The QuEChERS method

BOOK CHAPTER

Quick, easy, cheap, effective, rugged, and safe (QuEChERS) extraction

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In 2003, Anastassiades and Lehotay, along with their co-workers, published a fast method in which a good number of multiclass pesticides were extracted from fruits and vegetables employing acetonitrile (ACN) extraction/partitioning and dispersive solid-phase extraction (dSPE) [208]. That method was named as QuEChERS, an acronym created from the words *Quick, Easy, Cheap, Effective, Rugged* and *Safe*, inherent characteristics of the applied procedure that has been the cause of its outstanding success. Furthermore, and which is also of high importance, the work also introduced the concept of "dSPE" (for clean-up purposes), not previously named in that way.

After its publication, it immediately caught the attention of the scientific community and a good number of applications in the pesticide analysis field came out, especially for the analysis of other fruits and vegetables, since it demonstrated in a good number of occasions a higher recovery and reproducibility than existing methods. At the same time, and as a result of the specificity of each analyte and sample matrix, some modifications appeared: the use of buffers to avoid pH degradation of certain pesticides [209, 210], the introduction of new dSPE sorbents and salts, or even its application to analytes different than pesticides and to other matrices, among others. The method acquired such a dimension that one of its versions is indeed an AOAC Official Method [210] and another one a Standard Method of the European Committee for Standardization [209], both widely used nowadays specially in official laboratories. However, and despite the importance of both of them, there are more QuEChERS versions than desirable, up to the point, that many vendors sell different QuEChERS kits adapted to the user's needs and requests. Such kits have also greatly contributed to its expansion and wider application since the salts and sorbents do not need to be weighted in the laboratory with the consequent effort and loss of time.

The QuEChERS method is frequently included as part of "Green Analytical Chemistry" procedures [211, 212]. Indeed, it requires relatively short amounts of low toxicity and non-halogenated solvents and reagents as well as laboratory ware and no external energy supply (though in some cases the application of ultrasounds for a short period of time might be helpful). Besides, low amounts of money and time are needed, and a reasonable number of samples can be simultaneously extracted.

During the last years, the QuEChERS method is also trying to face an important objective: its miniaturization as well as its possible automation, which are not easy tasks, especially the last of them. Several interesting attempts, though still few, have been made in both directions providing a new horizon for the method.

I.4.4.1.- The original method

The original QuEChERS method was introduced in a context with an evolving need to develop more selective and sensitive analytical methods for the determination of pesticides residues, originated from the increasingly restrictive legislation related with environmental and agri-food safety. In particular, pesticides were the first to be highly regulated due to the widespread use of these compounds and to the hazardous effects of many of them.

Concerning pesticide analysis, throughout the last decades, many methods have been used to extract them from food commodities. The first methods, which today could be considered as traditional or classical methods, consisted of the mere use of single organic solvents, a mixture of them or an aqueous/organic solvent mixture with the addition of NaCl for the consequent separation of phases. In this sense, the first great known method which was widely applied since its introduction was the Mills method [213], which consists of the use of ACN and a later partitioning with nonpolar solvents such as hexane or petroleum ether. Such method was especially effective for the extraction of nonpolar pesticides. In 1999, in order to extract the increasingly polar pesticides that were being introduced into the market, Luke *et al.* [214] proposed the use of acetone rather than ACN in the initial extraction step as well as a subsequent partitioning employing petroleum ether and dichloromethane to remove the residual water in the organic phase and co-extracted polar material. The addition of small amounts of anhydrous Na_2SO_4 also helped to remove the water from the organic phase. However, the use of chlorinated solvents quickly fell into disuse due to their adverse effects on the environment and human health. In contrast, the application of other solvents such as ethyl acetate (EtOAc) or cyclohexane in the partitioning step [215] or the addition of different salts, namely NaCl or anhydrous $MgSO_4$, and fructose [216] won many adherents. Nevertheless, the organic phase could still contain water residues, which are so harmful for the subsequent chromatographic step (in particular, when GC was used) and even for possible specific clean-up steps based on conventional solid-phase extraction (SPE) procedures [217]. In 2002, only one year before the publication of the first QuEChERS article, Schenck and co-workers together with the father of the QuEChERS method, Dr. Steven J. Lehotay [218], demonstrated that anhydrous $MgSO_4$ exerts a stronger drying power compared to anhydrous Na_2SO_4 in organic extracts and that ACN was more easily and effectively separated from water than acetone.

Based on those previous findings, Anastasiades, Lehotay, Štajnbaher and Schenck [208] developed in 2003 the QuEChERS method for the multiresidue analysis of pesticides in fruits and vegetables as a user-friendly alternative to those traditional methods characterized by multiple stages and large sample and solvent amounts. This approach involves the development of a sample extraction with an organic solvent after suitable homogenization, the novel use of anhydrous $MgSO_4$ together with NaCl for salting-out induced partitioning of water and a minimal and very fast clean-up step called dSPE. Particularly, a relatively small amount of ACN (normally between 10 and 15 mL) is used to extract an aqueous-based sample in relation 1 g/mL, so that the analytes of interest are largely transferred into the organic phase while the undesirable co-extracted material remains in the aqueous phase that is discarded. In this sense, ACN was the selected organic solvent above acetone and ethyl acetate since it efficiently isolates a broad range of pesticides (nonpolar and relatively polar analytes) while minimizing the amount of lipophilic material. Besides, since ACN is soluble in water, it allows a good penetration into the aqueous phase of the samples. This step also includes the use of 4 g of anhydrous $MgSO_4$ to induce phase separation by saturation and heat generation around 40 °C (as a result of the exothermic hydration reaction) which aids in the extraction of nonpolar pesticides (avoiding the use of nonpolar solvents) as well as 1 g of NaCl to reduce the amount of polar interferences co-extracted. In this regard, the combined use of these salts showed better results in terms of recovery, phase separation, the amount of matrix components co-extracted and peak shapes than their individual use or using other salts such as LiCl, $MgCl_2$, $NaNO_3$ and Na_2SO_4 or even fructose. Then, the sample is stirred, centrifuged and an aliquot of the organic extract is subjected to the dSPE procedure. The great virtue of the dSPE approach is that, in contrast to traditional SPE, the extraction of the analytes or of the matrix components (it depends on its use) is carried out in the bulk solution. Hence, dSPE does not require the use of vacuum manifolds, columns and preconditioning steps as well as the collection or waste of solvent fractions, evaporation of the solvents, etc. In summary, it does not require a tedious and long procedure as well as the practice and exhaustive attention of the analyst. As dSPE sorbents, only 25 mg of primary-secondary amine (PSA) was selected (against a methacrylate-divinylbenzene copolymeric sorbent, graphitized carbon black (GCB), alumina-neutral, a strong-anion exchanger, cyanopropyl, aminopropyl and octadecylsilane (C_{18})) together with 150 mg of anhydrous $MgSO_4$ to remove polar matrix interferences (including sugars, fatty and other organic acids, and pigments) and traces of water, respectively, of a 1 mL aliquot of sample. Finally, an aliquot of the resulting extract is transferred to a vial and injected into the GC or LC system preferably using MS detectors as low purity extracts are obtained. With all the above, the original QuEChERS method allowed the analysis of a batch of 6-12 samples in 30-45 min with a cost of 1 USD per sample, obtaining high recovery values (85-101 % for 95 % of the pesticides studied) and repeatability (RSDs < 5 %) from a wide range of polarities, high sample throughput and requiring less work than the traditional methods, which minimize the errors.

Concerning sample processing, multiple advances have been made with the fundamental objective of obtaining smaller subsamples to improve efficiency without the detriment to representativeness or obtaining statistically reliable results when applying multiclass multiresidue methods. In fact, sample processing had been traditionally ignored against the sample preparation and the analytical instrument steps, but this is becoming increasingly crucial as automated high-throughput analysis is being implemented [219]. In this sense, in the first article of the QuEChERS method, attention was paid to the proper comminution of samples that achieved a good degree of homogeneity, but it was not new. De Kok *et al.* [220] were using 15 g subsamples in the mini-Luke method since the 1980s. Likewise, the QuEChERS method uses smaller subsamples (10-15 g for wet samples and 2-5 g for dried samples) with the same quality compared to larger subsamples (50-100 g) typically used in more traditional methods [220-222]. Particularly, sizes of subsamples as highly efficient as 2 g can be obtained through cryogenic processing using dry ice or liquid nitrogen, obtaining more reliable results and avoiding the loss of the most volatile analytes that when done at room temperature [223-224]. As a spectacular example, Fussell *et al.* [225] demonstrated that the degree of variability obtained for the extraction of chlorpyrifos in tomato for a subsample size of 5 g chopped with dry ice was similar to that of a sample of 110 g chopped at room temperature.

I.4.4.2.- First modifications

Since the first publication of the QuEChERS method, it has become the reference method for the analysis of pesticide residues worldwide in a large number of samples with very different characteristics [226], but with some exceptions as in the case of certain highly polar pesticides, e.g. glyphosate, caused by a poor or no partition into the organic layer. Moreover, the QuEChERS method has expanded well for other types of analytes demonstrating its potential greater utility. In fact, due to the possibility of its easy modification in terms of sample size, extraction solvent, type and amount of salts and sorbents, the QuEChERS approach could be considered as a sample preparation concept rather than a particular method. Accordingly, it serves as a template for further modifications depending on the properties of the analytes, the matrix composition and the equipment available. Hence, an incessant number of enhancements/modifications has emerged up to the point that a wide spectrum of combinations has arisen in many cases as a result of personal preferences, but many of them without transcendence or continuity. In this way, there is a need to harmonize through collaborative studies the high number of QuEChERS protocols investigated. In any case, individual efforts have focused on providing an effective initial extraction to maximize selectivity and recovery and subsequent cleaning of the extracts from matrices of different complexity to diminish matrix effect.

The first and most significant modification to date was the introduction of buffers in the initial extraction to avoid the loss of certain pH-sensitive pesticides. In fact, in the original study, pH had already been considered as a crucial aspect that affects recovery. It was studied in the range 2.5-7.0 by using H_2SO_4 or K_2CO_3 solutions and adjusted around 4, particularly for matrices with intrinsic high pH as a compromise between those pesticides that can be lost at low pH and those less stable at basic pH. Later, Lehotay *et al.* [227] validated the original QuEChERS method for the determination of 229 pesticides in fruits and vegetables using GC-MS and LC-MS/MS and also demonstrated that the use of PSA in the dSPE step in nonacidic matrices increases the pH of the final extracts to basic values with the consequent hydrolysis of pesticides such as captan, folpet, chlorothalonil and dichlofluanid. To solve the problem of pH-dependent pesticides and to expand the matrices covered, the use of a strong acetate buffer (pH 4.8) and a weaker citrate buffer (pH 5-5.5) were incorporated, resulting in the AOAC Official 2007.1 Method (AOAC method) [210] and in the European Standard Method EN 15662 (EN method) [2], respectively. Figure I.4 shows a detailed scheme of the main steps of three primary QuEChERS methods. The three versions were compared later by Lehotay *et al.* [228] to analyze 32 representative pesticides by GC-MS and LC-MS/MS in apple–blueberry sauce, peas and limes. The results demonstrated that the overall recovery was very close to 100 % with relative standard deviation (RSD) < 10 % for the majority of pesticides for all methods, but with very few exceptions. The recovery percentages of pymetrozine were higher and more consistent for the AOAC method (82 %, 7 % RSD) than the original (30 %, 100 % RSD) and the European Committee for Standardization (CEN) method (30 %, 51 % RSD) in all matrices and for thiabendazole in limes, but none of them provided good results for chlorothalonil, folpet and tolylfluanid in peas. Moreover, all methods gave equivalent amounts of matrix co-extractives, matrix effects and S/N ratios. In short, the AOAC method exhibited some advantages compared to the other two methods in terms of higher and more consistent recovery values for the pH-dependent pesticides in fruit and vegetable matrices. Despite this, the use of the more concentrated acetic acid (HOAc)/acetate buffer in the AOAC method could decrease the efficiency of PSA in the clean-up step [229]. However, this depends on the particular composition of each matrix. For example, Anastassiades *et al.* [230] found that the AOAC method gave 0.25 % of co-extractives in red currant whereas the CEN method gave 0.10 % of co-extractives, contrary to what Lehotay *et al.* [228] found in apple–blueberry sauce (original method 0.23 %, AOAC method 0.13 % and CEN method 0.17 %) using the same combination of sorbents in the dSPE step (50 mg PSA, 50 mg C_{18} and 150 mg anhydrous $MgSO_4$ per mL of extract).

As it could be seen, the use of C_{18} and GCB was tested from the beginning as sorbents in the dSPE step of the QuEChERS method, but with different objectives and consequences. On the one hand, C_{18} removes nonpolar interference substances (e.g. lipids) from extracts of fat content of 2–20 % (fish, oil, avocado, cereals, etc.) that modify ionization efficiency when using MS detection, but it does not influence recovery values, so it can only help in the dSPE procedure [231, 232]. Because of this, C_{18} has replaced low temperature precipitation (freezing-out), which is the simplest method for fat removal from extracts, but which is also time consuming and requires additional clean-up steps to remove remaining fat components [233, 234]. On the other hand, GCB is used to remove pigments (e.g. chlorophyll and carotenoids in green vegetables), but recovery percentages of certain planar analytes such as the pesticide hexachlorobenzene or polycyclic aromatic hydrocarbons (PAHs) and co-planar polychlorinated biphenyls (PCBs)

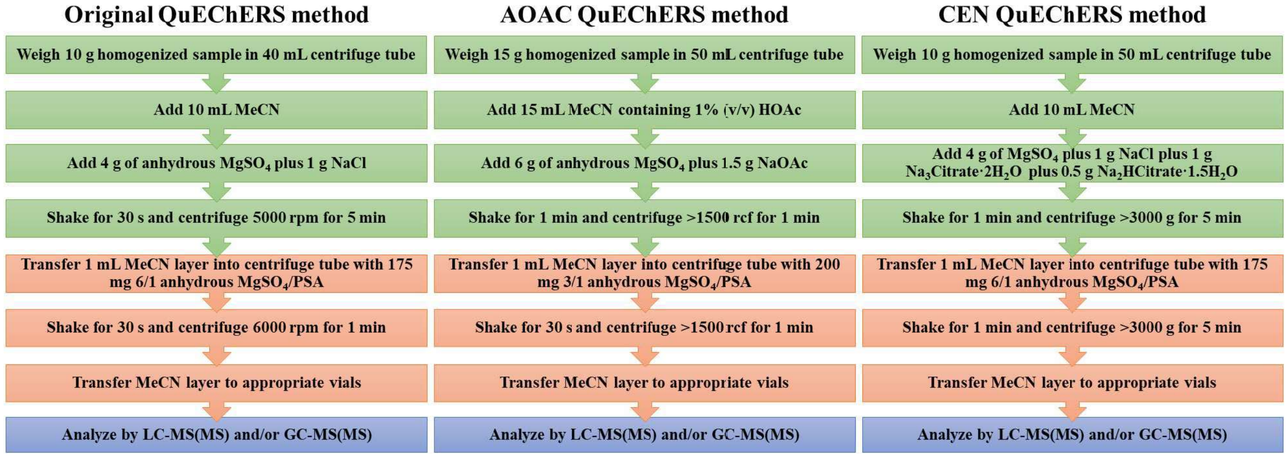


Figure I.4.- Schematic flow chart for the main steps of three primary QuEChERS methods based on [208-210], respectively.

(when they are the target analytes) are lowered as more chlorophyll is removed [235]. More recently, the so-called Z-Sep and Z-Sep+ sorbents have been used as clean-up materials to enhance this step-in pesticide analysis of commodities containing high amounts of fat [236, 237]. Both sorbents are based on zirconium dioxide and can replace the use of PSA and C_{18}, though Z-Sep is frequently used in combination with C_{18} for samples containing less than a 15 % of fat while Z-Sep+ is a combination of Z-Sep and C_{18} dual bonded to silica and recommended for samples containing more than a 15 % of fat.

One of the main problems of the use of NaCl or $MgSO_4$ in QuEChERS is that trace amounts of such salts in the final extract make necessary the development of periodic maintenance of chromatographic instruments: i.e. the replacement of liners in GC and the cleaning of the ion source in LC-MS. To solve this problem, an important modification was developed by González-Curbelo *et al.* [238] by using ammonium salts, since they are volatile enough to avoid these problems. Also, ammonium can enhance the formation of analyte ions instead of undesirable sodium adducts. Based on the previous work of Nanita and Padivitage [239] who compared the use of different salts in pesticide extraction prior to flow injection MS/MS analysis (9 food and biological matrices were studied), González-Curbelo *et al.* demonstrated that ammonium formate is an excellent salt to induce phase separation between the ACN extract and the water in the sample. Additionally, with the addition of formic acid, this provides suitable acidic buffering as in the two official QuEChERS methods. Among its advantages compared to previous versions, it can be pointed that a single salt reagent is used for salting-out rather than mixtures of each. Moreover, compared to $MgSO_4$, ammonium formate has a lower vaporization temperature which avoids any undesirable deposit as solids on the surfaces of the mass spectrometer [240, 241]. Specifically, 15 g of apple, lemon or lettuce or 5 g of wheat grains were extracted with 15 mL of ACN containing 5 % (v/v) of formic acid and 7.5 g of ammonium formate with and without the dSPE procedure. For wheat grains, 15 mL of water was also added, and samples were shaken for 1 h to promote a swelling process to increase the recovery yields, as recommended for low water content matrices

[242-244]. The method was fully validated, and it showed to recover a wide range of GC- and LC-amenable pesticides. Table I.7 shows the few works published to date using this new version of the method. As can be seen, the majority of them have been developed by Lehotay and co-workers but using only ammonium formate and ACN (without buffer) mostly using the same proportion of sample/ACN/ammonium formate. Regarding the co-extractive material, Han *et al.* [245] showed that initial extracts using the ammonium formate version had 3-fold less co-extractives than the original QuEChERS method (0.4 vs. 1.3 %) in avocado, but similar amounts for salmon and pork (0.6 % and 0.1 %, respectively). However, after the dSPE clean-up step, all final extracts were similar with 0.02–0.04 % co-extractives.

I.4.4.3.- Most recent developments

Apart from the previously commented improvements, the QuEChERS method has also evolved in different directions which should be also highlighted. On the one hand, the most important developments in the last years have focused on the introduction of other sorbents with a high matrix removal capacity as it will be indicated below. On the other hand, several attempts have also been made to modify the extraction/partitioning step as well as the format in which the SPE procedure is carried out. Finally, attempts have also been made towards its partial automation. In this sense, if automation of the whole method is finally achieved, it would improve even more the advantages of its application.

I.4.4.3.1.- Introduction of new sorbents

The greatest and most important modifications of the QuEChERS method are related with the use of new sorbents, many of which are also involved in conventional SPE methodologies. Among the different sorbents tested for the dSPE step (apart from the previously commented Z-Sep and Z-Sep+) the use of ChloroFiltr (UCT), CarbonX (United Science), Cleanert NANO (Agela), Oasis-Prime (Waters Chromatography), Phree (Phenomenex) and EMR-Lipid (Agilent), should be highlighted.

Table I.7.- Some examples of the use of ammonium salts in the QuEChERS method.

Analytes	Sample (amount)	Extraction		Sorbents in the dSPE step	Analytical technique	Recovery (%)	LOQs	Reference
		Solvents (volume)	Salts (amount)					
43 pesticides	Apple, lemon, and lettuce (15 g), and wheat grains (5g)	ACN with 5% (v/v) formic acid (10 mL)	NH_4HCOO, NH_4Cl or NH_4OAc (7.5 g)	$MgSO_4$ (150 mg), PSA (50 mg, 150 mg for wheat), C_{18} (50 mg) and GCB (7.5 mg) per mL extract	(LP)GC-MS/MS and HPLC-MS/MS	70-120 % for almost all analytes	< 5 µg/kg	[238]
42 pesticides, 3 PAHs, 9 PCBs and 5 FRs	Shrimps (10 g)	ACN (10 mL)	NH_4HCOO (5 g)	(A) $MgSO_4$ (75 mg); (B) $MgSO_4$ (75 mg) and PSA, C_{18}, and Z-Sep (25 mg each); (C) $MgSO_4$ (75 mg) and PSA, C_{18}, Z-Sep, and CarbonX (25 mg each); (D) $MgSO_4$ (25 mg) and PSA (25 mg); (E) $MgSO_4$ (75 mg) and C_{18} (25 mg); (F) $MgSO_4$ (75 mg) and Z-Sep (25 mg); (G) $MgSO_4$ (75 mg) and CarbonX (25 mg). All cases also in mode filter-vial d-SPE per 0.5 mL extract	(LP)GC-MS/MS and HPLC-MS/MS	70-120 % for 71 % of the analytes	< 5 µg/kg (< 0.5 µg/kg for PCBs)	[245]
150 pesticides, 15 PAHs, 14 PCBs, 6 PBDEs and 22 FRs	Salmon and croaker (2 g), and NIST Standard Reference Material 1947 (5 g)	ACN (1 mL per g of sample)	NH_4HCOO (5 g)	$MgSO_4$ (150 mg) and PSA, C_{18}, and Z-Sep (50 mg each) in mode filter-vial d-SPE per 0.5 mL extract	(LP)GC-MS/MS	70-120 % for almost all analytes	< 0.1 µg/kg (< 0.01 µg/kg for PCBs)	[246]
65 pesticides, 15 PAHs, 14 PCBs, 7 PBDEs and 16 FRs	Kale, pork, salmon and avocado (1 g each per mL of ACN)	ACN (1 mL per g of sample)	NH_4HCOO (0.5 g per g of sample)	EMR lipid (200 mg per mL extract)	(LP)GC-MS/MS	70-120 % for 73 % of the analytes in kale, 70 % in pork, 65 % in avocado, and 46 % in salmon	< 5 µg/kg	[247]

Table I.7.- (Continued).

Analytes	Sample (amount)	Extraction		Sorbents in the dSPE step	Analytical technique	Recovery (%)	LOQs	Reference
		Solvents (volume)	Salts (amount)					
192 pesticides, 14 PAHs, 7 PBDEs, 13 PCBs and 17 FRs	Beef, chicken and pork muscle (5 g)	ACN (5 mL)	NH_4HCOO (2.5 g)	$MgSO_4$ (90 mg) and PSA, C_{18}, and Z-Sep (30 mg each) in mode filter-vial d-SPE per 0.6 mL extract just for LP-GC-MS/MS	(LP)GC-MS/MS and UHPLC-MS/MS	70-120 % for 82 % of the analytes	< 5 µg/kg (< 0.5 µg/kg for PCBs)	[102]
19 pharmaceuticals and PCPs	Surface and sewage waters (10 mL)	ACN with 5 % (v/v) formic acid (10 mL)	$MgSO_4$ (4 g) and NH_4OAc (0.2 g)	NA	LC-MS/MS	73-125 %	0.002–0.25 µg /L	[248]
113 pesticides	Green and ripe mangoes (10 g)	ACN with 1 % (v/v) HOAc (10 mL)	$MgSO_4$ (4 g) and NH_4OAc (1.7 g)	(A) PSA (400 mg), GCB (400 mg) and $MgSO_4$ (1200 mg); (B) PSA (150 mg), GCB (15 mg) and $MgSO_4$ (900 mg); (C) MWCNTs (60 mg); (D) Z-Sep+ (500 mg); (E) PSA (400 mg), GCB (80 mg), $MgSO_4$ (1200 mg) and Z-Sep+ (480 mg). All cases per 6 mL extract just for GC-MS/MS	GC-MS/MS and UHPLC-MS/MS	70-120 % for almost all analytes	< 10 µg/kg	[249]

ACN: Acetonitrile; GC-MS/MS: Gas cromatography tandem mass spectrometry; GCB: Graphitized carbon black; HOAc: Acetic acid; LC-MS/MS: Liquid chromatography tandem mass spectrometry; LP-GC: Low-pressure gas chromatography; $MgSO_4$: Magnesium sulphate; MWCNTs: Multi-walled carbon nanotubes; NH_4HCOO: Amonium formate; PSA: Primary secondary amine; UHPLC-MS/MS: High-performance liquid chromatography tandem mass spectrometry.

CarbonX, ChloroFiltr and Cleanert NANO have been used to remove co-extracted chlorophyll from plant matrices as GCB does [135, 250-252], but also to remove co-extracted material from matrices of animal origin [108, 245]. Concerning CarbonX, which is non-friable GCB, this has been very efficient to clean extracts of QuEChERS using filter-vial dSPE [245] or SPE mini-cartridges [108, 252]. In the first case, a combination of 75 mg of anhydrous $MgSO_4$ plus 25 mg each of PSA, C_{18}, Z-Sep, and CarbonX and 75 mg of anhydrous $MgSO_4$ plus 25 mg of CarbonX work well for clean-up and analysis of pesticides and environmental contaminants in shrimp [245]. However, as it happens when using GCB, very lower recovery values for structurally planar compounds were obtained in comparison with other typical sorbents. Even so, Carbon X adsorb pesticides less strongly than GCB and it is easier to work. In the second case, automated mini-SPE containing 20 mg of anhydrous $MgSO_4$, 12 mg of PSA and C_{18} each, and 1 mg of CarbonX (45 mg total) analysis work better than using 20.7 of mg C_{18}, 8.3 mg of Z-Sep, and 1 mg of CarbonX (30 mg total) after QuEChERS extraction of kale, pork, and salmon [108]. Again, CarbonX partially retained analytes with co-planar chemical structures. As examples, hexachlorobenzene (HCB), Polybrominated diphenyl ethers (PBDE) 183 and co-planar PCBs (126 and 169) yielded 80 % relative recovery percentages, but still removing 95 % of co-extracted chlorophyll from initial QuEChERS extracts of kale. ChloroFiltr, a polymeric-based sorbent, has also been investigated for the selective reduction of chlorophyll from green plant extracts using 150 mg of anhydrous $MgSO_4$, 50 mg of PSA and 15 mg of ChloroFiltr each per mL of extract in dSPE mode without sacrificing the recovery of planar analytes [250, 251], but larger amounts of ChloroFiltr were not recommended because it swells substantially in ACN making it difficult to take aliquots of the supernatant [252]. Much more widely, multiwalled carbon nanotubes (MWCNTs) have been used as sorbents in dSPE because of their excellent properties such as extremely large surface area and high porosity, which provide a high capacity to remove colorants and fatty acids in matrices as complex as garland [253], tea [254] or garlic [255]. In fact, a new commercial product based on MWCNTs is called Cleanert

NANO, which is composed of functionalized MWCNTs including surface deactivation to ensure the recovery of pesticide with a benzene ring structure using only 10 mg per mL of extract [256]. Very recently, magnetic MWCNTs (Fe_3O_4-MWCNTs) were used as clean-up sorbents for the determination of veterinary drugs, pesticides and mycotoxins in eggs, and an external magnet was utilized instead the traditional centrifugation process which simplified the sample preparation process [257].

Oasis® Prime HLB [258] is a polymeric type sorbent that can be used to remove phospholipids in fatty matrices, that is typically commercialized and used packed in cartridges. Thus, after sample extraction, an aliquot of the extract is loaded in the cartridge for its clean-up. However, in this case, co-extracted components are not retained in the sorbent, but the analytes, while co-extracted compounds pass through the cartridge and they are discarded. Then, the analytes are finally eluted from the cartridge using a suitable solvent. As a result, the introduction of a SPE procedure for extraction purposes, clearly complicates the sample preparation procedure. This sorbent has been used in few occasions with this aim, such as for pesticide analysis in spices [90] or fruit extracts [260].

Another sorbent used for this purpose is EMR-Lipid, introduced in 2015 by Agilent Technologies [261], which can remove phospholipids and proteins. However, it does not function as a solid sorbent in dSPE. Indeed, and after it dissolves to saturation in the extract solution, the extraction mechanism is based on size exclusion and hydrophobic interactions. Long-chain hydrocarbons associated with lipids fit within the EMR-Lipid structure, where they are trapped. The lipid/EMR-Lipid complex is either precipitated out of solution or remain in the aqueous phase during the final salting-out step. Han *et al.* [247] have shown the first application of this new product in multiclass multiresidue analysis of pesticides and environmental contaminants in kale, salmon, avocado and pork. In particular, 65 pesticides and 52 environmental contaminants were studied. When using this material, water should be added to the initial extract prior to EMR-Lipid clean-up, which adds an additional step to the method and which can also complicate calculations, etc. Even though, it was found that EMR-Lipid efficiently removed 79–98 % of co-extracted matrix components, providing clean extracts and low background in GC–MS/MS analysis. Figure I.5 shows the non-evaporated co-extracts from kale, salmon, avocado and pork before and after EMR-Lipid clean-up, where it can be seen that the amount of material present decrease considerably after EMR-Lipid application. Authors also found that it removed up to 76 % of co-extracted chlorophyll without concomitant loss of co-planar analytes. Since then, EMR-Lipid has also been used as clean-up sorbent in few occasions, for the analysis of pesticides in spices [90], edible vegetable oils [262], virgin olive oil [263], insecticides in honeybee [264], and mycotoxin residues in edible nuts [265].

Figure I.5.- Image of non-evaporated co-extracts from different matrices before and after EMR-Lipid clean-up. Reprinted from [247] with permission from Elsevier.

I.4.4.3.2.- Extraction/partitioning modifications

As previously mentioned, the introduction of ammonium formate in 2014 [238] to promote extraction/partitioning in the first step of the QuEChERS method without the use of sodium or magnesium salts whose presence in the final extract is disadvantageous for the subsequent chromatographic analysis, is probably an important modification that will surely continue to be used in the future. Apart from that, another important development in the QuEChERS method is the so called QuPPe (Quick Polar Pesticides) method, though it only involves a single extraction step (no further dSPE procedure is developed). This method evolved as a result of the low ability of QuEChERS to extract polar pesticides with a poor chromatographic behaviour on RPLC columns, also important losses with generic sample treatment procedures and which require specific sample preparation methods and analysis. The QuPPe method was proposed by Anastassiades *et al.* [266] for the analysis of pesticides non-amenable by QuEChERS. It consisted on the extraction of 10 g of each commodity (5 g if dried fruits, vegetables, etc. are selected -water is also added in these cases-) with 10 mL of acidified MeOH for 5-30 minutes, depending on the commodity (heating may also be necessary, i.e. for paraquat and diquat analysis). After centrifugation and filtering of the supernatant, it is injected in the chromatographic system (specific and complex separations may be required depending on the polar pesticide). The QuPPe method is currently being updated to incorporate a higher number of pesticides. Such modifications can be found in [266]. With the aim of extending the applicability of the QuPPe approach, it was later combined with the QuEChERS method by Robles-Molina *et al.* [267] for the extraction of 41 multiclass pesticides covering a wide range of physicochemical properties across several orders of log K_{OW} (from -4 to +5.5). After the extraction, parallel HILIC/RPLC and RPLC/aqueous normal phase were assessed using LC–MS/MS. In this case, 10 g of sample (leek) were extracted/partitioned with 10 mL of MeOH containing 1 % of formic acid, 10 mL of ACN, 1.5 g of NaCl and the corresponding amount of ultra-pure water to achieve a final content of approximately 10 g depending on the vegetable. After agitation and centrifugation, two aliquots of the supernatant were subjected to a final dilution step (1:7 dilution factor), which was carried out by adding to 1 mL of the supernatant, 6 mL of ACN (0.1 % of formic acid) to the aliquot for HILIC analysis or 6 mL of ultrapure water (0.1 % of formic acid) for the extract submitted to RPLC analysis, so that they matched the initial gradient composition of both methods. Recovery values were in the range 70-120 % for most pesticides. Only compounds with extreme log K_{OW} values (resmethrin and streptomycin) were not recovered at all.

Another way of avoiding the presence of sodium or magnesium salts that can lead to the maintenance problems previously indicated, is also by not using salts in the first step but to freeze the extract to provide phase separation, as well as to eliminate fats. To achieve this goal, Norli *et al.* [268] used disposable syringes and a freezing block consisting of a laboratory rack with 15 mL centrifuge tubes immersed in a polystyrene box filled with a freezing gel (see Figure I.6) to maintain the temperature of the ACN extract at -24 ºC for 10 min. This approach which was applied for the extraction of 22 OCPs and 7 PCBs from fish (tilapia and salmon), was based on previous works in which lipid removal from organic solvents was carried out in a similar way [269]. For that purpose, 6 mL of the ACN extract were aspired into the disposable syringe which contained a polyethylene frit. The syringes were placed in the freezing device and kept for 2 hours at -24 ºC. Afterwards, the content of the syringed was poured into a tube containing 1.0 g of $CaCl_2$, shaken and centrifuged. The supernatant was decanted into a new tube containing 900 mg of $MgSO_4$ and 150 mg of PSA, shaken and centrifuged. After the freezing step, 69 % of the lipids in tilapia and 61 % in salmon were removed. Further reduction of co-extractives up to 96 % in tilapia and 87 % in salmon could be made with the dSPE step employing $CaCl_2$ and PSA. Recovery values for tilapia ranged from 70 to 115 % for all compounds, while for salmon they were in the range 43-118 % for the OCPs and 26-65 % for the PCBs.

Some years later, Shao *et al.* [270] developed a similar work. In that case, authors induced the partitioning of water/ACN phases by cooling the mixture down to -16 ºC overnight (12 h) and called the procedure "cold-induced aqueous ACN phase separation (CIPS)". As also tested by the authors, aqueous solutions of MeOH, acetone, and 2-propanol fail to undergo a similar phase separation at -16 ºC, which also happened to the semi-miscible solvent's butanol and EtOAc, beyond their initial, partial phasing at room temperature. As indicated in their work, the cooling phase separation proceeds as a descending cloud of microdroplets. Authors applied this CIPS-QuEChERS procedure to the extraction of nine pesticides from salmon. Beef was also tested as matrix but only to show the separation of phases. After cooling, the upper phase, which was rich in ACN (71.7 %) was a clear liquid. The middle phase was ice and precipitated lipids, while the lower phase was the residual matrix of undissolved salmon or meat. The salmon supernatant (not the beef one) was treated with anhydrous $MgSO_4$ and C_{18} for the dSPE clean-up, finding that recovery values were disparate, between 24-99 %. These preliminary studies suggested that further study on CIPS-QuEChERS should be developed. However, as previously shown, the use of sorbents able to efficiently extract lipids (i.e. C_{18}, EMR-lipid, etc.) is recommended.

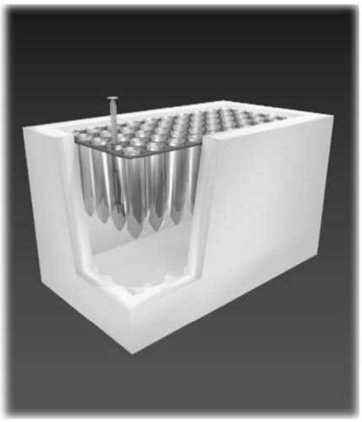


Figure I.6.- Freezing block consisting of a laboratory rack with 15 mL centrifuge tubes immersed in a polystyrene box filled with freezing gel. Reprinted from [268] with permission from Elsevier.

Apart from such work, and as previously commented, freezing-out or cryo-precipitation has also been used to eliminate fats prior to the dSPE step by freezing the extract at approx. -25 ºC for 1-2 hours [99,271]. However, and as it also happened in the work of Shao *et al.* [270], the sample pre-treatment time is increased. Moreover, it was well demonstrated for pesticide analysis that the freezing-out step is unnecessary when it is carried out after the dSPE step using PSA and C_{18} since the amount of co-extractives is equivalent [272].

I.4.4.3.3.- Variations in the SPE format and automation

As previously commented, some changes in the way the clean-up dSPE procedure is developed have been proposed in few occasions. An interesting example of these attempts, also towards the automation of part of the extraction process, was developed by Kaewsuya *et al.* [273] using pipet tips fitted with filtration screens and containing PSA (25 mg), $MgSO_4$ (75 mg) and GCB (12.5 mg). In this case, 250 multiclass pesticides were determined in carrots, tomatoes, green beans, broccoli, and celery. Thirty grams of each homogenized sample were weighted and 30 mL of ACN were added. The mixtures were shaken for 1 min followed by the addition of 3.0 g of NaCl and 12.0 g of anhydrous $MgSO_4$. The tubes were shaken again and centrifuged. Two hundred and fifty microlitres of the supernatant were slowly aspirated into the QuEChERS tips and then dispensed after a few seconds. This procedure was repeated three times with the final elution into a clean GC vial. The QuEChERS tip was further eluted from the top with an additional volume of 250 µL of ACN to ensure the pesticides were efficiently removed from the sorbent. The use of the tips avoided a second centrifugation step. High recovery (70-117 %) and good RSD values (< 12 %) were obtained for over 200 pesticides.

The use of magnetic materials, which is a current trend in Analytical Chemistry [274, 275] has also been used in the QuEChERS method as dSPE sorbent. The application of magnetic sorbents for magnetic dSPE was not developed until 1996, when Towler *et al.* [276] reported the recovery of different metals from seawater samples using manganese dioxide coated magnetite (Fe_3O_4) as the magnetic sorbent. However, the term magnetic SPE was only introduced three years later by Safariková *et al.* [285]. A clear example of the application of magnetic sorbents in QuEChERS is the work of Li *et al.* [278] in which bare Fe_3O_4 nanoparticles were synthesized following a simple chemical co-precipitation method and used. In this case, 101 multiclass pesticides were analysed in tomato, cucumber, orange and apple. After optimization of the amount of magnetic nanoparticles (m-NPs, 40 mg were used to clean 1 mL of the previous ACN extract), recovery was evaluated. One hundred milligrams of anhydrous $MgSO_4$, 10 mg of GCB and 50 mg of PSA were also added. Results showed that the recovery of 101 pesticides were in the 71.5-111.7 % range (RSDs < 10.5 %). The use of magnets to retain the sorbents simplifies the procedure by avoiding the centrifugation and filtration of the extracts. A similar approach was also previously developed by Zheng *et al.* [279] using Fe_3O_4 m-NPs combined with GCB and PSA as sorbents ("an aggregate wrap" of all of them) for the extraction of 10 target pesticides from cucumbers, gourds, cabbages and tomatoes. In their research, m-NPs were synthesized following a solvothermal process. Recovery values ranged from 69.9 to 125.0 % with RSDs less than 9.8 %. As previously commented, magnetic MWCNTs have also been used with success for this purpose [257].

One of the main problems of the QuEChERS method is that part of the sorbents of the dSPE procedure can be carried out during the removal of the supernatant. An interesting approach to avoid this issue and that has also facilitated/simplified part of the method is the use of filter-vials to develop the dSPE step [245] (see Figure I.7). In this case, an aliquot is added to the receptacle half of the vial (outer/bottom part) which contains a mixture of the clean-up sorbents. After vortex, the plunger half of the vial (inner/superior part), which contains a filter (i.e. 0.45 µm), is pressed down into the receptacle. In this way, a clean extract ready for its further analysis is obtained. It should also be highlighted that a high number of clean-ups/filtrations can also be carried out simultaneously and that the amount of the supernatant to be filtered and of the sorbents to be used can also be scaled. A similar approach can also be developed with the commercially available SpinFiltr® tubes from United Chemical Technologies [280]. However, in this case the sorbents are contained in the inner/upper tube which also has a 0.2 µm frit. Once the supernatant is introduced, vortex is applied followed by centrifugation. It is the centrifugation that promotes the final filtering.

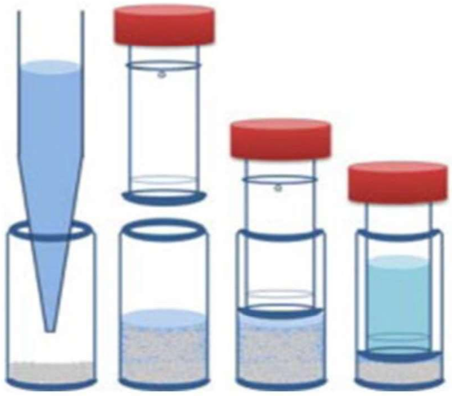


Figure I.7.- Procedure for filter-vial d-SPE: (1) pipette 0.5 mL of initial QuEChERS extract into the bottom piece containing the sorbents; (2) press filter plunger half-way into the bottom piece (3) shake for 30 s; (4) depress the filter plunger to filter the extract for analysis. Reprinted from [245] with permission from Elsevier.

The use of conventional SPE cartridges instead of the dSPE step, though more tedious and time consuming, has also been proposed [281] since it provides a better clean-up of the extracts maintaining the high recovery values obtained. For this purpose, columns of aminopropyl and PSA [282] or GCB and PSA [283], among others, have been used. In practise, the use of dSPE is more convenient since it is easier, faster, and also cheaper. However, if automation of the extraction can be developed, preferably with small cartridges to decrease the amounts of solvents and extracts loading, then its SPE might be competitive enough. Such approach was followed by Morris and Schriner [252] who proposed in 2015 the use of an automated mini SPE cartridge from ITSP Solutions to be used during QuEChERS clean-up. This approach was called “instrument top sample preparation” (ITSP) and it consisted of the use of a PAL HTS-xt robotic X-Y-Z autosampler from CTC Analytics (this autosampler is widely present nowadays in many analytical laboratories). After testing different sorbent mixtures (30 mg of Z-Sep/C_{18}/CarbonX (2:5:0.24), 45 mg of PSA/C_{18}/CarbonX/$MgSO_4$ (3:3:0.25:5), 20 mg of HLB/Z-Sep/CarbonX (1:1:0.22) -which were prepared in the laboratory- and 10 mg of Z-Sep or 30 mg of Z-

Sep$^+$ sorbents), it was found that the best results were obtained with the first of them eluting with formate buffer in ACN/MeOH (1:1). Such cartridges were applied for the extraction of 263 multiclass pesticides from avocado and citrus prior to (LC–MS/MS). In the case of avocado samples, they allowed the removal of 90 % of di- and triacylglycerols. Spiked recovery percentages were within 70-120 % and 20 % RSD for 243 of these analytes in avocado and 254 in citrus. This application of Morris and Schriner constitutes another of the few attempts of semi-automation of the QuEChERS method. Apart from it, it should also be indicated that Lehotay *et al.* [108] further explored the application of automated mini-SPE cartridges during the extraction of other pesticides and environmental contaminants avocado, salmon, pork loin, and kale as representative matrices, obtaining also good results.

I.4.4.4.- Applications

As it has already been suggested by Dr. S. J. Lehotay, one of the creators of the method [284], QuEChERS can be considered nowadays and as a "mega method", in the sense that the same fixed experimental conditions are appropriate for the extraction of a wide variety of analytes (pesticides, pharmaceutical compounds, mycotoxins, PAHs, PCBs, etc.) that could be also monitored together. Even though, it is not really frequent to analyse an extremely high number of multiclass compounds, though ideally, if needed, such approach would also be possible and of high value.

Among the different target analytes to which the QuEChERS method has been applied, pesticides are, by far, the ones most studied, which is more than logical, taken into account that the method was originally created for their analysis. This fact can be clearly observed in different review articles devoted to the analysis of pesticide residues [285-288] or to the revision of the QuEChERS method [226, 297]. As an example, Table I.8. compiles some works devoted to the analysis of a high number of pesticides from different complex samples, using a variety of analytical techniques. Nowadays, trends in this field (and also in the analysis of other compounds using QuEChERS) are focused on

Table I.8.- Some examples of the application of the QuEChERS method in pesticides analysis.

Analytes	Sample (amount)	Extraction		Sorbents in the dSPE step	Analytical technique	Recovery (%)	LOQs	Reference
		Solvents (volume)	Salts (amount)					
205 pesticides	Spice (2 g)	ACN (10 mL)	$MgSO_4$ (4 g), NaCl (1 g), $Na_3Cit.2H_2O$ (1 g), $Na_2HCit-1.5H_2O$ (0.5 g)	EMR-Lipid, EMR polish (0.2 g of NaCl and 0.8 g of $MgSO_4$)	GC-MS/MS	70-120 % for 90 % of the analytes	2 µg/kg	[90]
60 pesticides	Crayfish and mantis shrimp (10 g)	ACN (10 mL)	NaCl (3 g)	PSA (50 mg)	HPLC-MS/MS	70-120 %	0.4–10 µg/kg	[293]
40 pesticides	Apple, banana, broccoli, celery, grape, green bean, peach, potato, orange, and squash (15, 10, 5, 2 and 1 g)	ACN (1 mL per gram)	4/1 $MgSO_4$/NaCl (0.5 g per 1 g sample)	PSA (20 mg), C18 (2 mg), CarbonX, (12 mg) Filter vials (0.45 µm PVDF)	(LP)GC-MS/MS and UHPLC-MS/MS	70-120 %	-	[294]
69 pesticides	Wheat and rice straws (2.0 g)	H_2O with 2 % (v/v) formic acid (5 mL) (ACN (20 mL)	NaCl (3 g)	Wheat straw: $MgSO_4$ (30 mg) PSA (20 mg) Rice straw: $MgSO_4$ (30 mg) C_{18} (20 mg)	LC-MS/MS	70-120 % for 90 % of the analytes	40–200 µg/kg	[295]
60 pesticides	Cinnamon bark (2 g)	ACN (10 mL)	(A) NH_4HCO_2 (2.5 g) (B) NaCl (2.5 g)	$MgSO_4$ (150 mg) and C_{18} (50 mg)	LC-MS/MS	71-118 % for 73 % of the analytes	0.5 µg/kg	[296]]

Table I.8.-(Continued).

Analytes	Sample (amount)	Extraction		Sorbents in the dSPE step	Analytical technique	Recovery (%)	LOQs	Reference
		Solvents (volume)	Salts (amount)					
20 pesticides	Apple, broccoli, shallot (5 g) and tea (1 g)	ACN (20 mL)	$MgSO_4$ (2 g) and NaCl (2 g)	PVPP (150 mg), PSA (50 mg) and GCB (10 mg)	UPLC-MS/MS	73-106 %	1 -2 µg/kg	[297]
35 pesticides	Apple/pomarrosa (*Syzygium malaccense*), starfruit/carambola (*Averrhoa carambola*), yoyomo (*Spondias purpurea*) and papayuela (*Vasconcellea pubescens*) (15 g)	ACN with 1 % (v/v) HOAc (15 mL)	$MgSO_4$ (6 g) and NaOAc (1.5 g)	$MgSO_4$ (150 mg), PSA (50 mg), C_{18} (50 mg) and GCB (7.5 mg)	GC-MS/MS	70-120 % for 95 % of the analytes	5 µg/kg	[298]
170 pesticides	Green pepper and cucumber samples (15 g)	MeOH with 1 % (v/v) HOAc (15 mL)	$MgSO_4$ (6 g) and NaOAc (1.5 g)	$MgSO_4$ (112.5 mg), PSA (18.75 mg)	LC-MS/MS	70-120 % for 95 % of the analytes	0.1 µg/kg	[299]
99 pesticides	Groundnut, soybean, kidney bean, black bean, cowpea, chili pepper, Egusi seeds, coffee beans, cocoa beans, maize, white pepper, and Bambara nuts (5 g)	ACN (15 mL)	$Na_2HCit \cdot 1.5H_2O$ (0.75 g $Na_3Cit.2H_2O$ (1.5 g), NaCl (1.5 g), and $MgSO_4$ (6 g)	$MgSO_4$ (112.5 mg), PSA (37.5 mg), C_{18} (18.75 mg)	LC-MS/MS and GC-ECD	70-120 % for 60 % of the analytes	0.0004 and 0.0537 mg/kg	[300]

Table I.8.-(Continued).

Analytes	Sample (amount)	Extraction		Sorbents in the dSPE step	Analytical technique	Recovery (%)	LOQs	Reference
		Solvents (volume)	Salts (amount)					
43 pesticides	Honey and honeybee (0.5 g)	(A) Honey: ACN (5 mL) (B) Honeybee ACN (5 mL) and n-hexane (1.5 mL)	$MgSO_4$ (4 g) and NaCl (1 g)	$MgSO_4$ (150 mg), PSA (50 mg)	GC-MS/MS and LC-MS/MS	85–116 %	2.8 µg/kg	[301]

ACN: Acetonitrile; GC-MS/MS: Gas chromatography tandem mass spectrometry; HOAc: Acetic acid; MeOH: Methanol; PSA: Primary secondary amine; LC-MS/MS: Liquid chromatography tandem mass spectrometry; NaOAc: Sodium acetate Na_2HCit: Disodium hydrogen citrate; $Na_3Cit._2H_2O$: Sodium citrate; PVPP: Polyvinylpyrrolidone; UPLC-MS/MS: Ultra performance liquid chromatography tandem mass spectrometry.

the extension of the application of the method to other analytes and to highly complex matrices, to the detail study of matrix effects [84] as well as to the long-term routine applications of the method.

Table I.9 compiles some works dealing with the extraction of pharmaceuticals, mycotoxins and PAHs, the compounds most extracted with QuEChERS after pesticides, while Table I.10 compiles other works in which a miscellaneous variety of different analytes have been extracted, in order to show the wide application of the method. In the first case (pharmaceutical analysis), this field is an important application area, since many pharmaceutical compounds are being considered as emerging contaminants and, therefore, their monitoring is especially relevant nowadays. In these cases, many drugs are also ionizable and, therefore, a suitable control of the pH may also be required [226, 139]. Most of the applications of the QuEChERS method in this field frequently involve the simultaneously analysis of pharmaceuticals with other emerging contaminants.

Concerning mycotoxins analysis, all works have been focused on the food sample field, since food is the main route for human exposure and, among them, most applications have dealt with cereal extraction, since they are mainly formed in such matrices [226]. As previously indicated, the addition of water is required in such cases to promote a swelling process to increase the recovery yields.

Regarding PAHs analysis, their extraction has been mainly performed with the original method, even without the addition of a buffer, since they are not ionizable [226]. Most of those works have analysed the 16 PAHs included in the United States EPA priority pollutants list, though the analysis of their metabolites has also been developed though in fewer occasions [226].

The majority of the applications previously commented use, by far, MS/MS detectors, which are highly necessary since the method is not highly selective (as previously indicated it is indeed a "mega method") and also to unequivocally confirm the presence of such compounds in the selected samples, though "traditional" detectors have also been used [139]. In most cases, either LC or GC (in their different modalities) have been the analytical techniques of choice, though few applications of CE have also appeared [289, 290]. Its application has probably been hindered by the necessity of highly clean final extracts with a low conductivity, since a high conductivity of the injected solutions produces important current breakdowns. The fact that the QuEChERS method requires the use of salts and sorbents difficult the expansion of CE applications.

In many of those previous works, if a suitable study of the effect of each salt/sorbent is developed, a step by step approach has been frequently followed, though a good number of publications apply conventional conditions using commercial QuEChERS' kits (many vendors currently sell QuEChERS kits, also adapted to the user's needs), as a result of the advantage of not having to weight the salts and sorbents at the laboratory, which is quite time-consuming. Concerning the extraction solvent, though most works use ACN, others have also studied other solvents such as EtOAc, acetone, MeOH, n-hexane, etc. or mixtures of them, but the general approach is to use ACN.

Finally, it should also be highlighted that as it happens in many analytical procedures, ISs are also frequently used to correct the analytes loses that may also happen during the extraction. They are normally deuterated standards, though their high cost frequently ends up in the use of a reduced number of them. Apart from that, the presence of matrix components in the final extracts makes necessary the evaluation of the matrix effect [84] and the use of matrix-matched calibration to compensate them. Besides, and as also proposed by Dr. S. J. Lehotay [101, 292], the use of analyte protectants that help to reduce analyte tailing and decomposition within the GC inlet by masking the active sites that generate non-volatile compounds in the GC inlet is also highly recommended, especially for pesticide analysis.

Table I.9.- Some examples of the application of the QuEChERS method in pharmaceuticals, mycotoxins and PAHs analysis.

Analytes	**Sample (amount)**	**Extraction**		**Sorbents in the dSPE step**	**Analytical technique**	**Recovery (%)**	**LOQs**	**Reference**
		Solvents (volume)	**Salts (amount)**					
Pharmaceuticals								
6 pharmaceuticals	Soil (5 g)	(A) ACN (10 mL) (B) ACN/ water 70:30 v/v with 5% (v/v) HOAc (10 mL) (C) ACN with 5% (v/v) water (10 mL) (D) ACN/ water 70:30 v/v with 5% (v/v) HOAc (7,5 mL)	(A) $MgSO_4$ (4 g) and NaCl (1 g) (B) $MgSO_4$ (3 g) and NaCl (0.75 g) in version (D)	(A) PSA (25 mg), (B) C_{18} (25 mg)	HPLC-UV	83-113 %	3.5 µg/L	[302]
6 pharmaceuticals	Lagoon cockle (*Cerastoderma glaucum*), coquina clam (*Donax trunculus*), manila clam (*Ruditapes philippinarum*), striped venus clam (*Chamelea gallina*), sword razor clam (*Ensis sp.*) and mussel (*M. galloprovincialis*)	ACN (10 mL)	(A) $MgSO_4$ (4 g), NaCl (1 g), $Na_3Cit.2H_2O$ (1 g), $Na_2HCit\text{-}1.5H_2O$ (0.5 g) (B) $MgSO_4$ (6 g), NaOAc (1,5 g)	Silica gel (1 g) per mL extract	LC-MS/MS	61-95 %	1 µg/kg	[303]

Table I.9.-(Continued).

Analytes	Sample (amount)	Extraction		Sorbents in the dSPE step	Analytical technique	Recovery (%)	LOQs	Reference
		Solvents (volume)	Salts (amount)					
26 pharmaceuticals	Human whole blood (1 mL)	EtOAc (3 mL)	Saturated carbonate buffer (45 g $NaHCO_3$, 30 g Na_2CO_3 in distilled water) 100 µL	$MgSO_4$ (150 mg) PSA (50 mg) per mL extract	UHPLC-MS/MS	21-98 %	0.05 µg/L	[304]
15 emerging pollutants	Sediments (2 g)	ACN with 1 % (v/v) HOAc (10 mL)	$MgSO_4$ (6 g) and NaOAc (1.5 g)	$MgSO_4$ (900 mg) PSA (150 mg) and GCB (15 mg) per 6 mL extract	LC-MS/MS	40-98 %	0.5 µg/kg	[305]
Mycotoxins								
Zearalenone	Maize and samples for animal feed (rabbit and hamster) (15 g)	ACN with 1 % (v/v) HOAc (15 mL)	$MgSO_4$ (6 g) and NaOAc (1.5 g)	$MgSO_4$ (150 mg) and PSA, C_{18}, (50 mg each)	Automated fluorimetric sensor	93-107 %	15 µg/L	[306]
23 mycotoxins	Wheat and maize (2 g)	ACN with 5% (v/v) formic acid (10 mL)	$MgSO_4$ (4 g) and NaOAc (1 g)	Ultrafree®-MC	UPLC-MS/MS	60-98 %	0.13 µg/kg in wheat, 0.14 µg/kg in maize	[307]

Table I.9.-(Continued).

Analytes	Sample (amount)	Extraction		Sorbents in the dSPE step	Analytical technique	Recovery (%)	LOQs	Reference
		Solvents (volume)	Salts (amount)					
23 mycotoxins	Beer (15 mL)	ACN (5 mL)	$MgSO_4$ (4 g) and NaCl (1 g)	$MgSO_4$ (900 mg) and C_{18} (300 mg) per 6 mL extract	UPLC-MS/MS	70-110 % for almost all analytes	0.002 µg/L	[308]
15 mycotoxins	*Menthae haplocalycis* (1 g)	H_2O with 2 % (v/v) formic acid (5 mL), ACN (5 mL)	$MgSO_4$ (2 g) and NaCl (1 g)	$MgSO_4$ (150 mg) and C_{18} (50 mg)	LC-MS/MS	67.1-103 % for almost all analytes	0.007 µg/kg	[309]
11 mycotoxins	Wheat, maize and millet (2 g)	ACN (10 mL)	$MgSO_4$ (4 g) and NaCl (1 g)	$MgSO_4$ (600 mg) and PSA (200 mg)	DART-MS	84–118 %	50–150 µg/kg	[310]
11 mycotoxins	Functional and medicinal herbs (2 g)	ACN with 2% (v/v) formic acid (20 mL)	$MgSO_4$ (4 g), $Na_3Cit.2H_2O$ (1 g), NaCl (1 g), $Na_2HCit\text{-}1.5H_2O$ (0.5 g)	C_{18} (8.3 mg)	LC–MS/MS	52.4-91.2 %	0.25-2.5 µg/kg	[311]
15 mycotoxins	Liquorice (2 g)	ACN with 5% (v/v) formic acid (15 mL)	$MgSO_4$ (4 g), $Na_3Cit.2H_2O$ (1.5 g), NaCl (1 g), $Na_2HCit\text{-}1.5H_2O$ (1 g)	$MgSO_4$ (900 mg), PSA (150 mg), C_{18} (600 mg), and Si for the d-SPE cleanup (150 mg) per 6nL extract.	UHPLC-MS/MS	81-103 %	0.05 µg/kg	[312]

Table I.9.-(Continued).

Analytes	Sample (amount)	Extraction		Sorbents in the dSPE step	Analytical technique	Recovery (%)	LOQs	Reference
		Solvents (volume)	Salts (amount)					
Patulin	Strawberry (10 g)	ACN with 1% (v/v) HOAc (10 mL)	$MgSO_4$ (4 g), $Na_3Cit.2H_2O$ (1 g), NaCl (1 g), $Na_2HCit-1.5H_2O$ (0.5 g)	(A) $MgSO_4$ (150 mg), PSA (25 mg), GCB (7.5 g) (B) $MgSO_4$ (150 mg), PSA (50 mg)	HPLC-DAD	96-103 %	1.5 and 5 µg/kg	[313]
PAHs								
12 PAHs	Baby foods (10 g)	ACN (10 mL)	$MgSO_4$ (4 g) and NaCl (1 g)	$MgSO_4$ (150 mg), PSA (25 mg), C_{18} (25 mg)	GC-MS	72-112 %	1 µg/kg	[314]
23 PAHs	Smoked meat (2 g)	Water (1,6 mL) and ACN (2 mL)	$MgSO_4$ (3 g) and NaCl (0.5 g)	$MgSO_4$ (500 mg), Z-Sep (100 mg)	GC-MS	74-117 %	0.3 µg/kg and 0.9 µg/kg	[315]
5 PAHs	Strawberry, lemongrass, peppermint and boldo (1 g)	Water (10 mL) and EtOAc (10 mL)	$MgSO_4$ (4 g) and NaCl (1 g)	$MgSO_4$ (60 mg), PSA (20 mg), and silica gel (60 mg)	HPLC-FD	54-99 %	0.03-0.3 µg/kg	[316]

Table I.9.-(Continued).

Analytes	Sample (amount)	Extraction		Sorbents in the dSPE step	Analytical technique	Recovery (%)	LOQs	Reference
		Solvents (volume)	Salts (amount)					
16 PAHs	Soil (5 g)	Hexane:acetone or EtOAc (2:1 v/v) (30 mL)	$MgSO_4$ (4 g) and NaCl (1 g)	$MgSO_4$ (150 mg), PSA (50 mg), C_{18} (50 mg) clinoptilolite (50 mg), Florisil® (50 mg) and diatomaceous earth (50 mg)	GC-MS	23-109 %	0.60-1.53 µg/kg	[317]
16 PAHs	Vegetables (10 g)	ACN (30 mL)	$MgSO_4$ (4 g) and NaCl (1 g)	$MgSO_4$ (150 mg) and PSA (50 mg)	GC-MS	71-108 %	0.012 µg/kg	[318]
24 PAHs	Fish tissues, feeds and feed ingredients (1 g)	ACN (2 mL)	$MgSO_4$ (0.8 g)	$MgSO_4$ (150 mg), PSA (50 mg), C_{18} (50 mg)	GC-MS/MS	70-120 %	0.5 to 2 µg/kg	[319]
12 PAHs	Curry spice powder (2 g), salmon, mussels, shrimps, bacon, cutlets, wheat flour, infant formula, infant follow up formula, and infant foods. (10, 5, 2,1 g respectively)	Water (5 mL) and ACN (10 mL)	(A) $MgSO_4$ (4 g), NaCl (1 g), $Na_2HCit\text{-}1.5H_2O$ (0.5 g) and $Na_3Cit.2H_2O$ (1 g) (B) EMR-lipid d-SPE	(A) $MgSO_4$ (900 mg), PSA (150 mg), C_{18} (150 mg) per 8 mL extract (B) EMR polish containing (1:4, $NaCl/MgSO_4$) (2 g)	GC-MS/MS	50-120 %	≤0,3 and ≤0.9 µg/kg	[320]

ACN: Acetonitrile; GC-MS: Gas chromatography-mass spectrometry; GC-MS/MS: Gas chromatography tandem mass spectrometry; HOAc: Acetic acid; HPLC-DAD: Liquid chromatography-diode-array detection; HPLC-UV: Liquid chromatography-UV detection; HPLC-FD: High-performance liquid chromatography-fluorescence detection; MeOH: Methanol; PSA: Primary secondary amine; LC-MS/MS: Liquid Chromatography tandem mass spectrometry; NaOAc: Sodium acetate; Na_2HCit: Disodium hydrogen citrate; $Na_3Cit._2H_2O$: Sodium Citrate; UPLC-MS/MS: Ultra performance liquid chromatography tandem mass spectrometry.

Table I.10.- Some examples of the application of the QuEChERS method for multiresidue analysis.

Analytes	Sample (amount)	Extraction		Sorbents in the dSPE step	Analytical technique	Recovery (%)	LOQs	Reference
		Solvents (volume)	Salts (amount)					
16 PAHs, 12 PCBs and 7 OCPs	Spiked estuarine and marine sediments (10 g)	ACN with 1 % (v/v), HOAc (10 mL)	$MgSO_4$ (4 g) and NaCl (1 g)	$MgSO_4$ (150 mg) and PSA (50 mg)	GC-MS	62-131 %	0.01 µg/kg	[321]
16 PAHs, 7 PBDEs, 12 PCBs and 17 OCPs	Blood of sub-adult green turtles (Chelonia mydas) (1 g)	ACN (3 mL) and water (1 mL)	$MgSO_4$ (1 g) and NaCl (0.2 g)	$MgSO_4$ (150 mg), PSA (50 mg), C_{18} (50 mg)	GC–MS/MS	60-107 % for 51 % of the analytes	0.1 to 2 µg/L	[322]
65 pesticides and 200 environmental contaminants (PCBs, PAHs, PBDEs and other flame retardants)	Cattle, swine and poultry muscle tissues (2 g)	Water (1.6 mL) and ACN (2 mL)	$MgSO_4$ (0.8 g) and NaCl (0.2 g)	0.2 µm PVD containing 45 mg of 20/12/12/1 (w/w/w/w) $MgSO_4$, PSA, C_{18}.	(LP)GC-MS/MS and UHPLC-MS/MS	70-120 % for 82 % of the analytes	< 5 µg/kg	[323]
16 PAHs, 12 PCBs and 9 OCPs	Sediment (5 g)	Hexane/acetone, dichloromethane/acetone (20 mL)	$MgSO_4$ (4 g), NaCl (1 g), $Na_3Cit.2H_2O$ (1 g), $Na_2HCit\text{-}1.5H_2O$ (0.5 g)	$MgSO_4$ (150 mg) and PSA (50 mg)	GC–MS	PAHs: 60 – 103 %, PCBs: 76-131 % and OCPs: 81-137 %	0.02 µg/kg	[324]
90 pesticides, 16 PAHs, and 22 PCBs	Organic honey (5 g)	ACN (10 mL)	$MgSO_4$ (4 g), NaCl (1 g), $Na_3Cit.2H_2O$ (1 g), $Na_2HCit\text{-}1.5H_2O$ (0.5 g)	PSA (50 mg)	LC–MS/MS	60-103 %	3 µg/kg	[325]

Table I.10.-(Continued).

Analytes	Sample (amount)	Extraction		Sorbents in the dSPE step	Analytical technique	Recovery (%)	LOQs	Reference
		Solvents (volume)	Salts (amount)					
41 PCBs, 24 PBDEs and 17 PCDD/Fs	Blue mussels (*Mytilus edulis*) and Atlantic salmon (*Salmo salar*) (6 g)	EtOAc (10 mL)	$MgSO_4$ (4 g) and NaCl (2 g)	SPE column: 2 g of silica (deactivated with 2% H_2O), 1 cm of Na_2SO_4	GC-MS	70-100 %	0.05 µg/kg for PCBs, 0.2 µg/kg for PAHs and PBDEs and 1 ng/kg for PCDD/Fs	[326]
6 PCBs, 15 OCPs, 7 PBDEs, 4 PAHs and 17 PFASs	Mussels and clams (5 g)	HPLC-MS: Hexane/acetone 4/1 v/v (10 mL) GC-MS/MS: ACN (10 mL)	$MgSO_4$ (4 g) and NaCl (1 g)	Z-Sep (50 mg)	HPLC-MS and GC-MS/MS	70-120 %	0.005 µg/kg	[327]
7 PAHs, 7 PBDEs, 7 PCBs, 5 PBT chemicals, 7 ECCs	White sturgeon (*Acipenser transmontanus*) (5 g)	ACN (5 mL)	$MgSO_4$ (2 g) and NaCl (0.5 g)	$MgSO_4$ (150 mg), PSA (50 mg), C_{18} (50 mg)	GC-MS	71-98 % for PAHs, 60-107 % for PBDEs and PCBs, 86-107 % for PBTs, and 88-107 % for ECCs	15 µg/kg	[328]
4 pharmaceuticals, 4 pesticides and 4 PCPs	Sludge (10 g)	ACN with 1 % (v/v) HOAc (10 mL)	$MgSO_4$ (4 g) and NaCl (1 g)	(A) C_{18} (50 mg), (B) PSA (50 mg), (C) PSA (50 mg), C_{18} (50 mg), (D) PSA (50 mg), C_{18} (50 mg), chitin (50 mg) and GCB (7,5 mg) per 2 mL extract	LC-ESI-MS/MS	50-120 %	0.1 µg/kg	[329]

ACN: Acetonitrile; GC-MS/MS: Gas chromatography tandem mass spectrometry; LC-MS/MS: Liquid chromatography tandem mass spectrometry; Na_2HCit: Disodium hydrogen citrate; $Na_3Cit_{\cdot 2}H_2O$: Sodium citrate; OCPs: Organochlorine pesticides; OPPs: Organophosphorus pesticides; PAHs: Polycyclic aromatic hydrocarbons; PBDE: Polychlorinated diphenyl ethers; PBT: Persistent bioaccumulative and toxic chemicals; PCBs: Polychlorinated biphenyls; PCDD/Fs: Polychlorinated dibenzodioxins and dibenzofurans; PFAS: Perfluoroalkyl substances; PCPs: Personal care products; PSA: Primary secondary amine; PVD: Physical vapor deposition.

CHAPTER II

OBJECTIVES

II.- OBJECTIVES

Colombia has experienced in recent years a strong growth in the production and export of agri-food products. The country harvests a wide variety of agricultural products as a result of its privileged geographic location, climatic conditions, thermal floors and hydrographic basins. Colombia is unique for the food that it grows and produces for exportation around the world.

Agriculture has an important role in the Colombian economy. It is indeed the second generator of direct and indirect jobs and, for this reason, an increasing number of farmers know that they need to develop strategies to make their crops more productive and competitive in the global markets to meet the current worldwide demand. In this sense, the use of pesticides in modern agriculture is still high due to the advantages it brings in terms of quality and quantity of products. However, the intensive use of pesticides has awoken a special concern due to the risks and effects that they are causing to human life with its consumption and exposure, especially, when the most vulnerable population of the society is at risk. In the particular case of Colombia, between 1998 and 2014, more than 50,000 t of pesticides per year were used in the country, reaching 117,881 t in 2005. However, such amounts decreased down to 37,698 t in 2017 -data most recently available-.

The presence of pesticide residues in food matrices is of great interest nowadays, since it is important to ensure their safe consumption. In particular, it is necessary to identify and quantify pesticide residues, being a challenge for researchers to find and to suitably validate analytical methods that encompass different classes of analytes and agri-food matrices in a single analysis. At the same time, the extraction capacity of such methods should be efficient enough to comply with quantification at trace levels as indicated by current legislation, which is increasing its restrictions. In this sense, the QuEChERS method is one of the procedures most widely applied nowadays as a pesticide multiresidue method in food products. QuEChERS offers clear advantages for the obtaining of precise results, high recoveries, a simple and rapid treatment, reduced use of solvents and reagents, and requires the use of few laboratory materials and space to carry out sample preparation. It is also possible to treat several samples at a time, which increases its throughput. The method uses different reagents that have several purposes: reducing the water content of the extracts, facilitating the analysis of analytes sensitive to alkaline pH, promoting the effective extraction of the analytes to the organic phase, eliminating matrix components (pigments, lipids, sugars, etc.) that interfere/difficult the analysis and preserving the correct performance chromatographic and mass spectrometry systems.

With all the above considerations, the main objective of this PhD Thesis is to develop, validate, and apply "classical" and new versions of the QuEChERS method using GC-MS/MS for the determination of a wide range of pesticides residues in agri-food products of Colombia, especially, in minor tropical fruits, since they have hardly been applied to many of them. To achieve this goal, the following specific objectives were established:

1.- The development of an instrumental GC-MS/MS method for the correct separation and final quantification of the selected pesticide residues in the studied samples.

2.- The modification and comparison of different versions of the QuEChERS method for the extraction of the selected multi-class pesticide residues in different fruit commodities from Colombia, which include the optimization of the sorbent's composition of the dSPE clean-up step.

3.- The validation of the new methodologies proposed through calibration, recovery and repeatability studies as well as the evaluation of the matrix effect in each case.

4.- The analysis of several fruits (mainly tropical fruits) produced and marketed in Colombia (i.e. rose apple/pomarrosa, starfruit/carambola, yoyomo, papayuela, dried strawberry, dried blackberry, dried passion fruit, dried pineapple, dried grapes, dried uchuva, dried lulo, dried guanabana, dried pitahaya, gulupa, cherimoya, and avocado), in order to demonstrate the applicability of the developed methodologies for their systematic analysis, as well as to ensure their safe consumption by the population, and its commercialization according to the current international legislation.

CHAPTER III

EXPERIMENTAL

III.- EXPERIMENTAL

III.1.- Analytical standards, solvents, reagents and solutions

- Analytical standards of the pesticides propoxur (CAS 114-26-1), dichlorvos (CAS 62-73-7), carbofuran (CAS 1563-66-2), carbaryl (CAS 63-25-2), diphenylamine (CAS 122-39-4), chlorpropham (CAS 101-21-3), dichloran (CAS 99-30-9), atrazine (CAS 1912-24-9), lindane (CAS 58-89-9), propyzamide (CAS 23950-58-5), α-hexachlorocyclohexane (HCH, CAS 319-84-6), β-HCH (CAS 319-85-7), chlorpyriphos-methyl (CAS 5598-13-0), parathion-methyl (CAS 298-00-0), alachlor (CAS 15972-60-8), tolclofos-methyl (CAS 57018-04-9), metalaxyl (CAS 57837-19-1), pirimiphos-methyl (CAS 29232-93-7), fenitrothion (CAS 122-14-5), malathion (CAS 121-75-5), chlorpyriphos (CAS 2921-88-2), fenthion (CAS 55-38-9), triadimefon (CAS 43121-43-3), pirimiphos-ethyl (CAS 23505-41-1), heptachlor (CAS 76-44-8), aldrin (CAS 309-00-2), penconazole (CAS 66246-88-6), triflumizole (CAS 99387-89-0), methidathion (CAS 950-37-8), fenamiphos (CAS 22224-92-6), endosulfan A (CAS 958-98-8), myclobutanil (CAS 88671-89-0), dieldrin (CAS 60-57-1), oxyfluorfen (CAS 42874-03-3), buprofezin (CAS 69327-76-0), endrin (CAS 72-20-8), ethion (CAS 563-12-2), propiconazole (CAS 60207-90-1), tebuconazole (CAS 107534-96-3), iprodione (CAS 36734-19-7), EPN (CAS 2104-64-5), pyriproxyfen (CAS 95737-68-1), DDT (CAS 50-29-3), dichlorodiphenyldichloroethane (DDD, CAS 72-54-8), fenvalerate (CAS 51630-58-1), esfenvalerate (CAS 66230-04-4), deltamethrin (CAS 52918-63-5), dichlorodiphenyldichloroethylene (DDE, CAS 72-55-9). were purchased from Sigma-Aldrich Chemie and used without further purification (purity ≥ 95 %). Atrazine-d_5 (CAS 163165-75-1, purity 99.7 %), which was used as procedural IS and TPP (CAS 115-86-6, purity ≥ 99 %), which was used as quality control (QC), were purchased from Sigma-Aldrich Chemie. Table III.1 shows the chemical structure, molecular formulas and some physico-chemical properties of the pesticides studied in the present PhD Thesis ordered according to the elution time.

- 3-ethoxy-1,2-propanediol (ethylglycerol), L-gulonic acid-γ-lactone (gulonolactone), D-sorbitol and shikimic acid (all with purity ≥ 95.0 %) were also obtained from Sigma-Aldrich Chemie. A solution containing 100 g/L of ethylglycerol, 10 g/L of gulonolactone,10 g/L of

D-sorbitol and 5 g/L of shikimic acid was prepared in 4/1 (v/v) ACN/water containing 0.05 % (v/v) of formic acid as analyte protectants solution.

- ACN GC-MS grade, toluene, EtOAc, MeOH GC-ECD/FID grade, glacial HOAc, hydrochloric acid (HCl) and formic acid, were from Merck (Darmstadt, Germany).
- Anhydrous $MgSO_4$, NaOAc, NaCl, NH_4HCOO, sodium hydrogencitrate sesquihydrate and sodium citrate tribasic dehydrate, all with purity higher than 99.5 %, were purchased from Sigma-Aldrich Chemie.
- For dSPE clean-up, Supel^{TM} QuE (QuEChERS) PSA/C_{18} pre-weighed mixtures containing 150 mg of anhydrous magnesium sulphate, 50 mg of PSA and 50 mg of C_{18} in 2 mL mini-centrifuge tubes were from Supelco.
- GCB of 120/400 mesh was from Supelco.
- Milli-Q water (resistivity 1.82 MΩ/cm at 25 °C) was obtained from a Synergy® water purification system Millipore.
- Stock solutions of each analyte of 1000 mg/L were precisely prepared in toluene and stored in amber glass vials at -20 °C. For spiking of samples and calibration purposes, pesticide standard mixtures of different concentrations were prepared in ACN containing 0.05 % (v/v) of formic acid. Individual stock solutions of TPP of 1050 mg/L and of atrazine-d_5 of 750 mg/L were also prepared.

III.2.- Laboratory ware

- Syringes of 10 µL (needle of 42 mm length, 0.63 mm o.d. and cone tip) were from Shimadzu.
- Beakers of 50, 100, 250, 500 and 1000 mL were from Schott Duran.
- Fused silica capillary column SH-Rxi-5Sil MS (30 m × 0.25 mm i.d., 0.25 µm) was from Shimadzu.
- Amber glass vials of 2 mL, with in-insert, screw thread and polytetrafluoroethylene (PTFE)/silicone septa were from Supelco.

- Glass bottles of 500 and 1000 mL with polypropylene (PP) screw caps were from VWR International.
- Erlenmeyer flasks of 50 and 100 mL were from Duran.
- Pasteur pipettes were acquired from VWR International.
- Polyethylene terephthalate (PET) syringe filters with a pore size of 0.45 µm and 25 mm diameter (Chromafil® Xtra PET-45/25) and with a pore size of 0.20 µm and 15 mm diameter (Chromafil® Xtra PET-20/15) for polar and non-polar media were from Macherey-Nagel.
- PP centrifuge tubes of 15 and 50 mL were from NEST.
- Volumetric flasks of 10, 25, 50, 100 and 250 mL (class A type) were from Schott Duran.

III.3.- Glassware cleaning

Non-volumetric glassware was washed with tap water and soap, followed by Milli-Q water and dried in an oven at 120 ºC for 1 hour. After that, it was calcined at 550 ºC for 4-5 hours in a high temperature furnace.

Volumetric glassware was washed with tap water, followed by Milli-Q water and three times more with MeOH of high purity. Finally, it was dried at room temperature.

III.4.- Equipment

III.4.1.- Instruments

- PR-series analytical balance with a maximum weighing capacity of 220 g and 0.1 mg of resolution was from OHAUS.
- Manual adjustable Transferpette® S micropipettes with disposable plastic tips with different volume ranges (2-20 µL, 10-100 µL, 20-200 µL, 100-1000 µL and 500-5000 µL) were from Brand.
- The GC-QqQ-MS/MS analyses were carried out using a Shimadzu GCMS-TQ8040 system with an electron ionisation interface. For sample injection, an autosampler AOC 20i/s from Shimadzu was also used (Figure III.1).

III.4.2.- Apparatus

- Z 206 centrifuge with time and speed control with a maximum rotation speed of 6000 rpm (3000 x g) was from Hermle.
- Tube roller was from Scilogex.
- Lab Dancer vortex with a fixed speed 2800 rpm was from Scilogex.
- Synergy® water purification system-UV was from Millipore.
- Ultrasons-512 ultrasonic bath (1 L capacity) of 50/60 kHz was from Selecta.

Figure III.1.- Photograph of the GC-QqQ-MS/MS system used in this PhD Thesis.

III.4.3.- Software

- *Microsoft® Office Excel* 365 used for data processing including calibration curves preparation, recovery data calculations, etc.
- *Microsoft® Office Power Point* 365 was used for figures preparation.
- *GCMS Real Time Analysis* software was used for instrument control and *GCMS Postrun Analysis* software for data processing.
- *Chemdraw Professional 18.2* used for the drawing of the pesticide structures.

Table III.1.- Chemical structure and properties of the studied pesticides, IS and QC.

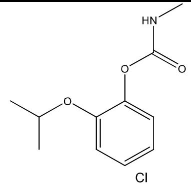
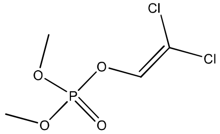
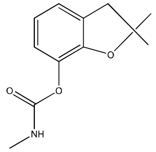
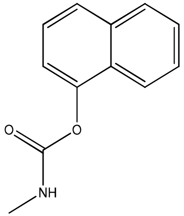
Analyte	Structure	Molecular formula	MM (g/mol)	Pesticide family	Log K_{OW}	Melting point – boiling point (°C)
Propoxur		$C_{11}H_{15}NO_3$	209.24	Carbamate	0.14	90 - descomposes on destilation
Dichlorvos		$C_4H_7C_{12}O_4P$	220.98	OPP	1.90	26 - descomposes before boliling
Carbofuran		$C_{12}H_{15}NO_3$	221.26	Carbamate	1.80	153.1- 254.0
Carbaryl		$C_{12}H_{11}NO_2$	201.22	Carbamate	2.36	138 - 210

Table III.1.- (Continued).

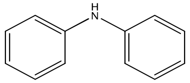
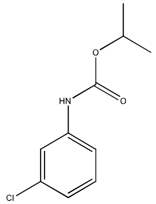
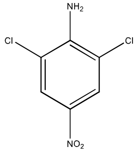
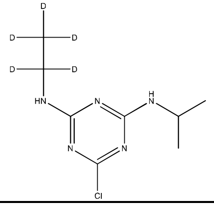
Analyte	Structure	Molecular formula	MM (g/mol)	Pesticide family	Log K_{OW}	Melting point – boiling point (°C)
Diphenylamine		$C_{12}H_{11}N$	169.23	Amine	3.82	53 - 298.8
Chlorpropham		$C_{10}H_{12}ClNO_2$	213.66	Carbamate	1.18	36 - 256
Dichloran		$C_6H_4Cl_2N_2O_2$	207.01	Chlorophenyl	2.80	193.2 - 191
Atrazine-d$_5$		$C_8H_9D_5ClN_5$	220.79	Triazine	2.70	175.8 - 203

Table III.1.- (Continued).

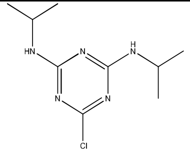
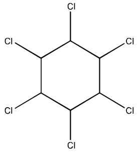
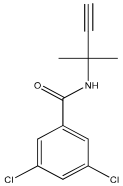
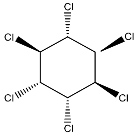
Analyte	Structure	Molecular formula	MM (g/mol)	Pesticide family	Log K_{OW}	Melting point – boiling point (°C)
Atrazine		$C_8H_{14}ClN_5$	215.68	Triazine	2.70	175.8 - 205
Lindane		$C_6H_6Cl_6$	290.82	OCP	3.50	112.9 - 323.4
Propyzamide		$C_{12}H_{11}Cl_2NO$	256.13	Benzamide	3.27	156 - 283
β-HCH		$C_6H_6Cl_6$	290.83	OCP	-	193.2 - 325

Table III.1.- (Continued).

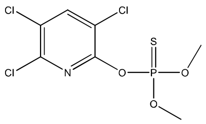
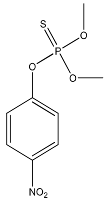
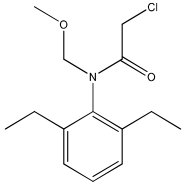
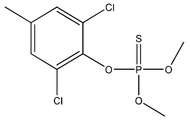
Analyte	Structure	Molecular formula	MM (g/mol)	Pesticide family	Log K_{OW}	Melting point – boiling point (°C)
Chlorpyriphos-methyl		$C_7H_7Cl_3NO_3PS$	322.53	OPP	4.00	46 - decomposes before boiling
Parathion-methyl		$C_8H_{10}NO_5PS$	263.21	OPP	3.00	35.5 - 154
Alachlor		$C_{14}H_{20}ClNO_2$	269.77	Chloroacetamide	3.09	41 - 100
Tolclofos-methyl		$C_9H_{11}Cl_2O_3PS$	301.13	Chlorophenyl	3.80	79 - decomposes before boiling

Table III.1.- (Continued).

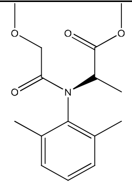
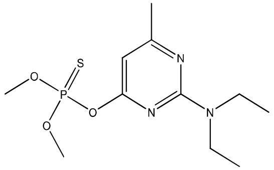
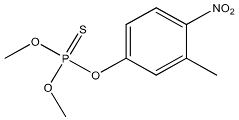
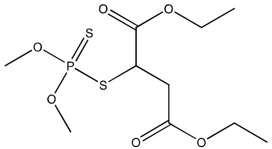
Analyte	Structure	Molecular formula	MM (g/mol)	Pesticide family	Log K_{OW}	Melting point – boiling point (°C)
Metalaxyl		$C_{15}H_{21}NO_4$	279.33	Phenylamide	1.75	72.0 - 295
Pirimiphos-methyl		$C_{11}H_{20}N_3O_3PS$	305.33	OPP	4.20	20.8 - decomposes before boiling
Fenitrothion		$C_9H_{12}NO_5PS$	277.23	OPP	3.32	116 - decomposes before boiling
Malathion		$C_{10}H_{19}O_6PS_2$	330.36	OPP	2.75	-20 - decomposes before boiling

Table III.1.- (Continued).

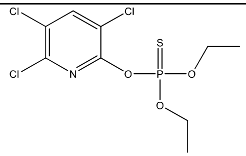
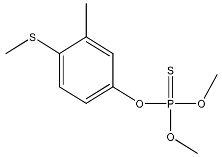
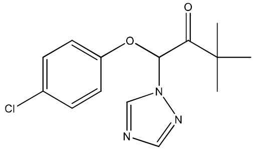
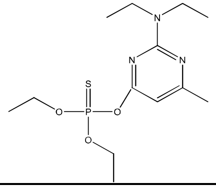
Analyte	Structure	Molecular formula	MM (g/mol)	Pesticide family	Log K_{OW}	Melting Point - boiling point (°C)
Chlorpyriphos		$C_9H_{11}Cl_3NO_3PS$	350.58	OPP	4.70	42 - decomposes before boiling
Fenthion		$C_{10}H_{15}O_3PS_2$	278.33	OPP	4.84	7.5 - 90
Triadimefon		$C_{14}H_{16}ClN_3O_2$	293.80	Triazole	3.18	82.3 - decomposes before boiling
Pirimiphos-ethyl		$C_{13}H_{24}N_3O_3PS$	305.34	OPP	4.85	15 - (-)

Table III.1.- (Continued).

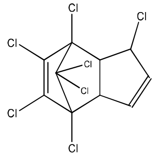
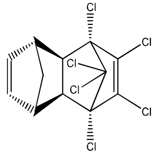
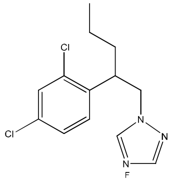
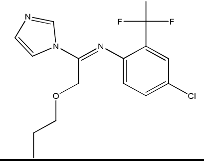
Analyte	Structure	Molecular formula	MM (g/mol)	Pesticide family	Log K_{OW}	Melting Point - boiling point (°C)
Heptachlor		$C_{10}H_5Cl_7$	373.32	OCP	5.44	95 - 135
Aldrin		$C_{12}H_8Cl_6$	364.91	OCP	6.50	104 - 145
Penconazole		$C_{13}H_{15}Cl_2N_3$	284.18	Triazole	3.72	60.3 - (-)
Triflumizole		$C_{15}H_{15}ClF_3N_3O$	345.75	Imidazole	4.77	63 - decomposes before boiling

Table III.1.- (Continued).

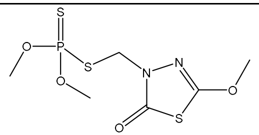
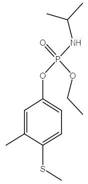
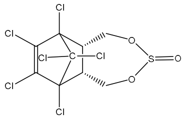
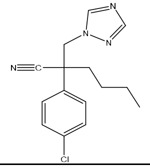
Analyte	Structure	Molecular formula	MM (g/mol)	Pesticide family	Log K_{OW}	Melting Point – boiling point (°C)
Methidathion		$C_6H_{11}N_2O_4PS_3$	302.3	OPP	2.57	39.5 - (-)
Fenamiphos		$C_{13}H_{22}NO_3PS$	303.36	OPP	3.30	46 - decomposes before boiling
Endosulfan A		$C_9H_6Cl_6O_3S$	406.93	OCP	4.75	80 - 106
Myclobutanil		$C_{15}H_{17}ClN_4$	288.78	Triazole	2.89	70.9 - 390.8

Table III.1.- (Continued).

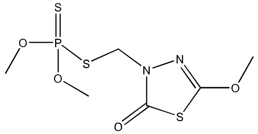
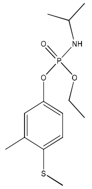
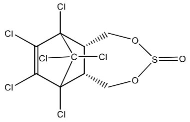
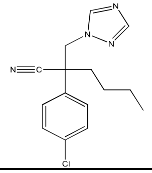
Analyte	Structure	Molecular formula	MM (g/mol)	Pesticide family	Log K_{OW}	Melting Point – boiling point (°C)
Methidathion		$C_6H_{11}N_2O_4PS_3$	302.3	OPP	2.57	39.5 - (-)
Fenamiphos		$C_{13}H_{22}NO_3PS$	303.36	OPP	3.30	46 - decomposes before boiling
Endosulfan A		$C_9H_6Cl_6O_3S$	406.93	OCP	4.75	80 - 106
Myclobutanil		$C_{15}H_{17}ClN_4$	288.78	Triazole	2.89	70.9 - 390.8

Table III.1.- (Continued).

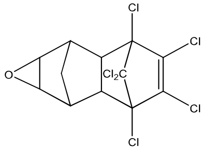
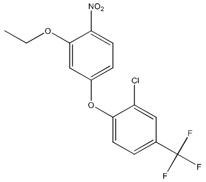
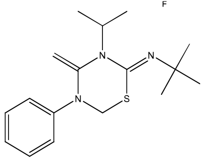
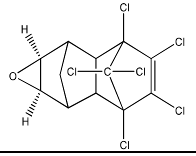
Analyte	Structure	Molecular formula	MM (g/mol)	Pesticide family	Log K_{OW}	Melting point – boiling point (°C)
Dieldrin		$C_{12}H_8Cl_6O$	380.91	OCP	3.70	177 - 385
Oxyfluorfen		$C_{15}H_{11}ClF_3NO_4$	361.70	Diphenyl ether	4.73	85.3 - 358.2
Buprofezin		$C_{16}H_{23}N_3OS$	305.44	Unclassified	4.93	105.1 - 252
Endrin		$C_{12}H_8Cl_6O$	380.91	OCP	3.20	200 - 245

Table III.1.- (Continued).

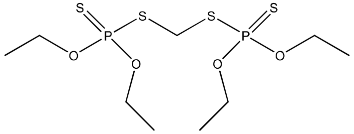
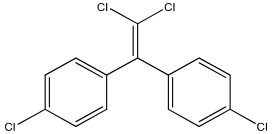
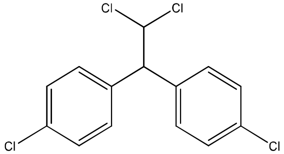
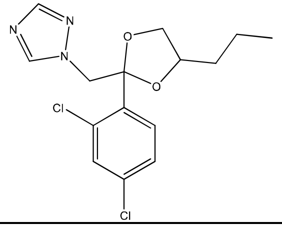
Analyte	Structure	Molecular formula	MM (g/mol)	Pesticide family	Log K_{OW}	Melting point – boiling point (°C)
Ethion		$C_9H_{22}O_4P_2S_4$	384.48	OPP	5.07	-12 - 165
DDE		$C_{14}H_8Cl_4$	318.02	OCP	6.51	89 - 336
DDD		$C_{14}H_{10}Cl_4$	320.04	OCP	3.72	110 - 350
Propiconazole		$C_{15}H_{17}Cl_2N_3O_2$	342.22	Triazole	3.70	-23 - decomposes before boiling

Table III.1.- (Continued).

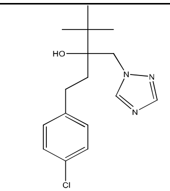
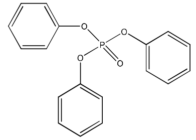
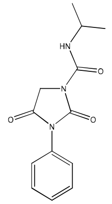
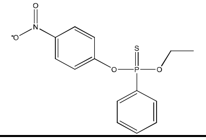
Analyte	Structure	Molecular formula	MM (g/mol)	Pesticide family	Log K_{OW}	Melting point – boiling point (°C)
Tebuconazole		$C_{16}H_{22}ClN_3O$	307.82	Triazole	6.02	105 - decomposes before boiling
TPP		$C_{18}H_{15}O_4P$	326.30	OPP	4.59	50.5 - 370
Iprodione		$C_{13}H_{13}Cl_2N_3O_3$	330.17	Dicarboximide	3.00	134 - -
EPN		$C_{14}H_{14}NO_4PS$	323.30	OPP	5.02	34.5 - 215

Table III.1.- (Continued).

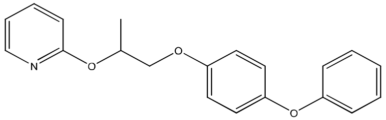
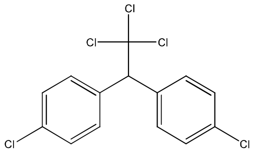
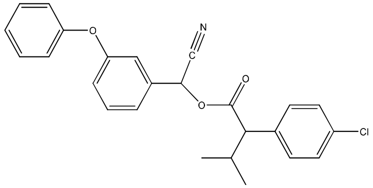
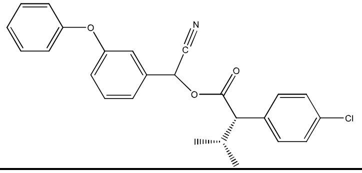
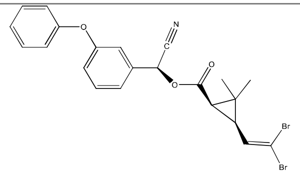
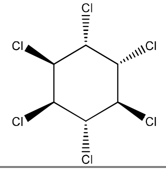
Analyte	Structure	Molecular formula	MM (g/mol)	Pesticide family	Log K_{OW}	Melting point – boiling point (°C)
Pyriproxyfen		$C_{20}H_{19}NO_3$	321.37	Hormone	5.37	49 - 318
DDT		$C_{14}H_9Cl_5$	354.50	OCP	6.91	109 - 185
Fenvalerate		$C_{25}H_{22}ClNO_3$	419.90	Pyrethroid	5.01	39.5 - decompose on destilation
Esfenvalerate		$C_{25}H_{22}ClNO_3$	419.91	Pyrethroid	6.24	59.1 - 356

Table III.1.- (Continued).

Analyte	Structure	Molecular formula	MM (g/mol)	Pesticide family	Log K_{OW}	Melting point – boiling point (°C)
Deltamethrin		$C_{22}H_{19}Br_2NO_3$	505.2	Pyrethroid	4.60	101 - decomposes before boiling
α-HCH		$C_6H_6Cl_6$	290.83	Organochlorine	3.82	159 - 288

Data taken from IUPAC PPDB-Pesticides properties database [330] and PubChem [331].

III.5.- Samples

In this PhD Thesis different fruits samples were analysed:

- *Section IV.1:*

Rose apple/pomarrosa, starfruit/carambola, yoyomo and papayuela were purchased from local food stores located in the city of Bogota, Colombia. Approximately, 1 kg of each sample was crushed, homogenized and stored under dark conditions at -18 °C.

- *Section IV.2:*

Dried strawberry, blackberry, passion fruit, pineapple and grapes were purchased from local food stores in Bogota. Since the dried fruits were already milled and homogenized, approximately 1 kg of each were directly used or previously mixed in equal proportions. For this purpose, 250 g of each of the dehydrated fruits were weighed, mixed in a glass container and stored under dark at room temperature.

- *Section IV.3:*

Approximately, 1 kg of dried uchuva, lulo, guanabana and pitahaya were purchased from local food stores in Bogota. Each dried fruit sample, which was already milled and homogenized, was stored in a glass container under dark at room temperature.

- *Section IV.4:*

Gulupa and chirimoya samples were purchased from local food stores located in the city of Bogotá. One kilogram of each sample was crushed, homogenized and stored under dark conditions at -18 °C.

III.6.- Chromatographic analysis

III.6.1.- GC-QqQ-MS/MS analysis

GC-QqQ-MS/MS was performed in a Shimadzu GCMS-TQ8040 system using ultrahigh purity helium as the carrier gas at 1.2 mL/min constant flow rate applying the following temperature program. The GC oven was initially maintained for 1 min at 50 °C, and then the temperature was increased to 180 °C at 25 °C/min. Then, it was increased to 230 °C at 5 °C/min and finally taken to 290 °C at 25 °C/min and held at that temperature for 6 min.

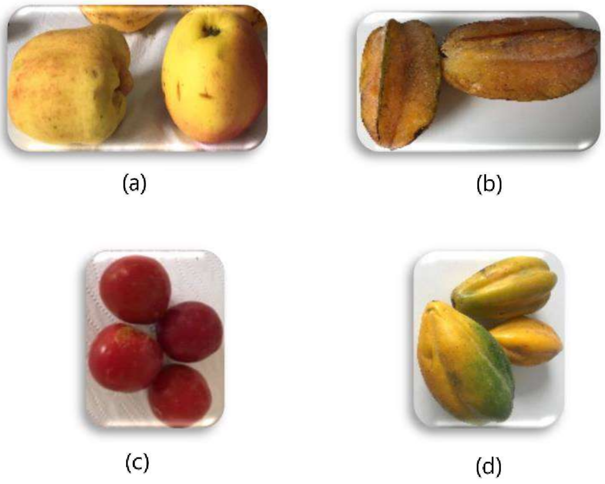
Total analysis time was 24.6 min. The MS interface temperature was 250 °C while the ion source was set at 300 °C. The injection was performed at 250 °C in the splitless mode, being the injection volume 1 µL. Between injections, the 10 µL syringe was washed with MeOH, EtOAc and ACN (a single rinse with each solvent was developed in each case).

III.7.- Sample pre-treatment procedures

III.7.1.- Extraction of pesticides from rose apple/pomarrosa, starfruit/carambola, yoyomo and papayuela (Section IV.1)

Fifteen grams of the homogenised samples were weighed into a 50 mL centrifuge tube and the pesticides and atrazine-d_5 solutions were carefully mixed and agitated in a tube roller for 5 min at 70 rpm to facilitate the contact of the sample with the analytes and the IS. Then, 15 mL of ACN containing 1 % (v/v) of HOAc were added and the sample was energetically hand-shaken for 2 min. Afterwards, to induce phase separation and pesticide partitioning, 6 g of anhydrous magnesium sulphate and 1.5 g of sodium acetate were added. Then, the mixture was vigorously shaken in a vortex for 10 s, agitated in a tube roller for 5 min at 70 rpm, and centrifuged for 5 min at 4000 rpm (see Figure III.2). Then, 1 mL of the supernatant was transferred to a 2-mL centrifuge tube that contained 50 mg of PSA, 150 mg of anhydrous magnesium sulphate, 50 mg of C_{18} and 7.5 mg of GCB. The tube was closed and immediately agitated in a tube roller for 5 min at 70 rpm to facilitate the contact of the salts and clean-up sorbents with the ACN extract. Next, centrifugation was carried out for 5 min at 4400 rpm. Two hundred microliters of the supernatant were taken and 20 µL of the analyte protectants mixture and 50 µL of the TPP solution were added. Finally, 1 µL of the mixture was injected in the GC-QqQ-MS/MS system.

For calibration, mixed standards were prepared at 5, 10, 25, 75, 200, 400 and 600 ng/g sample equivalents for the pesticides and 200 ng/g for the IS atrazine-d_5. For QC purposes, TPP solution was also added to yield a final concentration of 200 ng/g. An analyte protectants solution containing 10,000 ng/L of ethyl-glycerol, 1000 ng/L of gulonolactone, 1000 ng/L of d-sorbitol and 500 ng/L of shikimic acid was prepared in 4/1 (v/v) ACN/water containing 0.5 % (v/v) of formic acid were added to the final extract (final volume of 270 µL), just before their injection in the GC-QqQ-MS/MS system.



(a) (b)

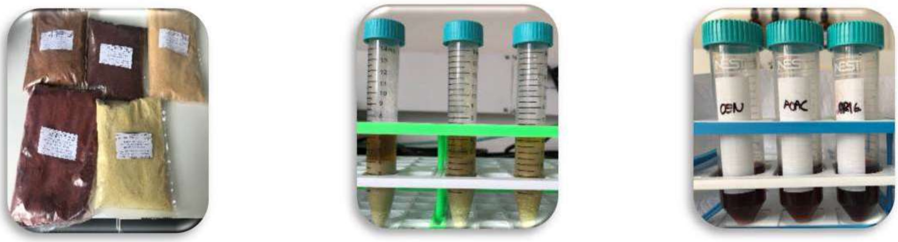
(c) (d)

Figure III.2.- Photographs of (a) rose apple/pomarrosa, (b) starfruit/carambola, (c) yoyomo and (d) papayuela, respectively.

III.7.2.- Extraction of pesticides from dried strawberry, blackberry, passion fruit, pineapple and grapes (Section IV.2)

In this section, three different methods were compared: A) Original QuEChERS method (unbuffered); B) OAC 2007.01 official method (buffered); and C) CEN 15662 official method (buffered). The three methods consisted of the following steps: 1) 5 g of a mixture of dried fruits composed of equal amounts of strawberry, blackberry, passion fruit, pineapple and grapes, or each of them separately (see Figure III.3), were introduced in a PP falcon tube of 50 mL; for recovery purposes, spikes were made to yield 25, 200 and 400 μg/kg for the pesticides, and 200 μg/kg for the IS, in the sample. 2). Thereafter, 10 mL of ACN were added for both the original and CEN 15662 methods, or 10 mL of ACN with 1 % (v/v) of HOAc for the AOAC 2007.01 method, and 10 mL of water for all methods. Then, the sample was thoroughly shaken employing an automated shaker for 1 h. 3) Next, 4 g of anhydrous magnesium sulphate and 1 g of sodium chloride were added for the original version, or 6 g of anhydrous magnesium sulphate and 1.5 g of sodium acetate for the AOAC 2007.01 version, or 4 g of anhydrous magnesium sulphate, 1 g of sodium chloride, 1 g of sodium citrate tribasic dehydrate and 0.5 g of sodium hydrogencitrate sesquihydrate for the CEN version. Then, the sample was vigorously shaken for 5 min by hand and centrifuged for 5 min at 4400 rpm. 4) 1 mL of the supernatant was transferred to a 2-mL tube containing 150 mg of anhydrous magnesium sulphate, 50 mg of PSA and 50 mg of C$_{18}$ for the original and AOAC 2007.01 methods, or 150 mg of anhydrous magnesium sulphate, 25 mg of PSA and 25 mg of C$_{18}$ for the CEN 15662 method. Then, the tube was vortexed for 30 s and centrifuged at 4400 rpm for 5 min. 5) Afterwards, 200 µL of the supernatant were transferred to the appropriately labelled autosampler vials and 50 µL of the TPP solution and 20 µL of the analytes protectants mixture, both in ACN, were added (total volume of 270 µL). 6). Finally, 1 µL was injected in the GC-QqQ-MS/MS system.

For calibration, mixed standards were prepared at 5, 10, 25, 75, 200, 400 and 600 µg/kg sample equivalents for the pesticides and 200 µg/kg for the IS atrazine-d$_5$. For QC purposes, TPP solution was also added to yield a final concentration of 200 µg/kg. An analyte protectants solution containing 10,000 ng/L of ethyl-glycerol, 1,000 ng/L of gulonolactone, 1,000 ng/L of d-sorbitol and 500 ng/L of shikimic acid was prepared in 4/1 (v/v) ACN/water containing 0.5 % (v/v) of formic acid and it was added to the final extract (final volume of 270 µL), just before their injection in the GC-QqQ-MS/MS system.



Dried fruits First partitioning step dSPE step

Figure III.3.- Photograph of the dried fruit samples analysed in this PhD Thesis as well as the extracts of the first partitioning step and dSPE step of the QuEChERS method applied to a mixture of the five fruits.

III.7.3.- Extraction of pesticides from uchuva, lulo, guanabana and pitahaya (Section IV.3)

Five grams of dried uchuva, dried lulo, dried guanabana and dried pitahaya were properly spiked for recovery studies, and slightly vortexed. Next, 10 mL of ACN with 1 % (v/v) of HOAc and 10 mL of water were added, and the sample was shaken for 1 h employing an automated shaker. Then, 6 g of anhydrous magnesium sulphate and 1.5 g of sodium acetate were added, and the sample was hand-shaken for 5 min and centrifuged for 5 min at 4400 rpm. Subsequently, the dSPE step was carried out transferring 1 mL of the supernatant to a 2-mL tube containing 150 mg of anhydrous magnesium sulphate, 50 mg of PSA and 50 mg of C_{18}. Immediately, the tube was vortexed for 30 s and centrifuged at 4400 rpm for 5 min. Afterwards, 200 µL of the supernatant were transferred to the appropriate vials and 50 µL of the TPP solution and 20 µL of the mixture of analytes protectants were added (total volume of 270 µL). Finally, 1 µL was injected in the GC-QqQ-MS/MS equipment.

For calibration, mixed standards were prepared at 5, 10, 25, 75, 200, 400 and 600 µg/kg sample equivalents for the pesticides and 200 µg/kg for the IS atrazine-d_5. For QC purposes, TPP solution was also added to yield a final concentration of 200 µg/kg. An analyte protectants solution containing 10,000 ng/L of ethyl-glycerol, 1000 ng/L of gulonolactone, 1000 ng/L of d-sorbitol and 500 ng/L of shikimic acid was prepared in 4/1 (v/v) ACN/water containing 0.5 % (v/v) of formic acid.

Figure III.4.- Photographs of dried (a) pitahaya, (b) uchuva, (c) lulo and (d) guanabana samples analysed in this PhD Thesis respectively.

III.7.4.- Extraction of pesticides from cherimoya and gulupa (Section IV.4)

The AOAC 2007.01 method consisted in the addition of 10 mL of ACN containing 1 % (v/v) of HOAc to 10 g of the homogenized samples and an energetic agitation by hand for 30 s. Then, 6 g of anhydrous $MgSO_4$ and 1.5 g of sodium acetate were added, and the sample was agitated in a tube roller at 70 rpm for 5 min and centrifuged for 5 min at 4400 rpm. One mL of the supernatant was transferred to a 2-mL tube containing 150 mg of anhydrous $MgSO_4$, 50 mg of PSA and 50 mg of C_{18} (different amounts of GCB were added). The tube was immediately closed, shaken in a vortex for 10 s, and agitated in a tube roller at 70 rpm for 5 min. Afterwards, centrifugation was carried out for 5 min at 4400 rpm.

The ammonium formate version of the method consisted in the addition of 10 mL of ACN, manual agitation for 30 s, addition of 5 g of ammonium formate plus agitation in a tube roller at 70 rpm for 5 min. One mL of the supernatant phase was transferred to a 2 mL centrifuge tube that contained 150 mg of anhydrous $MgSO_4$, 50 mg of PSA, 50 mg of C_{18} and 15 mg of GCB for cherimoya samples and 25 mg for gulupa (optimum GCB amounts). The tube was immediately closed, vigorously shaken in a vortex for 10 s and agitated in a tube roller at 70 rpm for 5 min. Afterwards, centrifugation was carried out for 5 min at 4400 rpm.

For both methods, 200 µL of the final supernatant were introduced in 2-mL vials and 20 µL of the analyte protectants mixture and 50 µL of the TPP solution in ACN were added. (see Figure III.5).

For calibration, mixed standards were prepared at 5, 10, 25, 50, 100, 200, 400 and 600 µg/kg sample equivalents for the pesticides and 200 µg/kg for the IS atrazine-d_5. For QC purposes, TPP solution was also added to yield a final concentration of 200 µg/kg. An analyte protectants solution containing 10,000 ng/L of ethyl-glycerol, 1000 ng/L of gulonolactone, 1000 ng/L of d-sorbitol and 500 ng/L of shikimic acid was prepared in 4/1 (v/v) ACN/water containing 0.5 % (v/v) of formic acid.

Figure III.5.- Photograph of gulupa (left) and cherimoya (right) samples analysed in this PhD Thesis.

III.7.5.- Determination of the coextracted material (Sections IV.2-IV.4)

For the determination of the coextracted material, a 1 mL aliquot of the supernatant was collected after applying the whole QuEChERS method. This extract was evaporated to dryness using a water bath at 40 ºC under a stream of air and the tube was left in the oven at 100 ºC for 1 h. It was allowed to cool for 20 min in a desiccator and weighed. This procedure was performed in triplicate for each of the samples. A similar procedure was also developed considering 1 mL of the ACN extract of the first partitioning step.

CHAPTER IV

RESULTS AND DISCUSSION

IV.- RESULTS AND DISCUSSION

In the following pages, a brief description of the results and discussion section of each paper, as well as a copy of them, will be presented.

IV.1.- High-throughput analysis of pesticides in minor tropical fruits from Colombia

*D.A. Varela-Martínez, M.Á. González-Curbelo**, J. González-Sálamo, J. Hernández-Borges**

Food Chemistry, 2019, 280, 221-230

The aim of this first work was the development and validation of a multiresidue method for the analysis of 35 multiclass representative pesticides in four minor tropical fruits from Colombia, i.e. rose apple/pomarrosa (*Syzygium malaccense*), starfruit/carambola (*Averrhoa carambola*), yoyomo (*Spondias purpurea*) and papayuela (*Vasconcellea pubescens*), as well as the analysis of different samples of each type. Sample preparation was developed applying the AOAC 2007.1 QuEChERS method which uses acid acid/acetate buffer, while the final analysis was carried out by GC-QqQ-MS/MS, using atrazine-d_5 as internal standard of the method and TPP as QC of the injection.

Since co-extracted matrix components may cause an inaccurate quantification of the target analytes and a decrease of the method's ruggedness as well as low analyte detectability, matrix-matched calibration was developed for each sample matrix. An analyte protectants mixture of 3-ethoxy-1,2-propanediol, L-gulonic acid γ-lactone, D-sorbitol and of shikimic acid was used for building pure both solvent and matrix-matched calibration curves. Determination coefficients higher than or equal to 0.9900 were obtained for all the pesticides and samples. Matrix effect evaluation revealed that for pomarrosa, 27 pesticides out of 35 showed acceptable matrix effect percentages, while 18 were for yoyomo and papayuela and 16 for carambola. Therefore, and although most pesticides showed acceptable matrix effects, matrix-matched calibration was found necessary. The effectiveness of the addition of analytes protectants was also evaluated, finding that the errors due to matrix-effects were dramatically reduced for all the pesticides and matrices, such reduction was even more remarkable for papayuela and pomarrosa and for some of the selected pesticides.

Concerning the trueness of the method, recovery values were determined at three concentration levels, finding that most pesticide analytes met the acceptability criteria of 70-120 % recovery percentages with RSD ≤ 20 %.

The lowest calibration levels (LCLs) of the method were 5 µg/kg for all pesticides in the studied matrices which are in accordance (or even lower) with the “default” and standard MRL of 10 µg/kg applied, for example, by the EU legislation, since there are not specific MRLs established in the Colombian legislation.

Several samples of each type bought in different parts of the city of Bogotá were analysed, finding residues of chlorpyrifos, chlorpyrifos-methyl and fenitrothion in some of the pomarrosa samples below the LCL while diphenylamine was also found in one yoyomo sample, also below the LCL.

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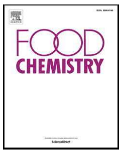

High-throughput analysis of pesticides in minor tropical fruits from Colombia

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ABSTRACT

In this work, a method has been applied and validated for the determination of a group of 35 multiclass pesticides in the minor tropical fruits rose apple/pomarrosa (*Syzygium malaccense*), starfruit/carambola (*Averrhoa carambola*), yoyomo (*Spondias purpurea*) and papayuela (*Vasconcellea pubescens*) cultivated and exported in Colombia. The AOAC 2007.1 QuEChERS method, that uses an acetic acid/acetate buffer, was applied together with gas chromatography coupled to a triple quadrupole mass spectrometer. The method was validated in terms of calibration, recovery at three levels of concentration and matrix effects (MEs). A mixture of analyte protectants was also used. A good linearity was obtained in all cases, while the study of the ME revealed the need of developing matrix-matched calibration for many pesticides. Recovery values were in the range 70–120% with relative standard deviation values less than 20% for most of the pesticides studied. The lowest calibration level was 5 μg/kg. Several samples of each type were analysed.

1. Introduction

Tropical fruits, which demand has increased in recent years as a result of their particular characteristics (flavour, vitamins and antioxidants content, etc.) (FAO, Document BA/TF03/15, 2003), have their origin in the tropics and subtropics, although their cultivars are not currently confined to such regions as long as particular geographic features make it possible. Nowadays, there are hundreds of edible tropical fruits around the world, some of them well-known and exported worldwide, while others are only recognised and appreciated locally. However, such tendency may revert if suitable horticultural practices and promotional efforts in market development are carried out, as it has happened in the last years for some of them. The majority of tropical fruits are consumed fresh, although processing industries have also been established. Among them, mango, pineapple, banana, papaya and avocado are the tropical fruits mostly produced and commercialised worldwide while the rest are frequently designated as minor tropical fruits. According to the Food and Agricultural Organization (FAO) of the United Nations, approximately 312 million of tons of major tropical fruits were produced in 2016 (FAOSTAT, 2018), which clearly shows their importance.

In the last years, Colombia has experienced a strong growth in the productivity and export of agricultural products (Ministry of Agriculture and Rural Development of Colombia, 2018). Among them, tropical fruits are especially relevant due to their variety and specific and identifying nature. This has made Colombia the ninth largest supplier of tropical fruits in the world in 2016 (The Statistics Portal, 2018), being Europe the main destination of these products. Among the different tropical fruits cultivated in the country, minor fruits such as rose apple/pomarrosa (*Syzygium malaccense*), starfruit/carambola (*Averrhoa carambola*), yoyomo (*Spondias purpurea*) and papayuela (*Vasconcellea pubescens*) have a high commercial value in national and international markets.

Like any other cultivar, pesticides are also applied to fight the different pests that affect minor tropical fruits (Sonke, Gillett, & Leppla, 2005). However, since such fruits are cultivated in a lesser extent, there is a minor market of pesticides and not enough attention is frequently paid to the development of analytical methods for the determination of pesticides in such matrices, and neither for the evaluation of pesticide content in them (Muller, 2007). Furthermore, very frequently, a complete list of authorised pesticides and maximum residue limits (MRLs) is not available. In the case of Colombia, as well as other Latin American countries, MRLs established by the Codex Alimentarius have been adopted (Codex Alimentarius. Food and Agricultural Organization of

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Table 1
Retention times, quantifier and qualifier transitions in GC-QqQ-MS/MS analyses of the selected pesticides.

Analyte	Retention time (min)	Standard deviation (n = 45)	Quantifier transition (*m/z*)	Collision energy (V)	Qualifier transition 1 (*m/z*)	Collision energy (V)	Qualifier transition 2 (*m/z*)	Collision energy (V)
Propoxur	5.47	0.01	110 → 64	20	152 → 110	10	110 → 82	15
Dichlorvos	5.88	0.03	109 → 79	10	185 → 109	20	185 → 79	25
Carbofuran	6.25	0.02	164 → 149	10	149 → 103	15	149 → 103	15
Carbaryl	7.68	0.02	116 → 115	5	144 → 115	25	144 → 116	5
Diphenylamine	8.60	0.01	168 → 167	10	169 → 168	5	169 → 167	5
Clorpropham	8.78	0.02	213 → 171	5	213 → 127	15	127 → 90	15
Dicloran	9.57	0.02	206 → 176	10	124 → 97	10	176 → 124	10
Atrazine-d5	9.68	0.01	205 → 127	10	220 → 178	5	205 → 178	5
Atrazine	9.71	0.01	215 → 173	5	215 → 200	10	200 → 173	10
Lindane	10.03	0.01	183 → 181	5	219 → 181	10	181 → 109	25
Propyzamide	10.08	0.01	173 → 145	15	175 → 173	5	173 → 109	25
Chlorpyrifos-methyl	11.27	0.01	288 → 286	5	286 → 93	25	286 → 125	25
Parathion-methyl	11.43	0.02	263 → 109	15	109 → 79	10	263 → 125	10
Alachlor	11.45	0.01	188 → 160	10	160 → 132	15	188 → 146	10
Tolclofos-methyl	11.45	0.01	265 → 250	15	267 → 265	5	265 → 125	5
Metalaxyl	11.61	0.02	206 → 132	20	160 → 146	10	206 → 160	15
Pirimiphos-methyl	11.95	0.01	290 → 233	10	305 → 290	10	290 → 276	10
Fenitrothion	12.07	0.01	277 → 260	5	277 → 109	20	125 → 109	15
Malathion	12.25	0.02	127 → 99	5	173 → 127	5	125 → 93	5
Chlorpyrifos	12.42	0.01	314 → 258	15	199 → 171	15	197 → 97	15
Fenthion	12.58	0.01	278 → 109	20	278 → 137	10	278 → 245	10
Triamidefon	12.78	0.02	208 → 181	10	208 → 128	15	128 → 85	10
Pirimiphos-ethyl	13.05	0.01	333 → 168	25	333 → 318	10	318 → 180	10
Penconazole	13.59	0.02	161 → 159	5	248 → 159	25	248 → 161	5
Triflumizole	14.07	0.03	278 → 73	5	278 → 206	20	278 → 179	5
Methidathion	14.33	0.02	145 → 85	10	145 → 58	15	145 → 93	10
Myclobutanil	15.60	0.03	179 → 125	15	179 → 150	10	179 → 82	10
Dieldrin	15.55	0.03	263 → 191	30	263 → 193	30	263 → 81	35
Oxyfluorfen	15.67	0.02	361 → 300	15	252 → 223	15	300 → 252	15
Buprofezin	15.85	0.01	172 → 57	20	175 → 172	5	105 → 83	10
Endrin	16.32	0.01	263 → 193	30	263 → 228	20	263 → 228	20
Ethion	16.73	0.01	153 → 97	10	153 → 125	5	231 → 153	5
Propiconazole	17.55	0.01	175 → 173	5	259 → 69	10	259 → 173	10
Tebuconazole	17.82	0.02	250 → 125	20	250 → 70	10	125 → 70	10
Triphenylphosphate	17.89	0.01	326 → 325	5	326 → 169	25	326 → 215	25
EPN	18.39	0.01	185 → 157	5	169 → 157	5	157 → 141	10
Pyriproxyfen	19.02	0.01	136 → 107	10	136 → 96	15	136 → 78	15

the United Nations, 2018), but no MRLs have been specifically fixed for the four minor tropical fruits previously mentioned, though for "yoyomo", which is a sort of plum, its MRLs could be assembled. Even though, the exports of such products require the compliance with the MRLs established in the country of destination and their suitable analysis is compulsory at some stage.

In the literature, few examples of the determination of different groups of pesticides in minor tropical fruits can be found (Botero-Coy, Marín, Serrano, Sancho, & Hernández, 2015; Pakvilai et al., 2011; Yang, Luo, Li, & Liu, 2016; España Amórtegui & Guerrero Dallos, 2015; Yang, Luo, Duan, Li, & Liu, 2018). In all of them, the demands of analytical methods as well as pesticide occurrence in such samples have been highlighted. In the particular case of the work of Pakvilai et al. (Pakvilai et al., 2011), authors determined 6 synthetic pyrethroid residues (lambda cyhalothrin, permethrin, cyfluthrin, cypermethrin, fenvalerate, and deltamethrin) in vegetable, fruit, sediment, and surface water samples by gas chromatography (GC) with electro capture detection (ECD). Among the fruit samples, rose apples from Thailand were analyzed. In two works carried out by Yang et al. (2016, 2018) authors determined 9 (imidacloprid, acetamiprid, carbendazim, diflubenzuron, chlorbenzuron, phoxim, pyrimethanil, abamectin and iprodione) and 50 pesticides, respectively, in starfruits, Indian jujubes and wax apples (the last of them were analysed only in one of the works) from China by ultra-high performance liquid chromatography (UPLC) tandem mass spectrometry (MS/MS). While Botero-Coy et al. (2015) analysed 20 pesticides in seven Colombian tropical fruits (uchuva, tamarillo, granadilla, gulupa, maracuya, papaya, and pithaya), and five more matrices highly consumed in Colombia (lulo, carambola, feijoa, mangostan, and guayaba). The main objective of the work was the assessment of matrix effects (MEs), while analytes determination was carried out by liquid chromatography (LC)-MS/MS. As can be seen, among the four minor tropical fruits previously indicated (rose apple/pomarrosa, starfruit/carambola, yoyomo and papayuela), pomarrosa, yoyomo and papayuela from Colombia have not been previously studied and only one work has analysed starfruits from Colombia (Botero-Coy et al., 2015) but only one sample from that country was analysed.

As a result, the aim of this work was the development and validation of a multiresidue method for the analysis of 35 multiclass pesticides using GC–MS/MS in rose apple/pomarrosa, starfruit/carambola, yoyomo and papayuela from Colombia, as well as the analysis of different samples of each type. In order to cover a wide range of chemicals used in minor fruits production, representative pesticides belonging to different chemical families (e.g., organophosphorus pesticides, organochlorine pesticides, triazines, triazoles, carbamates, imidazoles, etc.) and with various chemical activities (e.g., insecticides, fungicides, herbicides, nematicide, acaricide, etc.) were selected. To the best of our knowledge, the analysis of pesticide residues in the minor tropical fruits yoyomo (*Spondias purpurea*) and papayuela (*Vasconcellea pubescens*) has not been developed so far. Besides, no data has been previously reported regarding the pesticide content of such fruits, as well as that of rose apple/pomarrosa (*Syzygium malaccense*), cultivated in Colombia. Furthermore, as mentioned above, among the four selected matrices, only starfruits/carambola have been previously studied, but a different group of pesticides were selected and only one sample from Colombia was analysed.

2. Materials and methods

2.1. Reagents

Pesticide reference standards, all of 95.9% of purity or higher, were obtained from Sigma-Aldrich (St. Louis, MO, USA). Atrazine-d_5 (ethyl-d_5), purity 99.7%, which was used as procedural internal standard (IS), was purchased from Sigma-Aldrich. Triphenylphosphate (TPP) was added to all final extracts for quality control (QC) just prior to GC–MS/MS analyses. A complete list of the monitored chemicals, their retention times (t_R), and MS/MS transitions is provided in Table 1. Analyte protectants consisting of 3-ethoxy-1,2-propanediol (ethylglycerol), L-gulonic acid-γ-lactone (gulonolactone), D-sorbitol, and shikimic acid (all with purity ≥ 95%) were obtained from Sigma-Aldrich.

Stock solutions of each pesticide were prepared in toluene at concentrations of approximately 1000 mg/L and stored in amber glass vials at −20 °C. For spiking of samples, pesticide standard mixtures of different concentrations were prepared in acetonitrile (ACN) containing 0.05% (v/v) of formic acid. A stock solution of TPP of 1050 mg/L as well as a solution of atrazine-d_5 of 750 mg/L were also prepared. For calibration, mixtures of the standard and the IS were prepared to yield 5, 10, 25, 75, 200, 400 and 600 μg/kg sample equivalents for the pesticides and 200 μg/kg for the IS. For QC purposes, the TPP solution was also added to yield a final concentration of 200 μg/kg. Analyte protectants solution containing 100 g/L of ethylglycerol, 10 g/L of gulonolactone, 10 g/L of D-sorbitol and 5 g/L of shikimic acid was prepared in 4/1 (v/v) ACN/water containing 0.05% (v/v) of formic acid.

ACN GC–MS grade, toluene, ethyl acetate, methanol (MeOH) GC-ECD/flame ionization detector grade and glacial acetic acid (HOAc) were from Merck (Darmstadt, Germany), anhydrous $MgSO_4$ and sodium acetate were from Sigma-Aldrich. For dispersive solid-phase extraction (dSPE) clean-up, Supel™ QuE PSA/C_{18} pre-weighed mixtures containing 150 mg of anhydrous $MgSO_4$, 50 mg of primary secondary amine (PSA) and 50 mg of octadecylsilane (C_{18}) in 2-mL mini-centrifuge tubes were from Supelco (Bellefonte, PA, USA). Graphitised carbon black (GCB) of 120/400 mesh was from Supelco and 7.5 mg was separately added to the dSPE tubes.

2.2. Samples

Rose apple/pomarrosa, starfruit/carambola, yoyomo and papayuela minor tropical fruits from Colombia were purchased from local food stores. Approximately, 1 kg of each fruit were cut into small portions with a knife and comminuted in a 2 L chopper (Oster, México).

2.3. GC–MS/MS conditions

The GC–MS/MS analyses were carried out using a Shimadzu GCMS-TQ8040 triple-quadrupole (QqQ) mass spectrometer with an electron ionisation interface. For sample injection, an autosampler AOC 20i/s from Shimadzu was also used. GCMS Real Time Analysis software was used for instrument control and GCMS Postrun Analysis software for data processing. A SH-Rxi-5Sil MS analytical column (30 m, 0.25 mm i.d., 0.25 μm film thickness) from Shimadzu was used. Ultrahigh purity He was used as the carrier gas at 1.2 mL/min constant flow rate. The GC oven was initially maintained for 1 min at 50 °C, and then the temperature was increased to 180 °C at 25 °C/min. Then, it was increased to 230 °C at 5 °C/min and finally taken to 290 °C at 25 °C/min and held at that temperature for 6 min. Total analysis time was 24.6 min. The MS interface temperature was 250 °C while the ion source was set at 300 °C. The injection was performed at 250 °C in the splitless mode, being the injection volume 1 μL. After 1 min from the injection, the split was opened. Before each sequence, a full autotune of the MS was conducted, and between injections, the 10 μL syringe was washed with MeOH, ethyl acetate and ACN (a single rinse with each solvent was developed in each case).

2.4. Sample preparation

Fifteen grams of the homogenised samples were weighed into a 50-mL centrifuge tube and analytes and atrazine-d_5 solutions were added (except for the matrix-matched calibration, in which analytes and the IS, as well as TPP, were added after the QuEChERS procedure). Samples and standards were carefully mixed and agitated in a tube roller (Scilogex Mx-t6-pro) for 5 min at 70 rpm before the extraction procedure to facilitate the contact of the sample with the analytes and the IS. Then, 15 mL of ACN containing 1% (v/v) of HOAc were added and the sample was energetically hand-shaken for 2 min. Afterwards, to induce phase separation and pesticide partitioning, 6 g of anhydrous $MgSO_4$ and 1.5 g of sodium acetate were added. Then, the mixture was vigorously shaken in a vortex for 10 *sec*, agitated in a tube roller (Scilogex Mx-t6-pro) for 5 min at 70 rpm, and centrifugated for 5 min at 4000 rpm. Then, 1 mL of the supernatant was transferred to a 2-mL centrifuge tube that contained 50 mg of PSA, 150 mg of anhydrous $MgSO_4$, 50 mg of C_{18} and 7.5 mg of GCB. The tube was closed and immediately agitated in a tube roller (Scilogex Mx-t6-pro) for 5 min at 70 rpm to facilitate the contact of the salts and clean-up sorbents with the ACN extract. Next, centrifugation was carried out for 5 min at 4400 rpm. Two hundred microliters of the supernatant were taken and 20 μL of the analyte protectants mixture and 50 μL of the TPP solution were added. Finally, 1 μL of the mixture was injected in the GC system.

3. Results and discussion

3.1. GC-QqQ-MS/MS analysis

As shown in Table 1, a total of 35 targeted chemicals plus the IS (atrazine-d_5) and the QC (TPP), were monitored in GC-QqQ-MS/MS with 8 overlapping peaks. These pesticides were selected to cover a wide range of representative analytes of different chemical classes commonly monitored in many laboratories worldwide. TPP was selected as QC of the injection, while atrazine-d_5 was used as IS of the method to correct possible loses of the analytes. They were permanently checked during the whole development of the work, in particular, during validation as well as sample analysis.

For the separation, the thermal gradient described in Section 2.3 was applied with a total analysis time of 24.6 min. In all cases, a single quantifier transition and two qualifiers were selected (Table 1 also contains each transition as well as their collision energies, which were optimised in the range 5–40 V in 5 V intervals).

3.2. Matrix-matched calibration

As a result of the complexity of the selected samples, co-extracted matrix components may cause an inaccurate quantification of the target analytes, a decrease of the method's ruggedness as well as low analyte detectability (Anastassiades, Maštovská, & Lehotay, 2003; Maštovská, Lehotay, & Anastassiades, 2005). Such MEs are inevitably encountered in pesticide residue analysis. In GC, when matrix components are injected, they tend to block the active sites of the GC inlet and column (mainly free silanol groups). This fact clearly reduces the analyte loss caused by adsorption or degradation of the analyte in such active sites. In the end, an enhancement of the signal (and therefore an over-estimation of the analytes' concentration) is obtained, respect to that of pure solvents (Rahman, Abd El-Aty, & Shim, 2013). On the contrary, the accumulation of non-volatile compounds in the GC inlet may cause a decrease of the signal (analyte losses or peak tailing) as a result of the presence of new active sites (Anastassiades et al., 2003; Maštovská et al., 2005), but this effect is less common. To overcome this problem (since a complete elimination of the MEs sources is not possible in practice), matrix-matched calibration curves are developed (because it is a very practical approach for compensating them) (SANTE Guidance, 2017; Lehotay et al., 2010) as well as the use of analyte protectants that

Table 2
Matrix-matched calibration data of the selected pesticides and ME percentage.

Analyte	Sample	Studied linear range[a] (μg/kg)	Regression equation (n = 5)		$S_{y/x}$	R^2	ME[b] (%)
			$b \pm s_b \cdot t_{(0.05;7)}$	$a \pm s_a \cdot t_{(0.05;7)}$			
Propoxur	Carambola	5–600	$4.15\cdot10^{-2} \pm 7.98\cdot10^{-4}$	$2.61\cdot10^{-1} \pm 2.27\cdot10^{-1}$	$1.76\cdot10^{-1}$	0.9997	51
	Papayuela	5–600	$3.12\cdot10^{-2} \pm 9.31\cdot10^{-4}$	$4.07\cdot10^{-2} \pm 2.65\cdot10^{-1}$	$2.05\cdot10^{-1}$	0.9993	13
	Pomarrosa	5–600	$2.24\cdot10^{-2} \pm 9.88\cdot10^{-4}$	$-6.82\cdot10^{-2} \pm 2.81\cdot10^{-1}$	$2.17\cdot10^{-1}$	0.9985	−18
	Yoyomo	5–600	$4.84\cdot10^{-2} \pm 1.81\cdot10^{-3}$	$1.57\cdot10^{-2} \pm 5.15\cdot10^{-1}$	$3.98\cdot10^{-1}$	0.9989	75
	Standard calibration	5–600	$2.75\cdot10^{-2} \pm 1.53\cdot10^{-3}$	$2.32\cdot10^{-1} \pm 4.34\cdot10^{-1}$	$3.36\cdot10^{-1}$	0.9977	–
Dichlorvos	Carambola	5–600	$3.79\cdot10^{-3} \pm 3.15\cdot10^{-4}$	$1.79\cdot10^{-1} \pm 8.95\cdot10^{-2}$	$6.92\cdot10^{-2}$	0.9957	−40
	Papayuela	5–600	$4.66\cdot10^{-3} \pm 3.14\cdot10^{-4}$	$2.84\cdot10^{-2} \pm 8.93\cdot10^{-2}$	$6.90\cdot10^{-2}$	0.9966	−27
	Pomarrosa	5–600	$5.09\cdot10^{-3} \pm 1.95\cdot10^{-4}$	$7.83\cdot10^{-2} \pm 5.54\cdot10^{-2}$	$4.28\cdot10^{-2}$	0.9989	−20
	Yoyomo	5–600	$3.15\cdot10^{-3} \pm 3.12\cdot10^{-4}$	$4.80\cdot10^{-1} \pm 8.87\cdot10^{-2}$	$6.86\cdot10^{-2}$	0.9938	−51
	Standard calibration	5–600	$6.43\cdot10^{-3} \pm 5.40\cdot10^{-4}$	$-6.45\cdot10^{-2} \pm 1.54\cdot10^{-1}$	$1.19\cdot10^{-1}$	0.9947	–
Carbofuran	Carambola	5–600	$9.47\cdot10^{-3} \pm 1.89\cdot10^{-4}$	$4.94\cdot10^{-2} \pm 5.38\cdot10^{-2}$	$4.16\cdot10^{-2}$	0.9997	41
	Papayuela	5–600	$7.71\cdot10^{-3} \pm 1.18\cdot10^{-4}$	$7.08\cdot10^{-5} \pm 3.37\cdot10^{-2}$	$2.60\cdot10^{-2}$	0.9998	15
	Pomarrosa	5–600	$6.21\cdot10^{-3} \pm 1.38\cdot10^{-4}$	$1.47\cdot10^{-2} \pm 3.93\cdot10^{-2}$	$3.04\cdot10^{-2}$	0.9996	−7
	Yoyomo	5–600	$9.41\cdot10^{-3} \pm 1.09\cdot10^{-3}$	$4.52\cdot10^{-1} \pm 3.10\cdot10^{-1}$	$2.40\cdot10^{-1}$	0.9900	40
	Standard calibration	5–600	$6.69\cdot10^{-3} \pm 3.31\cdot10^{-4}$	$3.91\cdot10^{-2} \pm 9.42\cdot10^{-2}$	$7.28\cdot10^{-2}$	0.9981	–
Carbaryl	Carambola	5–600	$5.63\cdot10^{-2} \pm 2.39\cdot10^{-3}$	$2.43\cdot10^{-1} \pm 6.79\cdot10^{-1}$	$5.25\cdot10^{-1}$	0.9986	51
	Papayuela	5–600	$5.36\cdot10^{-2} \pm 1.90\cdot10^{-3}$	$-2.51\cdot10^{-1} \pm 5.42\cdot10^{-1}$	$4.19\cdot10^{-1}$	0.9990	44
	Pomarrosa	5–600	$4.62\cdot10^{-2} \pm 2.15\cdot10^{-3}$	$-7.83\cdot10^{-4} \pm 6.13\cdot10^{-1}$	$4.74\cdot10^{-1}$	0.9984	24
	Yoyomo	5–600	$7.14\cdot10^{-2} \pm 2.42\cdot10^{-3}$	$7.30\cdot10^{-1} \pm 6.89\cdot10^{-1}$	$5.32\cdot10^{-1}$	0.9991	92
	Standard calibration	5–600	$3.70\cdot10^{-2} \pm 1.80\cdot10^{-3}$	$2.66\cdot10^{-3} \pm 5.13\cdot10^{-1}$	$3.96\cdot10^{-1}$	0.9982	–
Diphenylamine	Carambola	5–600	$1.89\cdot10^{-1} \pm 2.53\cdot10^{-3}$	$2.54\cdot10^{-1} \pm 7.20\cdot10^{-1}$	$5.57\cdot10^{-1}$	0.9999	37
	Papayuela	5–600	$1.62\cdot10^{-1} \pm 4.22\cdot10^{-3}$	$-1.98\cdot10^{-1} \pm 0.12\cdot10$	$9.27\cdot10^{-1}$	0.9995	17
	Pomarrosa	5–600	$1.52\cdot10^{-1} \pm 3.02\cdot10^{-3}$	$-1.09\cdot10^{-1} \pm 8.58\cdot10^{-1}$	$6.63\cdot10^{-1}$	0.9997	10
	Yoyomo	5–600	$2.28\cdot10^{-1} \pm 9.63\cdot10^{-3}$	$8.41\cdot10^{-2} \pm 0.27\cdot10$	$0.21\cdot10$	0.9987	65
	Standard calibration	5–600	$1.38\cdot10^{-1} \pm 3.22\cdot10^{-3}$	$-7.22\cdot10^{-1} \pm 9.15\cdot10^{-1}$	$7.07\cdot10^{-1}$	0.9996	–
Chlorpropham	Carambola	5–600	$7.01\cdot10^{-3} \pm 9.62\cdot10^{-5}$	$-1.03\cdot10^{-2} \pm 2.74\cdot10^{-2}$	$2.11\cdot10^{-2}$	0.9999	13
	Papayuela	5–600	$6.98\cdot10^{-3} \pm 1.25\cdot10^{-4}$	$-1.45\cdot10^{-2} \pm 3.56\cdot10^{-2}$	$2.75\cdot10^{-2}$	0.9998	12
	Pomarrosa	5–600	$6.38\cdot10^{-3} \pm 1.45\cdot10^{-4}$	$-1.28\cdot10^{-2} \pm 4.13\cdot10^{-2}$	$3.19\cdot10^{-2}$	0.9996	3
	Yoyomo	5–600	$7.31\cdot10^{-3} \pm 2.37\cdot10^{-4}$	$-2.14\cdot10^{-2} \pm 6.73\cdot10^{-2}$	$5.20\cdot10^{-2}$	0.9992	18
	Standard calibration	5–600	$6.19\cdot10^{-3} \pm 1.46\cdot10^{-4}$	$-4.91\cdot10^{-2} \pm 4.14\cdot10^{-2}$	$3.20\cdot10^{-2}$	0.9996	–
Dicloran	Carambola	5–600	$4.46\cdot10^{-3} \pm 1.66\cdot10^{-4}$	$-3.17\cdot10^{-2} \pm 4.72\cdot10^{-2}$	$3.65\cdot10^{-2}$	0.9990	24
	Papayuela	5–600	$4.78\cdot10^{-3} \pm 2.66\cdot10^{-4}$	$-4.55\cdot10^{-2} \pm 7.57\cdot10^{-2}$	$5.85\cdot10^{-2}$	0.9977	33
	Pomarrosa	5–600	$4.80\cdot10^{-3} \pm 1.74\cdot10^{-4}$	$-2.67\cdot10^{-2} \pm 4.95\cdot10^{-2}$	$3.83\cdot10^{-2}$	0.9990	33
	Yoyomo	5–600	$4.92\cdot10^{-3} \pm 2.23\cdot10^{-4}$	$-2.62\cdot10^{-2} \pm 6.34\cdot10^{-2}$	$4.90\cdot10^{-2}$	0.9984	37
	Standard calibration	5–600	$3.59\cdot10^{-3} \pm 7.71\cdot10^{-5}$	$-2.28\cdot10^{-2} \pm 2.19\cdot10^{-2}$	$1.70\cdot10^{-2}$	0.9996	–
Atrazine	Carambola	5–600	$3.98\cdot10^{-3} \pm 1.26\cdot10^{-4}$	$-1.61\cdot10^{-2} \pm 3.58\cdot10^{-2}$	$2.77\cdot10^{-2}$	0.9992	0.9
	Papayuela	5–600	$4.13\cdot10^{-3} \pm 1.04\cdot10^{-4}$	$-1.05\cdot10^{-2} \pm 2.97\cdot10^{-2}$	$2.30\cdot10^{-2}$	0.9995	4
	Pomarrosa	5–600	$4.11\cdot10^{-3} \pm 6.71\cdot10^{-5}$	$-8.39\cdot10^{-3} \pm 1.91\cdot10^{-2}$	$1.48\cdot10^{-2}$	0.9998	4
	Yoyomo	5–600	$3.98\cdot10^{-3} \pm 1.20\cdot10^{-4}$	$-3.18\cdot10^{-3} \pm 3.40\cdot10^{-2}$	$2.63\cdot10^{-2}$	0.9993	0.8
	Standard calibration	5–600	$3.94\cdot10^{-3} \pm 7.32\cdot10^{-5}$	$-5.56\cdot10^{-3} \pm 2.08\cdot10^{-2}$	$1.61\cdot10^{-2}$	0.9997	–
Lindane	Carambola	5–600	$8.63\cdot10^{-3} \pm 3.98\cdot10^{-4}$	$-3.55\cdot10^{-2} \pm 1.13\cdot10^{-1}$	$8.75\cdot10^{-2}$	0.9984	−35
	Papayuela	5–600	$8.20\cdot10^{-3} \pm 2.16\cdot10^{-4}$	$5.43\cdot10^{-2} \pm 6.14\cdot10^{-2}$	$4.74\cdot10^{-2}$	0.9995	−38
	Pomarrosa	5–600	$9.89\cdot10^{-3} \pm 9.58\cdot10^{-5}$	$4.18\cdot10^{-2} \pm 2.72\cdot10^{-2}$	$2.11\cdot10^{-2}$	0.9999	−25
	Yoyomo	5–600	$1.08\cdot10^{-2} \pm 2.59\cdot10^{-4}$	$6.31\cdot10^{-2} \pm 7.36\cdot10^{-2}$	$5.69\cdot10^{-2}$	0.9996	−19
	Standard calibration	5–600	$1.33\cdot10^{-2} \pm 2.79\cdot10^{-4}$	$4.88\cdot10^{-2} \pm 7.92\cdot10^{-2}$	$6.13\cdot10^{-2}$	0.9997	–
Propyzamide	Carambola	5–600	$4.54\cdot10^{-2} \pm 4.46\cdot10^{-4}$	$8.35\cdot10^{-3} \pm 1.27\cdot10^{-1}$	$9.80\cdot10^{-2}$	0.9999	3
	Papayuela	5–600	$4.58\cdot10^{-2} \pm 8.70\cdot10^{-4}$	$-8.02\cdot10^{-2} \pm 2.48\cdot10^{-1}$	$1.91\cdot10^{-1}$	0.9997	4
	Pomarrosa	5–600	$4.23\cdot10^{-2} \pm 1.28\cdot10^{-3}$	$-1.28\cdot10^{-1} \pm 3.63\cdot10^{-1}$	$2.81\cdot10^{-1}$	0.9993	−3
	Yoyomo	5–600	$4.69\cdot10^{-2} \pm 8.16\cdot10^{-4}$	$-2.84\cdot10^{-2} \pm 2.32\cdot10^{-1}$	$1.79\cdot10^{-1}$	0.9998	7
	Standard calibration	5–600	$4.37\cdot10^{-2} \pm 1.23\cdot10^{-3}$	$-2.53\cdot10^{-1} \pm 3.50\cdot10^{-1}$	$2.71\cdot10^{-1}$	0.9994	–
Chlorpyrifos-methyl	Carambola	5–600	$1.18\cdot10^{-2} \pm 6.72\cdot10^{-4}$	$-8.37\cdot10^{-2} \pm 1.91\cdot10^{-1}$	$1.48\cdot10^{-1}$	0.9976	−43
	Papayuela	5–600	$1.32\cdot10^{-2} \pm 6.25\cdot10^{-4}$	$-4.58\cdot10^{-2} \pm 1.78\cdot10^{-1}$	$1.37\cdot10^{-1}$	0.9983	−36
	Pomarrosa	5–600	$1.77\cdot10^{-2} \pm 3.50\cdot10^{-4}$	$-2.82\cdot10^{-2} \pm 9.94\cdot10^{-2}$	$7.69\cdot10^{-2}$	0.9997	−14
	Yoyomo	5–600	$1.56\cdot10^{-2} \pm 3.54\cdot10^{-4}$	$6.98\cdot10^{-3} \pm 1.01\cdot10^{-1}$	$7.79\cdot10^{-2}$	0.9996	−24
	Standard calibration	5–600	$2.08\cdot10^{-2} \pm 4.85\cdot10^{-4}$	$-8.61\cdot10^{-2} \pm 1.38\cdot10^{-1}$	$1.07\cdot10^{-1}$	0.9996	–
Parathion-methyl	Carambola	5–600	$3.60\cdot10^{-3} \pm 3.04\cdot10^{-4}$	$-4.58\cdot10^{-2} \pm 8.64\cdot10^{-2}$	$6.68\cdot10^{-2}$	0.9946	−46
	Papayuela	5–600	$4.93\cdot10^{-3} \pm 3.68\cdot10^{-4}$	$-4.49\cdot10^{-2} \pm 1.05\cdot10^{-1}$	$8.10\cdot10^{-2}$	0.9958	−26
	Pomarrosa	5–600	$7.07\cdot10^{-3} \pm 3.47\cdot10^{-4}$	$-5.42\cdot10^{-2} \pm 9.86\cdot10^{-2}$	$7.62\cdot10^{-2}$	0.9982	4
	Yoyomo	5–600	$4.80\cdot10^{-3} \pm 2.12\cdot10^{-4}$	$-2.71\cdot10^{-2} \pm 6.03\cdot10^{-2}$	$4.66\cdot10^{-2}$	0.9985	−28
	Standard calibration	5–600	$6.74\cdot10^{-3} \pm 5.01\cdot10^{-4}$	$-9.61\cdot10^{-2} \pm 1.43\cdot10^{-1}$	$1.10\cdot10^{-1}$	0.9958	–
Alachlor	Carambola	5–600	$1.32\cdot10^{-2} \pm 6.14\cdot10^{-4}$	$-6.96\cdot10^{-2} \pm 1.75\cdot10^{-1}$	$1.35\cdot10^{-1}$	0.9984	−18
	Papayuela	5–600	$1.23\cdot10^{-2} \pm 3.95\cdot10^{-4}$	$-1.35\cdot10^{-2} \pm 1.12\cdot10^{-1}$	$8.69\cdot10^{-2}$	0.9992	−24
	Pomarrosa	5–600	$1.41\cdot10^{-2} \pm 3.64\cdot10^{-4}$	$-2.63\cdot10^{-2} \pm 1.04\cdot10^{-1}$	$8.01\cdot10^{-2}$	0.9995	−13
	Yoyomo	5–600	$1.49\cdot10^{-2} \pm 3.23\cdot10^{-4}$	$3.40\cdot10^{-2} \pm 9.19\cdot10^{-2}$	$7.10\cdot10^{-2}$	0.9996	−8
	Standard calibration	5–600	$1.63\cdot10^{-2} \pm 3.79\cdot10^{-4}$	$-2.17\cdot10^{-2} \pm 1.08\cdot10^{-1}$	$8.32\cdot10^{-2}$	0.9996	–

(*continued on next page*)

Table 2 (*continued*)

Analyte	Sample	Studied linear range[a] (μg/kg)	Regression equation (n = 5)		$S_{y/x}$	R^2	ME[b] (%)
			$b \pm s_b \cdot t_{(0.05;7)}$	$a \pm s_a \cdot t_{(0.05;7)}$			
Tolclofos-Methyl	Carambola	5–600	$1.79\cdot10^{-2} \pm 7.73\cdot10^{-4}$	$-6.94\cdot10^{-2} \pm 2.20\cdot10^{-1}$	$1.70\cdot10^{-1}$	0.9986	−29
	Papayuela	5–600	$1.75\cdot10^{-2} \pm 5.48\cdot10^{-4}$	$-2.88\cdot10^{-2} \pm 1.56\cdot10^{-1}$	$1.21\cdot10^{-1}$	0.9993	−31
	Pomarrosa	5–600	$2.14\cdot10^{-2} \pm 3.21\cdot10^{-4}$	$-1.85\cdot10^{-2} \pm 9.14\cdot10^{-2}$	$7.06\cdot10^{-2}$	0.9998	−15
	Yoyomo	5–600	$2.19\cdot10^{-2} \pm 4.51\cdot10^{-4}$	$4.15\cdot10^{-2} \pm 1.28\cdot10^{-1}$	$9.93\cdot10^{-2}$	0.9997	−13
	Standard calibration	5–600	$2.54\cdot10^{-2} \pm 5.20\cdot10^{-4}$	$-6.05\cdot10^{-2} \pm 1.48\cdot10^{-1}$	$1.14\cdot10^{-1}$	0.9997	–
Metalaxyl	Carambola	5–600	$6.39\cdot10^{-3} \pm 2.34\cdot10^{-4}$	$-1.75\cdot10^{-2} \pm 6.67\cdot10^{-2}$	$5.15\cdot10^{-2}$	0.9990	−3
	Papayuela	5–600	$6.44\cdot10^{-3} \pm 9.66\cdot10^{-5}$	$5.71\cdot10^{-3} \pm 2.75\cdot10^{-2}$	$2.12\cdot10^{-2}$	0.9998	−2
	Pomarrosa	5–600	$6.17\cdot10^{-3} \pm 1.37\cdot10^{-4}$	$-7.27\cdot10^{-3} \pm 3.89\cdot10^{-2}$	$3.01\cdot10^{-2}$	0.9996	−6
	Yoyomo	5–600	$6.39\cdot10^{-3} \pm 1.22\cdot10^{-4}$	$-5.16\cdot10^{-3} \pm 3.46\cdot10^{-2}$	$2.68\cdot10^{-2}$	0.9997	−3
	Standard calibration	5–600	$6.62\cdot10^{-3} \pm 2.38\cdot10^{-4}$	$-5.35\cdot10^{-2} \pm 6.77\cdot10^{-2}$	$5.24\cdot10^{-2}$	0.9990	–
Pirimiphos-methyl	Carambola	5–600	$6.51\cdot10^{-3} \pm 2.97\cdot10^{-4}$	$-3.88\cdot10^{-2} \pm 8.45\cdot10^{-2}$	$6.53\cdot10^{-2}$	0.9984	−28
	Papayuela	5–600	$6.37\cdot10^{-3} \pm 2.05\cdot10^{-4}$	$-1.45\cdot10^{-2} \pm 5.82\cdot10^{-2}$	$4.50\cdot10^{-2}$	0.9992	−30
	Pomarrosa	5–600	$7.92\cdot10^{-3} \pm 2.44\cdot10^{-4}$	$-1.45\cdot10^{-2} \pm 6.94\cdot10^{-2}$	$5.36\cdot10^{-2}$	0.9993	−13
	Yoyomo	5–600	$7.84\cdot10^{-3} \pm 1.83\cdot10^{-4}$	$-1.11\cdot10^{-2} \pm 5.19\cdot10^{-2}$	$4.01\cdot10^{-2}$	0.9996	−14
	Standard calibration	5–600	$9.12\cdot10^{-3} \pm 2.12\cdot10^{-4}$	$-3.58\cdot10^{-2} \pm 6.03\cdot10^{-2}$	$4.66\cdot10^{-2}$	0.9996	–
Fenitrothion	Carambola	5–600	$4.06\cdot10^{-3} \pm 3.30\cdot10^{-4}$	$-5.53\cdot10^{-2} \pm 9.38\cdot10^{-2}$	$7.25\cdot10^{-2}$	0.9950	−45
	Papayuela	5–600	$5.41\cdot10^{-3} \pm 3.32\cdot10^{-4}$	$-4.05\cdot10^{-2} \pm 9.44\cdot10^{-2}$	$7.30\cdot10^{-2}$	0.9972	−27
	Pomarrosa	5–600	$7.71\cdot10^{-3} \pm 3.25\cdot10^{-4}$	$-5.81\cdot10^{-2} \pm 9.23\cdot10^{-2}$	$7.14\cdot10^{-2}$	0.9987	3
	Yoyomo	5–600	$5.19\cdot10^{-3} \pm 2.14\cdot10^{-4}$	$-2.06\cdot10^{-2} \pm 6.08\cdot10^{-2}$	$4.70\cdot10^{-2}$	0.9987	−30
	Standard calibration	5–600	$7.46\cdot10^{-3} \pm 6.59\cdot10^{-4}$	$-1.15\cdot10^{-1} \pm 1.88\cdot10^{-1}$	$1.45\cdot10^{-1}$	0.9941	–
Malathion	Carambola	5–600	$7.67\cdot10^{-3} \pm 7.09\cdot10^{-4}$	$-9.02\cdot10^{-2} \pm 2.02\cdot10^{-1}$	$1.56\cdot10^{-1}$	0.9936	−54
	Papayuela	5–600	$1.09\cdot10^{-2} \pm 8.87\cdot10^{-4}$	$-1.00\cdot10^{-1} \pm 2.52\cdot10^{-1}$	$1.95\cdot10^{-1}$	0.9950	−35
	Pomarrosa	5–600	$1.81\cdot10^{-2} \pm 4.28\cdot10^{-4}$	$-4.07\cdot10^{-2} \pm 1.22\cdot10^{-1}$	$9.41\cdot10^{-2}$	0.9996	7
	Yoyomo	5–600	$1.05\cdot10^{-2} \pm 5.55\cdot10^{-4}$	$8.81\cdot10^{-3} \pm 1.58\cdot10^{-1}$	$1.22\cdot10^{-1}$	0.9979	−37
	Standard calibration	5–600	$1.68\cdot10^{-2} \pm 9.60\cdot10^{-4}$	$-1.66\cdot10^{-1} \pm 2.73\cdot10^{-1}$	$2.11\cdot10^{-1}$	0.9975	–
Chlorpyrifos	Carambola	5–600	$1.21\cdot10^{-2} \pm 4.64\cdot10^{-4}$	$-4.82\cdot10^{-2} \pm 1.32\cdot10^{-1}$	$1.02\cdot10^{-1}$	0.9989	−18
	Papayuela	5–600	$1.19\cdot10^{-2} \pm 3.33\cdot10^{-4}$	$-1.40\cdot10^{-2} \pm 9.46\cdot10^{-2}$	$7.31\cdot10^{-2}$	0.9994	−20
	Pomarrosa	5–600	$1.35\cdot10^{-2} \pm 2.69\cdot10^{-4}$	$-2.69\cdot10^{-2} \pm 7.66\cdot10^{-2}$	$5.92\cdot10^{-2}$	0.9997	−9
	Yoyomo	5–600	$1.42\cdot10^{-2} \pm 3.88\cdot10^{-4}$	$4.50\cdot10^{-3} \pm 1.10\cdot10^{-1}$	$8.54\cdot10^{-2}$	0.9994	−4
	Standard calibration	5–600	$1.49\cdot10^{-2} \pm 3.58\cdot10^{-4}$	$-4.40\cdot10^{-2} \pm 1.02\cdot10^{-1}$	$7.87\cdot10^{-2}$	0.9996	–
Fenthion	Carambola	5–600	$1.38\cdot10^{-2} \pm 6.96\cdot10^{-4}$	$-8.90\cdot10^{-2} \pm 1.98\cdot10^{-1}$	$1.53\cdot10^{-1}$	0.9981	−33
	Papayuela	5–600	$1.52\cdot10^{-2} \pm 5.75\cdot10^{-4}$	$-4.78\cdot10^{-2} \pm 1.64\cdot10^{-1}$	$1.26\cdot10^{-1}$	0.9989	−25
	Pomarrosa	5–600	$1.88\cdot10^{-2} \pm 3.61\cdot10^{-4}$	$-3.42\cdot10^{-2} \pm 1.03\cdot10^{-1}$	$7.95\cdot10^{-2}$	0.9997	−8
	Yoyomo	5–600	$1.64\cdot10^{-2} \pm 4.78\cdot10^{-4}$	$-2.48\cdot10^{-2} \pm 1.36\cdot10^{-1}$	$1.05\cdot10^{-1}$	0.9994	−20
	Standard calibration	5–600	$2.06\cdot10^{-2} \pm 8.90\cdot10^{-4}$	$-1.52\cdot10^{-1} \pm 2.53\cdot10^{-1}$	$1.96\cdot10^{-1}$	0.9986	–
Triamidefon	Carambola	5–600	$1.37\cdot10^{-2} \pm 1.65\cdot10^{-4}$	$-7.86\cdot10^{-4} \pm 4.68\cdot10^{-2}$	$3.62\cdot10^{-2}$	0.9999	−0.8
	Papayuela	5–600	$1.38\cdot10^{-2} \pm 3.03\cdot10^{-4}$	$4.08\cdot10^{-2} \pm 8.62\cdot10^{-2}$	$6.67\cdot10^{-2}$	0.9996	0
	Pomarrosa	5–600	$1.37\cdot10^{-2} \pm 2.80\cdot10^{-4}$	$-1.08\cdot10^{-2} \pm 7.95\cdot10^{-2}$	$6.15\cdot10^{-2}$	0.9997	−1
	Yoyomo	5–600	$1.48\cdot10^{-2} \pm 4.44\cdot10^{-4}$	$2.07\cdot10^{-2} \pm 1.26\cdot10^{-1}$	$9.77\cdot10^{-2}$	0.9993	7
	Standard calibration	5–600	$1.38\cdot10^{-2} \pm 5.65\cdot10^{-4}$	$-6.89\cdot10^{-2} \pm 1.61\cdot10^{-1}$	$1.24\cdot10^{-1}$	0.9987	–
Pirimiphos-ethyl	Carambola	5–600	$3.46\cdot10^{-3} \pm 1.25\cdot10^{-4}$	$-2.00\cdot10^{-2} \pm 3.56\cdot10^{-2}$	$2.75\cdot10^{-2}$	0.9990	−7
	Papayuela	5–600	$3.24\cdot10^{-3} \pm 6.57\cdot10^{-5}$	$-7.80\cdot10^{-3} \pm 1.87\cdot10^{-2}$	$1.44\cdot10^{-2}$	0.9997	−13
	Pomarrosa	5–600	$3.39\cdot10^{-3} \pm 8.76\cdot10^{-5}$	$-1.25\cdot10^{-2} \pm 2.49\cdot10^{-2}$	$1.93\cdot10^{-2}$	0.9995	−9
	Yoyomo	5–600	$4.03\cdot10^{-3} \pm 1.65\cdot10^{-4}$	$-1.20\cdot10^{-2} \pm 4.70\cdot10^{-2}$	$3.64\cdot10^{-2}$	0.9987	8
	Standard calibration	5–600	$3.73\cdot10^{-3} \pm 1.03\cdot10^{-4}$	$-1.99\cdot10^{-2} \pm 2.94\cdot10^{-2}$	$2.27\cdot10^{-2}$	0.9994	–
Penconazole	Carambola	5–600	$2.52\cdot10^{-2} \pm 1.58\cdot10^{-3}$	$3.28\cdot10^{-2} \pm 4.48\cdot10^{-1}$	$3.46\cdot10^{-1}$	0.9971	12
	Papayuela	5–600	$2.56\cdot10^{-2} \pm 8.28\cdot10^{-4}$	$-4.70\cdot10^{-2} \pm 2.36\cdot10^{-1}$	$1.82\cdot10^{-1}$	0.9992	14
	Pomarrosa	5–600	$2.44\cdot10^{-2} \pm 4.86\cdot10^{-4}$	$-3.86\cdot10^{-2} \pm 1.38\cdot10^{-1}$	$1.07\cdot10^{-1}$	0.9997	9
	Yoyomo	5–600	$2.75\cdot10^{-2} \pm 1.59\cdot10^{-3}$	$2.90\cdot10^{-1} \pm 4.53\cdot10^{-1}$	$3.50\cdot10^{-1}$	0.9977	22
	Standard calibration	5–600	$2.25\cdot10^{-2} \pm 1.17\cdot10^{-3}$	$-1.48\cdot10^{-1} \pm 3.34\cdot10^{-1}$	$2.58\cdot10^{-1}$	0.9979	–
Triflumizole	Carambola	5–600	$6.31\cdot10^{-3} \pm 1.91\cdot10^{-4}$	$-3.47\cdot10^{-2} \pm 5.43\cdot10^{-2}$	$4.20\cdot10^{-2}$	0.9993	9
	Papayuela	5–600	$6.94\cdot10^{-3} \pm 2.29\cdot10^{-4}$	$-2.61\cdot10^{-2} \pm 6.52\cdot10^{-2}$	$5.04\cdot10^{-2}$	0.9992	20
	Pomarrosa	5–600	$7.14\cdot10^{-3} \pm 1.67\cdot10^{-4}$	$-2.86\cdot10^{-2} \pm 4.75\cdot10^{-2}$	$3.67\cdot10^{-2}$	0.9996	23
	Yoyomo	5–600	$6.00\cdot10^{-3} \pm 1.63\cdot10^{-4}$	$-1.69\cdot10^{-2} \pm 4.65\cdot10^{-2}$	$3.59\cdot10^{-2}$	0.9994	3
	Standard calibration	5–600	$5.78\cdot10^{-3} \pm 5.91\cdot10^{-4}$	$-1.03\cdot10^{-1} \pm 1.68\cdot10^{-1}$	$1.30\cdot10^{-1}$	0.9922	–
Methidathion	Carambola	5–600	$1.19\cdot10^{-2} \pm 1.11\cdot10^{-3}$	$-1.67\cdot10^{-1} \pm 3.15\cdot10^{-1}$	$2.44\cdot10^{-1}$	0.9934	−61
	Papayuela	5–600	$2.01\cdot10^{-2} \pm 1.43\cdot10^{-3}$	$-1.36\cdot10^{-1} \pm 4.08\cdot10^{-1}$	$3.15\cdot10^{-1}$	0.9962	−34
	Pomarrosa	5–600	$2.78\cdot10^{-2} \pm 1.41\cdot10^{-3}$	$-2.26\cdot10^{-1} \pm 4.00\cdot10^{-1}$	$3.09\cdot10^{-1}$	0.9981	−10
	Yoyomo	5–600	$1.31\cdot10^{-2} \pm 8.66\cdot10^{-4}$	$-5.61\cdot10^{-2} \pm 2.46\cdot10^{-1}$	$1.90\cdot10^{-1}$	0.9967	−57
	Standard calibration	5–600	$3.09\cdot10^{-2} \pm 2.68\cdot10^{-3}$	$-5.56\cdot10^{-1} \pm 7.61\cdot10^{-1}$	$5.88\cdot10^{-1}$	0.9944	–
Myclobutanil	Carambola	5–600	$2.51\cdot10^{-2} \pm 1.72\cdot10^{-3}$	$2.86\cdot10^{-2} \pm 4.88\cdot10^{-1}$	$3.77\cdot10^{-1}$	0.9965	9
	Papayuela	5–600	$2.75\cdot10^{-2} \pm 7.72\cdot10^{-4}$	$-3.64\cdot10^{-2} \pm 2.20\cdot10^{-1}$	$1.70\cdot10^{-1}$	0.9994	19
	Pomarrosa	5–600	$2.70\cdot10^{-2} \pm 9.75\cdot10^{-4}$	$-9.01\cdot10^{-2} \pm 2.77\cdot10^{-1}$	$2.14\cdot10^{-1}$	0.9990	17
	Yoyomo	5–600	$2.67\cdot10^{-2} \pm 2.21\cdot10^{-3}$	$3.70\cdot10^{-1} \pm 6.28\cdot10^{-1}$	$4.86\cdot10^{-1}$	0.9948	16
	Standard calibration	5–600	$2.29\cdot10^{-2} \pm 1.62\cdot10^{-3}$	$-3.26\cdot10^{-1} \pm 4.61\cdot10^{-1}$	$3.56\cdot10^{-1}$	0.9962	–

(*continued on next page*)

Table 2 (*continued*)

Analyte	Sample	Studied linear range[a] (μg/kg)	Regression equation (n = 5)		$S_{y/x}$	R^2	ME[b] (%)
			$b \pm s_b \cdot t_{(0.05;7)}$	$a \pm s_a \cdot t_{(0.05;7)}$			
Dieldrin	Carambola	5–600	$3.56\cdot10^{-3} \pm 8.91\cdot10^{-5}$	$-7.57\cdot10^{-3} \pm 2.53\cdot10^{-2}$	0.20·10	0.9995	−14
	Papayuela	5–600	$3.23\cdot10^{-3} \pm 4.20\cdot10^{-5}$	$4.12\cdot10^{-3} \pm 1.20\cdot10^{-2}$	$9.24\cdot10^{-3}$	0.9999	−22
	Pomarrosa	5–600	$3.51\cdot10^{-3} \pm 7.25\cdot10^{-5}$	$-1.05\cdot10^{-3} \pm 2.06\cdot10^{-2}$	$1.59\cdot10^{-2}$	0.9997	−15
	Yoyomo	5–600	$4.09\cdot10^{-3} \pm 1.52\cdot10^{-4}$	$6.72\cdot10^{-3} \pm 4.32\cdot10^{-2}$	$3.34\cdot10^{-2}$	0.9990	−1
	Standard calibration	5–600	$4.17\cdot10^{-3} \pm 4.53\cdot10^{-4}$	$-5.29\cdot10^{-2} \pm 1.29\cdot10^{-1}$	$9.95\cdot10^{-2}$	0.9912	–
Oxyfluorfen	Carambola	5–600	$1.90\cdot10^{-3} \pm 1.40\cdot10^{-4}$	$-2.49\cdot10^{-2} \pm 3.97\cdot10^{-2}$	$3.07\cdot10^{-2}$	0.9959	−0.4
	Papayuela	5–600	$2.36\cdot10^{-3} \pm 9.22\cdot10^{-5}$	$-1.64\cdot10^{-2} \pm 2.62\cdot10^{-2}$	$2.03\cdot10^{-2}$	0.9988	23
	Pomarrosa	5–600	$2.55\cdot10^{-3} \pm 8.56\cdot10^{-5}$	$-2.01\cdot10^{-2} \pm 2.44\cdot10^{-2}$	$1.88\cdot10^{-2}$	0.9991	33
	Yoyomo	5–600	$2.00\cdot10^{-3} \pm 1.22\cdot10^{-4}$	$-2.47\cdot10^{-2} \pm 3.46\cdot10^{-2}$	$2.67\cdot10^{-2}$	0.9972	4
	Standard calibration	5–600	$1.91\cdot10^{-3} \pm 2.12\cdot10^{-4}$	$-4.45\cdot10^{-2} \pm 6.03\cdot10^{-2}$	$4.66\cdot10^{-2}$	0.9907	–
Buprofezin	Carambola	5–600	$8.61\cdot10^{-3} \pm 1.51\cdot10^{-4}$	$-1.48\cdot10^{-2} \pm 4.30\cdot10^{-2}$	$3.32\cdot10^{-2}$	0.9998	−6
	Papayuela	5–600	$8.85\cdot10^{-3} \pm 1.55\cdot10^{-4}$	$-5.76\cdot10^{-3} \pm 4.40\cdot10^{-2}$	$3.40\cdot10^{-2}$	0.9998	−4
	Pomarrosa	5–600	$8.81\cdot10^{-3} \pm 1.85\cdot10^{-4}$	$-1.17\cdot10^{-2} \pm 5.26\cdot10^{-2}$	$4.07\cdot10^{-2}$	0.9997	−4
	Yoyomo	5–600	$9.42\cdot10^{-3} \pm 3.23\cdot10^{-4}$	$-1.56\cdot10^{-2} \pm 9.19\cdot10^{-2}$	$7.10\cdot10^{-2}$	0.9991	1
	Standard calibration	5–600	$9.26\cdot10^{-3} \pm 3.51\cdot10^{-4}$	$-4.70\cdot10^{-2} \pm 1.00\cdot10^{-1}$	$7.73\cdot10^{-2}$	0.9989	–
Endrin	Carambola	5–600	$2.09\cdot10^{-3} \pm 7.08\cdot10^{-5}$	$-1.48\cdot10^{-2} \pm 2.01\cdot10^{-2}$	$1.56\cdot10^{-2}$	0.9991	−15
	Papayuela	5–600	$2.16\cdot10^{-3} \pm 3.79\cdot10^{-5}$	$-6.27\cdot10^{-3} \pm 1.08\cdot10^{-2}$	$8.34\cdot10^{-3}$	0.9998	−12
	Pomarrosa	5–600	$2.42\cdot10^{-3} \pm 5.07\cdot10^{-5}$	$-1.08\cdot10^{-2} \pm 1.44\cdot10^{-2}$	$1.12\cdot10^{-2}$	0.9997	−2
	Yoyomo	5–600	$2.37\cdot10^{-3} \pm 1.14\cdot10^{-4}$	$-5.16\cdot10^{-3} \pm 3.24\cdot10^{-2}$	$2.51\cdot10^{-2}$	0.9983	−4
	Standard calibration	5–600	$2.48\cdot10^{-3} \pm 6.95\cdot10^{-5}$	$-3.14\cdot10^{-3} \pm 1.98\cdot10^{-2}$	$1.53\cdot10^{-2}$	0.9994	–
Ethion	Carambola	5–600	$7.48\cdot10^{-3} \pm 6.35\cdot10^{-4}$	$2.67\cdot10^{-1} \pm 1.81\cdot10^{-1}$	$1.40\cdot10^{-1}$	0.9946	−41
	Papayuela	5–600	$1.02\cdot10^{-2} \pm 5.18\cdot10^{-4}$	$-3.31\cdot10^{-2} \pm 1.47\cdot10^{-1}$	$1.14\cdot10^{-1}$	0.9981	−20
	Pomarrosa	5–600	$1.33\cdot10^{-2} \pm 3.87\cdot10^{-4}$	$-3.63\cdot10^{-2} \pm 1.10\cdot10^{-1}$	$8.51\cdot10^{-2}$	0.9994	3
	Yoyomo	5–600	$8.51\cdot10^{-3} \pm 4.14\cdot10^{-4}$	$-5.93\cdot10^{-3} \pm 1.18\cdot10^{-1}$	$9.10\cdot10^{-2}$	0.9982	−33
	Standard calibration	5–600	$1.28\cdot10^{-2} \pm 5.44\cdot10^{-4}$	$-9.01\cdot10^{-2} \pm 1.55\cdot10^{-1}$	$1.20\cdot10^{-1}$	0.9986	–
Propiconazole	Carambola	5–600	$9.63\cdot10^{-3} \pm 5.37\cdot10^{-4}$	$2.00\cdot10^{-2} \pm 1.53\cdot10^{-1}$	$1.18\cdot10^{-1}$	0.9977	3
	Papayuela	5–600	$1.06\cdot10^{-2} \pm 5.78\cdot10^{-4}$	$1.19\cdot10^{-1} \pm 1.64\cdot10^{-1}$	$1.27\cdot10^{-1}$	0.9977	14
	Pomarrosa	5–600	$7.64\cdot10^{-3} \pm 8.80\cdot10^{-4}$	$6.54\cdot10^{-1} \pm 2.50\cdot10^{-1}$	$1.94\cdot10^{-1}$	0.9901	−17
	Yoyomo	5–600	$1.05\cdot10^{-2} \pm 6.20\cdot10^{-4}$	$1.49\cdot10^{-1} \pm 1.76\cdot10^{-1}$	$1.36\cdot10^{-1}$	0.9974	13
	Standard calibration	5–600	$9.26\cdot10^{-3} \pm 2.96\cdot10^{-4}$	$-4.40\cdot10^{-2} \pm 8.42\cdot10^{-2}$	$6.51\cdot10^{-2}$	0.9992	–
Tebuconazole	Carambola	5–600	$1.29\cdot10^{-2} \pm 5.33\cdot10^{-4}$	$-7.56\cdot10^{-3} \pm 1.52\cdot10^{-1}$	$1.17\cdot10^{-1}$	0.9987	14
	Papayuela	5–600	$1.44\cdot10^{-2} \pm 3.17\cdot10^{-4}$	$-1.99\cdot10^{-2} \pm 9.02\cdot10^{-2}$	$6.97\cdot10^{-2}$	0.9996	28
	Pomarrosa	5–600	$1.44\cdot10^{-2} \pm 2.71\cdot10^{-4}$	$-2.53\cdot10^{-2} \pm 7.72\cdot10^{-2}$	$5.97\cdot10^{-2}$	0.9997	28
	Yoyomo	5–600	$1.49\cdot10^{-2} \pm 6.06\cdot10^{-4}$	$1.13\cdot10^{-1} \pm 1.72\cdot10^{-1}$	$1.33\cdot10^{-1}$	0.9988	33
	Standard calibration	5–600	$1.12\cdot10^{-2} \pm 7.04\cdot10^{-4}$	$-1.53\cdot10^{-1} \pm 2.00\cdot10^{-1}$	$1.55\cdot10^{-1}$	0.9970	–
EPN	Carambola	5–600	$3.94\cdot10^{-3} \pm 2.50\cdot10^{-4}$	$-3.84\cdot10^{-2} \pm 7.10\cdot10^{-2}$	$5.49\cdot10^{-2}$	0.9970	−41
	Papayuela	5–600	$5.91\cdot10^{-3} \pm 5.14\cdot10^{-4}$	$-8.32\cdot10^{-2} \pm 1.46\cdot10^{-1}$	$1.13\cdot10^{-1}$	0.9943	−11
	Pomarrosa	5–600	$7.99\cdot10^{-3} \pm 3.32\cdot10^{-4}$	$-3.70\cdot10^{-2} \pm 9.44\cdot10^{-2}$	$7.30\cdot10^{-2}$	0.9987	19
	Yoyomo	5–600	$4.21\cdot10^{-3} \pm 1.69\cdot10^{-4}$	$-8.72\cdot10^{-3} \pm 4.80\cdot10^{-2}$	$3.71\cdot10^{-2}$	0.9988	−37
	Standard calibration	5–600	$6.70\cdot10^{-3} \pm 4.14\cdot10^{-4}$	$-7.53\cdot10^{-2} \pm 1.18\cdot10^{-1}$	$9.11\cdot10^{-2}$	0.9971	–
Pyriproxyfen	Carambola	5–600	$1.18\cdot10^{-2} \pm 5.90\cdot10^{-4}$	$1.72\cdot10^{-1} \pm 1.68\cdot10^{-1}$	$1.30\cdot10^{-1}$	0.9981	−26
	Papayuela	5–600	$1.95\cdot10^{-2} \pm 3.61\cdot10^{-4}$	$-5.22\cdot10^{-2} \pm 1.03\cdot10^{-1}$	$7.94\cdot10^{-2}$	0.9997	22
	Pomarrosa	5–600	$1.97\cdot10^{-2} \pm 4.07\cdot10^{-4}$	$2.93\cdot10^{-2} \pm 1.16\cdot10^{-1}$	$8.95\cdot10^{-2}$	0.9997	23
	Yoyomo	5–600	$1.96\cdot10^{-2} \pm 4.74\cdot10^{-4}$	$3.52\cdot10^{-2} \pm 1.35\cdot10^{-1}$	$1.04\cdot10^{-1}$	0.9996	23
	Standard calibration	5–600	$1.59\cdot10^{-2} \pm 8.56\cdot10^{-4}$	$-1.46\cdot10^{-1} \pm 2.44\cdot10^{-1}$	$1.88\cdot10^{-1}$	0.9978	–

b: slope; S_b: standard deviation of the slope; a: intercept; S_a: standard deviation of the intercept; R^2: determination coefficient; $S_{y/x}$: standard deviation of the estimate. [a]For standard calibration, data was converted to μg/kg for comparison purposes though the studied linear range was 3.7–444 μg/L. [b]Calculated following the equation used by Kwon et al. (2012).

help to reduce analyte tailing and decomposition within the GC inlet by masking such active sites (Anastassiades et al., 2003; Maštovská et al., 2005). In particular, an analyte protectants mixture of 3-ethoxy-1,2-propanediol, L-gulonic acid γ-lactone, D-sorbitol and of shikimic acid was used for building pure solvent and matrix-matched calibration curves as previously proposed (González-Curbelo, Lehotay, Hernández-Borges, & Rodríguez-Delgado, 2014; Han, Matarrita, Sapozhnikova, & Lehotay, 2016; Maštovská et al., 2005). The concentrations of 3-ethoxy-1,2-propanediol, L-gulonic acid γ-lactone, D-sorbitol and of shikimic acid in the 20 μL solution added at the end of the procedure (see Section 2.4) were 10, 1, 1 and 0.5 g/L, respectively. The direct application of the AOAC 2007.1 QuEChERS method was developed, and the final extracts were enriched with the target analytes, the IS and the QC.

Linearity was evaluated by means of building the calibration curves in the 3.7–444 μg/L range (5–600 μg/kg in the sample) in pure solvent and in matrix-matched standards of each kind of sample. Table 2 shows the calibration data obtained for each pesticide and matrix, including the full calibration curve with the standard deviations of the slope and intercepts, as well as the determination coefficient (R^2) and the standard deviation of the estimate. As can be seen in the table, determination coefficients higher than or equal to 0.9900 were obtained for all the pesticides and samples.

Regarding the ME, it was estimated by comparing the slopes of pure solvent calibration curves and those obtained with matrix-matched standards. The ME was calculated as %ME = [(slope of matrix-matched calibration-slope of solvent calibration)/(slope of solvent calibration)] × 100 as previously developed (Kwon, Lehotay, & Geis-Asteggiante, 2012). Such data is also compiled in Table 2. A negative value of ME indicates signal suppression and a positive value represents an enhancement in the peak area. Fig. 1 shows the variation of the ME *vs* the t_R for each fruit. This approach is very useful to show exactly where MEs are occurring at the conditions of the analyses (Kwon et al.,

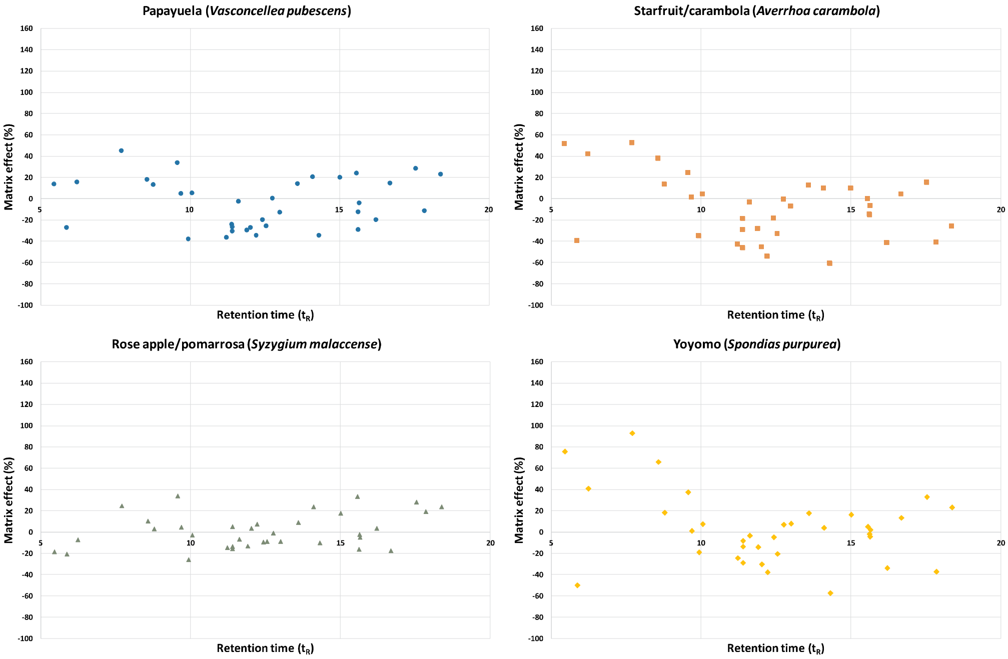

Fig. 1. Representation of the ME percentage (normalised to atrazine-d_5) *vs* t_R for each analysed sample matrix.

2012). If ± 20% of ME is chosen as the acceptable range for non-matrix-matched standard calibration (SANTE Guidance, 2017), for pomarrosa, 27 pesticides out of 35 showed acceptable ME percentages, while 18 were for yoyomo and papayuela and 16 for carambola. Therefore, and although most pesticides showed acceptable MEs, matrix-matched calibration should be developed. As can be seen in the figure, papayuela and pomarrosa gave the lowest %ME range (basically they were all between ± 40%) and, among them, pomarrosa (between +33% and −26%). ME of those pesticides that elute first (the carbamates propoxur, carbofuran, carbaryl, and chlorpropham, -except dichlorvos-) in carambola and yoyomo showed a clear signal enhancement. For papayuela, such ME was only observed for carbaryl while for yoyomo it also happened for carbaryl, diphenylamine and dicloran. In the case of carambola and yoyomo, dichlorvos (t_R of 5.88 min) and some pesticides above 10 min of t_R also showed an important signal inhibition, around −40%, but without a clear tendency.

Concerning the effectiveness of the addition of analyte protectants, Fig. 2 shows the relative responses of all the selected pesticides in pomarrosa with and without the addition of analytes protectants as previously proposed (Anastassiades et al., 2003), using a matrix-matched standard of 0.8 mg/L. As can be seen in the figure, the errors due to MEs were also dramatically reduced for all the pesticides and matrices, this also happened for the rest of the matrices (see Figs. 1–3 of the Supplementary Material). Such reduction was even more remarkable for papayuela and pomarrosa, and for the pesticides dichlorvos, carbaryl, diphenylamine, chlorpropam and dicloran in the four samples (this also happened to other pesticides in each type of sample).

3.3. Trueness assessment

Finally, a recovery study was also carried out to assess the trueness of the developed method, by spiking the different matrices at three levels of concentrations (10, 75 and 400 µg/kg). Table 3, compiles the recovery values obtained for each level. As it can be seen in the table, recoveries were essentially very similar in the four minor tropical fruits selected except in certain specific cases. As can be seen in the table, most pesticide analytes met the acceptability criteria of 70–120% recovery percentages with RSD ≤ 20% (SANTE Guidance, 2017). Average recovery values were slightly lower than 70% for the three levels of concentration for methidathion in carambola and chlorpyrifos-methyl in papayuela, though they were consistent (RSDs < 16%). On the contrary, mean recovery percentages were higher than 140% for the three concentration levels for dichlorvos in yoyomo while punctual recovery values higher than 120% were achieved in certain cases (they are marked in bold in Table 3).

The lowest calibration levels (LCLs) were 5 µg/kg for all pesticides in the studied matrices. As previously indicated, no specific MRLs have been set for any pesticide in the selected matrices by the Codex Alimentarius, which is the reference for Colombia's pesticide legislation. However, such LCLs values are in accordance with the "default" and standard MRL of 10 µg/kg applied, for example, by the EU legislation (Regulation 396/2005, 2005).

The high sensitivity of the methodology is also in accordance with the LCLs/LOQs obtained with other methods in which pesticides were analysed in minor tropical fruits (FAO, Document BA/TF03/15, 2003; España Amórtegui & Guerrero Dallos, 2015; Paz et al., 2015; Yang et al., 2016). In the particular cases of the works of Yang et al. in which starfruits from China were analysed (Yang et al., 2016; Yang et al., 2018) and Botero-Coy et al., who also analysed pesticides in the same fruits from Colombia (Botero-Coy et al., 2015), though LC-MS/MS was used in both cases and not GC–MS/MS like in our work, the LOQs/LCLs achieved were the same order of magnitude for those pesticides in common with this work. Concerning the work of Pakvilai et al. (Pakvilai et al., 2011), in which GC-ECD was used for the analysis of 6

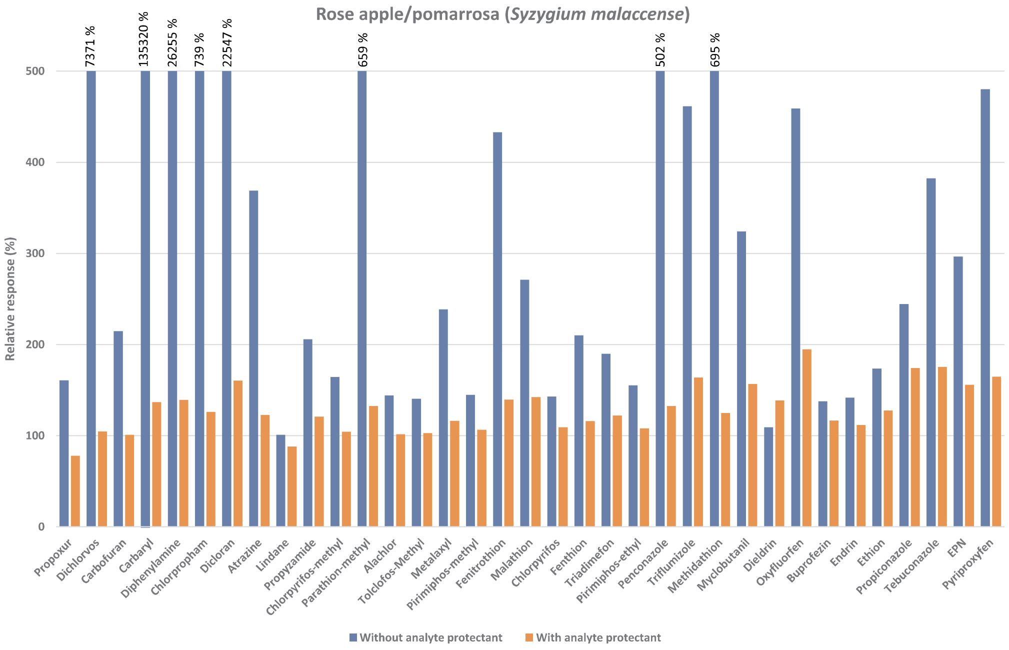

Fig. 2. Comparison of relative responses of the 35 selected pesticides at 0.8 mg/L obtained without (blue) and with (orange) the mixture of analyte protectants (3-ethoxy-1,2-propanediol, L-gulonic acid γ-lactone, D-sorbitol and shikimic acid at 10, 1, 1 and 0.5 g/L, respectively) for rose apple/pomarrosa (*Syzygium malaccense*). The relative responses were determined from the relationships: (blue) peak area in the matrix-matched standard/peak area in solvent standard × 100%, and (orange) peak area in matrix + analyte protectant/peak area in solvent with analyte protectant × 100%. Values over 100% are overestimations due to the matrix-induced response effect. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

pesticides (none of them were in common with our work) in rose apples from Thailand, the LODs of the method (LOQs were not reported) were in the range 0.11–0.65 mg/kg, which were much higher than the ones obtained in our work.

A general and more detailed comparison of the performance/characteristics of our work with those previously developed in which pesticides were determined in the same minor tropical fruits of the same or different origin can be seen in Table 1 of the Supplementary Material.

3.4. Analysis of real samples

In order to demonstrate the applicability of the method, 5 samples of carambola and papayuela and 6 samples of pomarrosa and yoyomo bought in different parts of the city of Bogotá were analysed. Confirmation of the identity of the compound in the samples was based on the agreement in retention time (maximum deviation ± 0.2 min between the analyte in sample and the reference standard), and on the acquisition of three MS/MS transitions (one quantifier and two qualifiers, see Table 1) and the compliance of q/Q ratio with maximum tolerance of ± 30% (SANTE Guidance, 2017). Results are shown in Table 4. As can be seen in the table, residues of chlorpyrifos, chlorpyrifos-methyl and fenitrothion were found in pomarrosa below the LCL while diphenylamine was found in yoyomo, also below the LCL. Regarding the presence of these pesticides in such samples, it should be remarked that, as previously indicated, no MRLs are established for them in such matrices. Even though, it can be concluded that none of samples contained the target analytes above 5 μg/kg (being the default/standard MRL that of 10 μg/kg).

As mentioned above, only Botero-Coy et al. (2015) have previously analysed pesticide residues in two carambola samples (one of them collected in Colombia) in which the only pesticides in common with our work were carbofuran, parathion-methyl, malathion and chlorpyrifos, since LC-MS/MS was used. However, Botero-Coy et al. only detected residues of carbendazim, dimethoate and triaclopid, which were not included in our selection. Pesticide occurrence found in this work, constitutes a complimentary information to that obtained by Botero-Coy et al. in which two samples (only one from Colombia) were analysed.

4. Conclusions

The AOAC 2007.1 QuEChERS method was successfully applied for the extraction of 35 multiclass pesticides from the minor tropical fruits rose apple/pomarrosa, starfruit/carambola, yoyomo and papayuela from Colombia. The recovery values were in the range 70–120% with RSD values lower than 20% for most of the pesticides studied in this work. The existence of ME was evidenced for a good number of the pesticides studied, especially in carambola and yoyomo samples. The analysis of real samples revealed the presence of chlorpyrifos, chlorpyrifos-methyl, fenitrothion and diphenylamine in some of the samples, but it all cases below the LCL of the method (5 μg/kg). The application of the QuEChERS method to the analysis of these minor fruits, some of them not previously analysed with this method, provides relevant data concerning the presence of these pesticides in such samples of interest.

Conflict of interest

Authors declare no conflict of interest.

Table 3
Average recoveries (RSDs) of the selected pesticides in representative matrices validation of the final method (n = 5 at each spiking level). Bold text indicates recovery outside the 70–120% range.

Pesticide	Carambola			Papayuela			Pomarrosa			Yoyomo		
	10 µg/kg	75 µg/kg	400 µg/kg	10 µg/kg	75 µg/kg	400 µg/kg	10 µg/kg	75 µg/kg	400 µg/kg	10 µg/kg	75 µg/kg	400 µg/kg
Propoxur	82(5)	74(4)	85(11)	77(14)	91(9)	106(2)	**126**(8)	114(13)	111(5)	77(14)	101(6)	110(7)
Dichlorvos	**123**(4)	78(13)	106(14)	**140** (11)	78(7)	76(3)	111(11)	115(8)	111(6)	**140**(11)	**159(22)**	**178**(11)
Carbofuran	116(20)	79(8)	91(7)	96(7)	**121**(1)	103(2)	**127**(8)	104(13)	105(7)	96(7)	**128**(9)	118(4)
Carbaryl	**167**(10)	107(4)	102(5)	**171**(8)	**122**(8)	111(0)	**129**(14)	113(12)	106(7)	84(12)	112(3)	**122**(2)
Diphenylamine	89(4)	72(5)	91(6)	88(6)	109(3)	100(2)	113(10)	111(10)	107(6)	88(6)	**137**(9)	**132**(11)
Clorpropham	71(8)	100(4)	107(3)	85(3)	111(3)	85(1)	112(16)	110(8)	107(7)	85(3)	**123**(5)	120(2)
Dicloran	119(16)	113(5)	113(3)	85(12)	111(4)	105(2)	87(6)	**122**(6)	**126(5)**	85(12)	113(6)	114(1)
Atrazine	107(8)	105(4)	103(2)	79(7)	112(4)	96(1)	107(10)	103(6)	101(6)	79(7)	105(1)	108(11)
Lindane	107(7)	86(3)	80(4)	102(4)	84(4)	70(4)	119(14)	111(6)	98(9)	102(4)	106(5)	106(10)
Propyzamide	80(9)	98(4)	105(2)	84(7)	116(3)	101(1)	96(3)	107(8)	104(7)	84(7)	102(2)	106(12)
Chlorpyrifos-methyl	73(9)	97(2)	93(3)	77(10)	**68**(3)	**65**(6)	92(9)	106(4)	101(9)	77(10)	103(2)	105(9)
Parathion-methyl	75(12)	**143**(4)	**135**(3)	85(12)	73(5)	77(3)	120(3)	**123**(7)	112(7)	85(12)	113(4)	111(10)
Alachlor	88(11)	98(2)	93(3)	83(8)	92(3)	83(2)	110(5)	100(10)	98(7)	83(8)	101(4)	104(11)
Tolclofos-methyl	84(7)	97(1)	91(3)	85(7)	79(3)	75(3)	115(13)	101(6)	98(8)	85(3)	102(2)	100(10)
Metalaxyl	98(13)	105(4)	101(2)	78(6)	108(1)	96(2)	93(16)	97(10)	99(7)	78(6)	91(7)	100(14)
Pirimiphos-methyl	81(12)	97(2)	90(3)	79(11)	78(3)	76(3)	82(11)	96(6)	94(8)	79(11)	101(3)	101(10)
Fenitrothion	75(11)	**136**(2)	**127**(2)	82(15)	71(6)	74(4)	76(17)	118(9)	110(9)	82(15)	109(5)	109(10)
Malathion	83(10)	**134**(2)	115(2)	90(15)	**66**(4)	71(5)	78(12)	110(9)	106(7)	90(15)	111(3)	116(10)
Chlorpyrifos	76(6)	91(3)	84(2)	76(7)	78(5)	74(4)	85(7)	90(5)	90(7)	76(7)	96(2)	98(10)
Fenthion	80(9)	113(3)	106(2)	80(16)	73(3)	72(5)	84(4)	101(6)	97(8)	85(11)	98(1)	97(11)
Triamidefon	89(4)	107(4)	104(2)	73(15)	110(4)	96(3)	111(8)	97(10)	97(7)	80(8)	94(4)	100(12)
Pirimiphos-ethyl	80(10)	94(4)	89(2)	80(15)	92(3)	87(4)	93(16)	84(8)	90(7)	83(14)	105(2)	101(10)
Penconazole	88 (19)	86(8)	96(4)	84(6)	103(3)	91(4)	72(6)	98(10)	94(8)	84(6)	93(9)	103(14)
Triflumizole	75(10)	109(2)	100(1)	82(10)	95(4)	89(3)	76(5)	87(8)	89(7)	82(10)	92(4)	100(11)
Methidathion	**60**(5)	74(5)	**62**(3)	81(14)	70(4)	70(5)	**128**(4)	113(8)	108(7)	81(14)	110(5)	111(11)
Myclobutanil	87(17)	101(7)	116(5)	93(10)	106(3)	96(2)	**67**(6)	102(10)	101(8)	93(10)	110(11)	117(13)
Dieldrin	82(8)	85(4)	83(2)	85(6)	87(4)	84(4)	**140**(5)	90(9)	88(7)	85(6)	90(4)	96(13)
Oxyfluorfen	70(9)	**139**(6)	110(2)	79(9)	98(5)	94(5)	72(15)	93(5)	94(5)	79(9)	85(6)	99(13)
Buprofezin	73(7)	93(2)	92(2)	80(6)	100(3)	87(3)	90(8)	87(10)	89(7)	80(6)	83(17)	96(12)
Endrin	71(13)	106(6)	90(2)	76(9)	**169**(4)	83(5)	87(14)	87(8)	90(6)	76(9)	74(35)	96(13)
Ethion	110(12)	**154**(3)	116(2)	87(13)	70(4)	71(4)	84(10)	95(9)	94(6)	87(13)	103(4)	102(10)
Propiconazole	99(20)	99(5)	100(4)	92(13)	106(4)	92(4)	77(10)	99(7)	92(10)	93(7)	93(8)	103(13)
Tebuconazole	91(8)	107(6)	111(3)	93(7)	102(4)	92(2)	71(9)	95(7)	96(7)	93(7)	101(6)	108(13)
EPN	89(10)	**143**(6)	120(2)	**154**(19)	**130**(7)	84(5)	93(10)	95(5)	95(4)	111(7)	87(13)	101(14)
Pyriproxyfen	85(11)	105(4)	111(2)	**127**(18)	97(4)	89(3)	92(11)	89(6)	93(6)	115(13)	91(6)	93(15)

Table 4
Pesticide content of several tropical fruits samples analysed by the proposed QuEChERS-GC-QqQ-MS/MS method.

Tropical fruits	Sample	Zone	Date of collection	Pesticides detected	Concentration (µg/kg)
Carambola	1	Colina campestre (Bogotá)	May 2018	–	–
	2	Nogal (Bogotá)	May 2018	–	–
	3	Spring (Bogotá)	May 2018	–	–
	4	Chapinero (Bogotá)	May 2018	–	–
	5	Santa Isabel (Bogotá)	May 2018	–	–
Papayuela	1	Colina campestre (Bogotá)	May 2018	–	–
	2	Nogal (Bogotá)	May 2018	–	–
	3	Spring (Bogotá)	May 2018	–	–
	4	Chapinero (Bogotá)	May 2018	–	–
	5	Santa Isabel (Bogotá)	May 2018	–	–
Pomarrosa	1	Colina campestre (Bogotá)	May 2018	–	–
	2	Nogal (Bogotá)	May 2018	–	–
	3	Spring (Bogotá)	May 2018	Chlorpyrifos	< LCL
	4	Chapinero (Bogotá)	May 2018	–	–
	5	Santa Isabel (Bogotá)	May 2018	Chlorpyrifos-methyl	< LCL
	6	Suba (Bogotá)	May 2018	Fenitrothion	< LCL
Yoyomo	1	Colina campestre (Bogotá)	May 2018	–	–
	2	Nogal (Bogotá)	May 2018	–	–
	3	Spring (Bogotá)	May 2018	Diphenylamine	< LCL
	4	Chapinero (Bogotá)	May 2018	–	–
	5	Santa Isabel (Bogotá)	May 2018	–	–
	6	Suba (Bogotá)	May 2018	–	–

(–) Pesticides were not detected.

Declaration of interests

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.foodchem.2018.12.045.

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SUPPLEMENTARY MATERIAL

High-throughput analysis of pesticides in minor tropical fruits from Colombia

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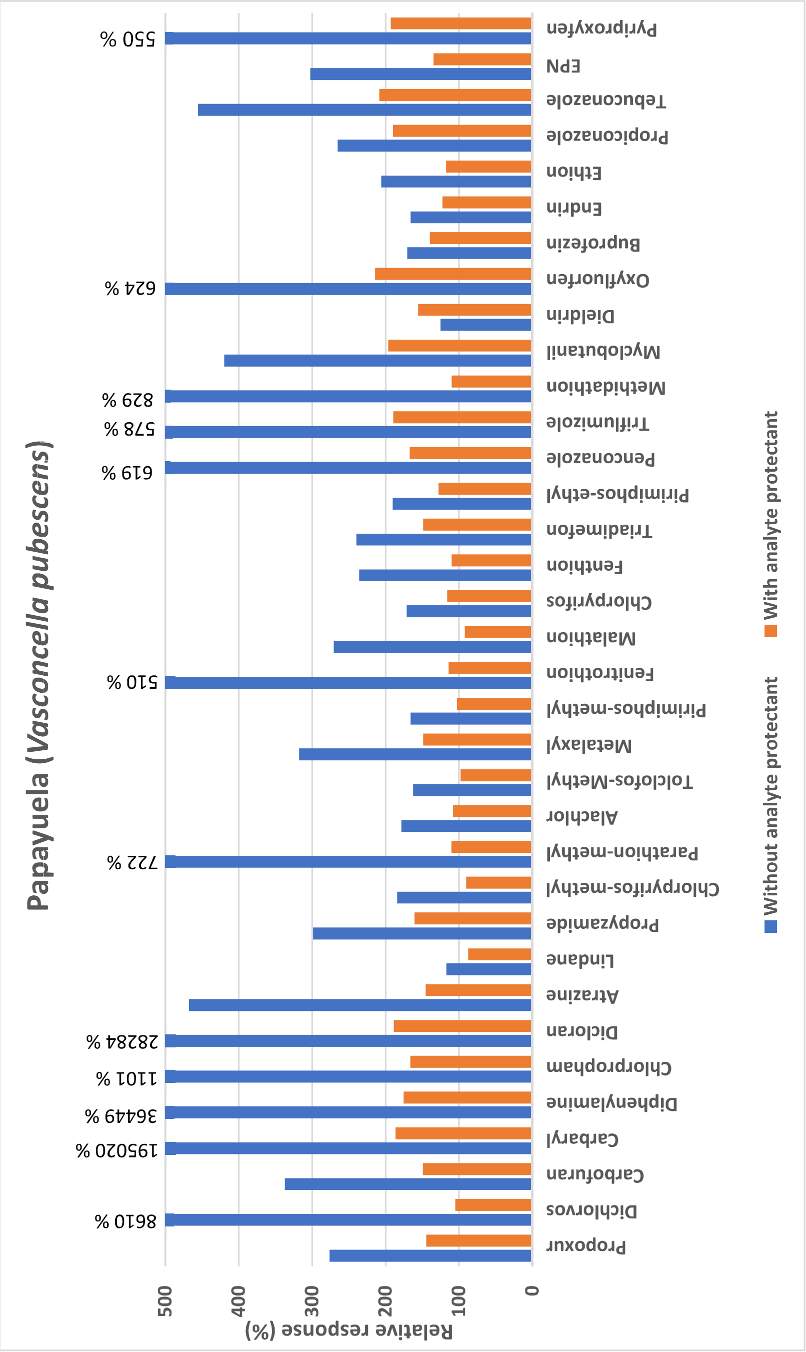
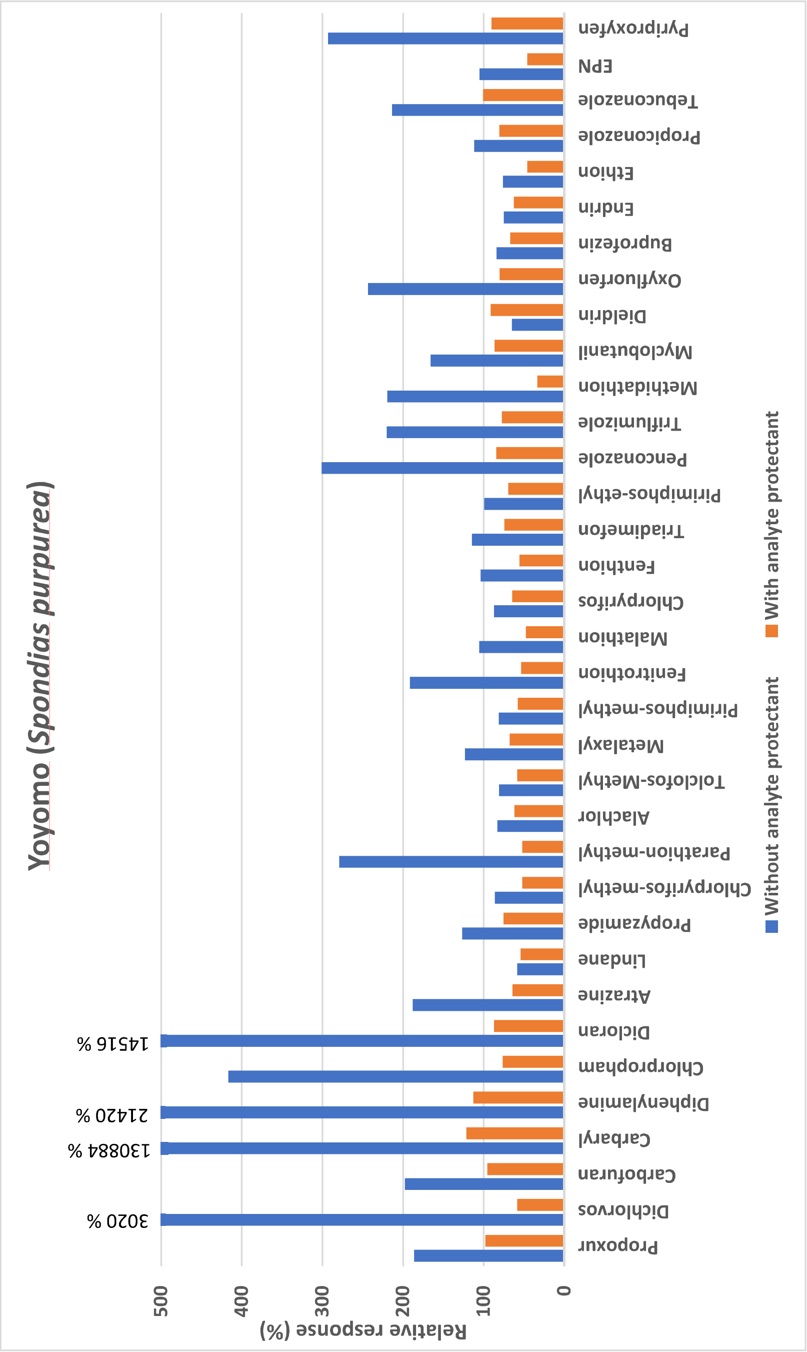
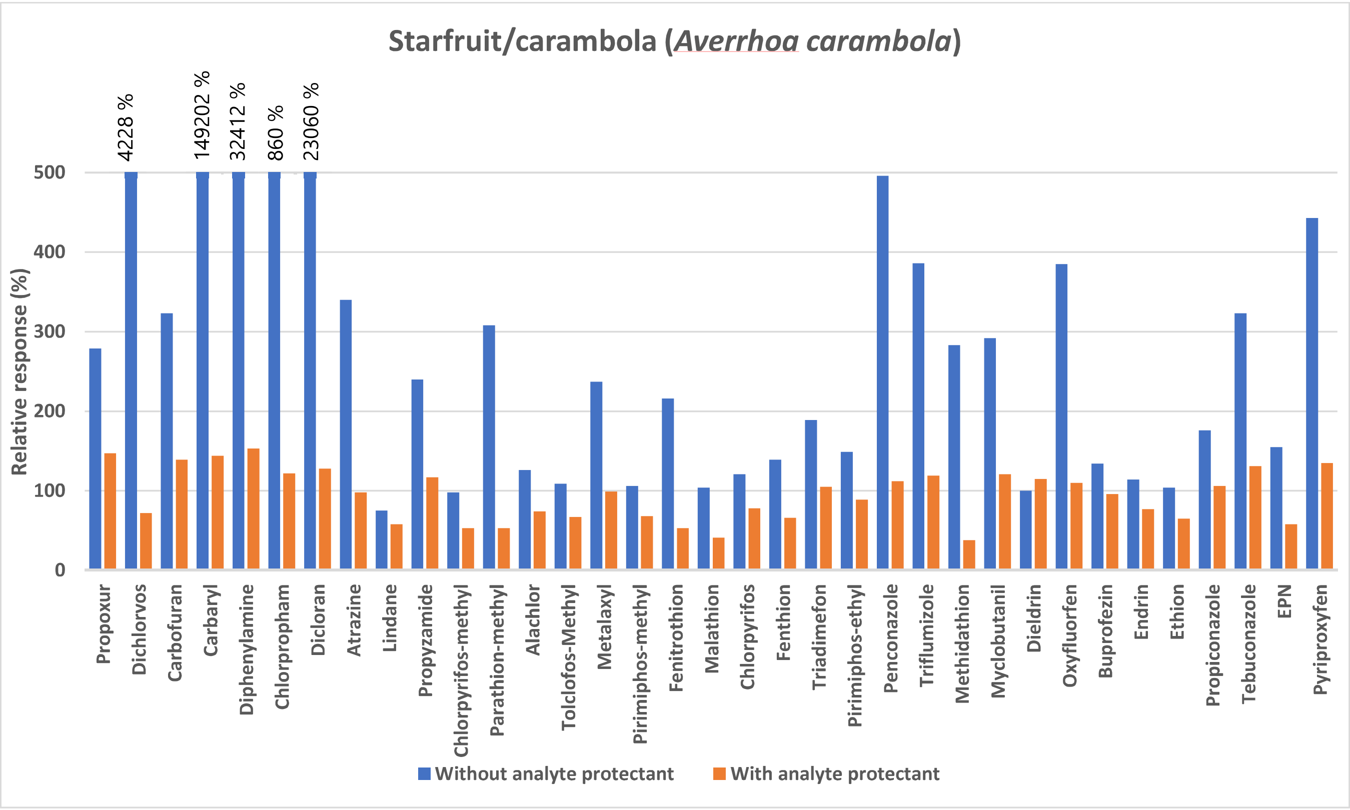
Food Chemistry, 2019, 280, 221-230



Varela-Martínez et al. Figure 1S



Varela-Martínez et al. Figure 2S



Varela-Martínez et al. Figure 3S

Table 1S.- Comparison of this work with those previously developed in which pesticides were determined in the same minor tropical fruits of the same or different origin.

Number of pesticides studied	**Pesticides in common with this work**	**Samples**	**Sample preparation procedure**	**Determination technique**	**Recovery values**	**LODs/LOQs**	**References**
6 synthetic pyrethroids	-	Vegetable, fruit (i.e. **rose apple**), sediment, and surface water samples from Thailand	Fruit: SLE with DCM and SPE with graphite carbon	GC-ECD	-	LODs: 0.11-0.65 mg/kg	Pakvilai et al., 2011
19 pesticides	Carbofuran, parathion-methyl, malathion and chlorpyrifos	Uchuva, tamarillo, granadilla, gulupa, maracuya, papaya, and pithaya from Colombia, and lulo, **carambolo**, feijoa, mangostan, and guayaba consumed in Colombia	QuEChERS	LC-MS/MS	70-120 % for most analytes	LODs: 0.5–3.0 μg/kg	Botero-Coy et al., 2015
9 pesticides	-	**Starfruits**, Indian jujubes and wax apples from China	SLE with ACN and SPE	UPLC-MS/MS	61-129 %	LOQs: 0.01-0.1 mg/kg	Yang et al., 2016
50 pesticides	Atrazine, buprofezin, carbofuran, chlorpyrifos, dichlorvos, malathion, metalaxyl and triadimefon.	**Starfruits** and Indian jujubes from China	QuEChERS	UPLC-MS/MS	76-119 %	LOQs: 0.1-12 μg/kg	Yang et al., 2018
35 pesticides	**-**	**Rose apple/pomarrosa, starfruit/carambola, yoyomo and papayuela from Colombia**	**QuEChERS**	**GC-MS/MS**	**70-120 % for most analytes**	**LOQs:**	**This work**

SLE: Solid-liquid extraction; ACN: Acetonitrile; SPE: Solid-phase extraction; DCM: Dichloromethane

IV.2.- Analysis of multiclass pesticides in dried fruits using QuEChERS-gas chromatography tandem mass spectrometry

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Food Chemistry, 2019, 297, 124961

The aim of this work was to study the application of three different versions of the QuEChERS method (original, AOAC 2007.01 and CEN 15662 methods) for the extraction of 38 multiclass representative pesticides from dried fruits, in particular, from a mixture of dried strawberry, blackberry, passion fruit, pineapple and grapes. The first method is the classical version in which no buffering is considered, while the second uses the HOAc/acetate buffer and the third a citrate buffer. GC-QqQ-MS/MS was used as separation and determination technique using atrazine-d_5 as internal standard of the method and TPP as QC of the injection.

Initially, the three versions of the method were applied for the extraction of the selected pesticides from a spiked mixture of dried strawberry, blackberry, passion fruit, pineapple and grapes. Swelling of the sample by adding water was found necessary to achieve a high extraction efficiency. The amount of co-extracted material per mL of extract before and after the application of the dSPE procedure in each case was developed, finding that the employment of the dSPE clean-up step decreased coextracted material up to a 65.4 %, being the application of the AOAC 2007.1 version the one that provided the lowest amount of coextracts. Concerning the recovery values of each method, which were studied at three concentration levels, most of the pesticides studied presented overall recovery values in the range 70-120 % with RSD ≤ 20 % for all methods, except for some pesticides. However, results for the AOAC 2007.01 method were more consistent.

For comparison purposes, matrix-matched calibration was also developed for the three methods, using in all cases the analytes protectants of our previous manuscript. Results showed that the number of pesticides with a medium matrix effect was quite similar when the three methods were applied, however, the number of pesticides with a soft matrix effect was lower using the AOAC 2007.01 method and, as a result, it was finally selected.

To fully demonstrate the applicability of the AOAC 2007.01 official method to the extraction of the same group of 38 pesticides from the individual dried fruits, matrix-matched calibration, matrix effect and recovery values at three different concentration levels were also calculated and compared. Acceptable determination coefficients (R^2) values as well as recovery were obtained for all pesticides and matrices. Concerning matrix effects, all the matrices showed similar effects, though they were in general strong for nearly half of the pesticides.

Finally, several samples of each type bought in different parts of the city of Bogotá were analysed, finding residues of chlorpyrifos and iprodione in some of the samples, above the LCL of the method (5 μg/kg), as well as metalaxyl, but below such LCL.

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Analysis of multiclass pesticides in dried fruits using QuEChERS-gas chromatography tandem mass spectrometry

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ABSTRACT

In this work, three versions of the QuEChERS method (original, AOAC 2007.01 and CEN 15662) were evaluated for the extraction of 38 multiclass pesticides from a mixture of five dried fruits (strawberry, blackberry, passion fruit, pineapple and grapes) prior to their gas chromatography tandem mass spectrometry analysis. Among them, the AOAC 2007.01 method provided the best results in terms of lower amount of matrix co-extractives, matrix effect, extraction efficiency and precision. Its application to the analysis of the same pesticides in the individual dried fruits provided good recovery (between 70 and 120%) and relative standard deviation values (< 20%) for most pesticides at three spiked levels. Matrix effect assessment revealed the necessity of taking into account such effect. Matrix-matched calibration data were also satisfactory for all analytes and matrices being the $R^2 \geq 0.9900$ and the lowest calibration level 5 μg/kg, which is lower than the agreed limit set at 10 μg/kg for monitoring purposes in food applications. Three samples of each type were also analysed, finding residues of metalaxyl, chlorpyrifos and iprodione in some of them.

1. Introduction

As it is well-known, fruits are important components of a healthy diet since apart from their nutritional content (vitamins, fibre, etc.), their consumption has other clear benefits on human's health (Slavin & Lloyd, 2012; Riboli & Horel, 2003; Hung et al., 2004). However, most fruits are produced on a seasonal basis and, therefore, they are not available fresh during the rest of the year. A good alternative to maintain the consumption of fruits throughout the year is by eating the so-called dehydrated or dried fruits, which, as a result of the elimination of a large proportion of their water content, are high-caloric snacks rich in nutrients (Alasalvar & Shahidi, 2013a; Alasalvar & Shahidi, 2013b). In fact, they are nutritionally equivalent to fresh fruits in smaller serving sizes (Chang, Alasalvar, & Shahidi, 2016).

Drying is one of the oldest and most common preservation methods since water removal minimizes many of the moisture-driven deterioration reactions. Thanks to the process of dehydration, fruits as a whole or cut into small pieces or slices can be preserved under perfect conditions for much longer time than fresh fruits, and without the addition of additives (though in some cases sugar solutions or a fruit juice concentrate is added before drying as it frequently happens with blueberries, cherries or strawberries, among others). As a result, their distribution and storage are much easier. Regarding drying methods, water can be eliminated naturally under the sun or using special dryers or dehydrating devices which are frequently based on hot-air, freeze, vacuum or microwave drying (Alasalvar & Shahidi, 2013a; Alasalvar & Shahidi, 2013b). Storage stability greatly depends on the drying method followed (Karam, Petit, Zimmer, Djantou, & Scher, 2016).

Concerning dried fruits production, according to 2017 statistics of the International Nut and Dried Fruit Council (Nuts & Dried Fruits: Statistical yearbook, 2017/2018), those with the highest production are raisins with 1,196,500 metric tonnes (MT), followed by dates (1,025,000 MT), prunes (242,666 MT), apricots (226,760 MT) and figs (135,400 MT). However, statistics on the production of other dried

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fruits are generally scarce (Chang et al., 2016), though they are widely offered in different stores, markets, etc.

Similarly to fresh fruits, dried fruits may also contain pesticide residues (Zhao, Kong, Wei, & Yang, 2014) and, therefore, suitable analysis should be developed to guarantee their safe consumption. Among the current sample preparation methods most commonly applied nowadays for pesticide residues analysis, the QuEChERS method can be highlighted as a result of its inherent properties: rapidity, facility, low cost, effectivity, ruggedness and safety (González-Curbelo et al., 2015; Wilkowska & Biziuk, 2011). Originally developed for the analysis of pesticides in fresh fruits and vegetables, the method was also modified to expand its application to other commodities, including dried fruits, which analysis is particularly complex as a result of their low water content. Therefore, since dried fruits can be considered as concentrated forms of fresh fruits, the most important modification should involve the addition of water to promote a swelling process which improves the extraction yield, as it has been done for other food matrices of low water content such as cereal grains (González-Curbelo, Lehotay, Hernández-Borges, & Rodríguez-Delgado, 2014; Kolberg, Prestes, Adaime, & Zanella, 2011) and flours (Kolberg et al., 2011; González-Curbelo, Dionis-Delgado, Asensio-Ramos, & Hernández-Borges, 2012; González-Curbelo, Socas-Rodríguez, Herrero, Herrera-Herrera, & Hernández-Borges, 2017). However, a complete reconstitution cannot be achieved with the simple addition of water. Hence, it is necessary to carry out a detailed study of the method for specific dried fruits.

Despite the high interest of the analysis of pesticide residues in this type of samples, up to now, and to the best of our knowledge, the number of published works related with this topic is extremely reduced (Rasche, Fournes, Dirks, & Speer, 2015; Liu et al., 2016; Rutkowska, Łozowicka, & Kaczyński, 2019). As an example, Rasche et al. (Rasche et al., 2015) studied the application and modification of the QuEChERS method to three dried fruits (raisins, apples and blackcurrant) prior to their determination by gas chromatography tandem mass spectrometry (GC–MS/MS). In particular, the CEN 15,662 method was applied including a swelling process using 10 mL of water and 10 mL of acetonitrile (ACN) for 5 g of each dried fruit during 30 min of agitation. Conversely, Liu et al. (Liu et al., 2016) applied a new unbuffered QuEChERS method to determine 29 pesticides in dried red peppers. In this case, 2 g of sample together with 5 mL of water were soaked for 20 min prior to the addition of 20 mL of 99/1 (v/v) ACN/acetic acid, unlike when they used undried peppers in which they did not add water. Finally, Rutkowska et al. (Rutkowska et al., 2019) also applied CEN 15,662 method for the determination of 236 pesticides in three dried herbs (*Centaurea cyanus L., Matricaria chamomilla L., Thymus vulgaris L.*) and in dried fruit currants and chokeberry. For that purpose, and regarding the first step of the extraction method, 10 mL of water were added to 2 g of the homogenized samples before the final addition of 10 mL of ACN containig 1% of formic acid.

The aim of this work was to study the application of different versions of the QuEChERS method (original, AOAC 2007.01 and CEN 15,662 methods) for the extraction of 38 multiclass pesticides from dried fruits, in particular, from a mixture of dried strawberry, blackberry, passion fruit, pineapple and grapes. Once selected, the method was applied to the extraction of each dried fruit alone. As previously indicated, to the best of our knowledge, this is the first time that the QuEChERS method is applied to the extraction of pesticides from these particular dried fruits, and one of the very few works of the literature in which dried fruits have been analysed since limited information on this issue is currently available.

2. Materials and methods

2.1. Reagents

Analytical standards of the pesticides studied (all with purity ≥ 95.9%) as well as atrazine-d_5 (purity of 99.7%) and triphenylphosphate (TPP, purity of 99.0%) as procedural internal standard (IS) and quality control (QC) of the injection, respectively, were obtained from Sigma-Aldrich (St. Louis, MO, USA). Analytes protectants formed by 3-ethoxy-1,2-propanediol (ethylglycerol), L-gulonic acid-γ-lactone (gulonolactone), D-sorbitol and shikimic acid (all with purity ≥ 95.0%) were also obtained from Sigma-Aldrich.

Individual stock solutions of each pesticide at approximately 1000 mg/L, atrazine-d_5 at 750 mg/L and TPP at 1050 mg/L were prepared in toluene and stored in the darkness at −20 °C. For spiking purposes (spiking before the extraction procedure), mixtures of the pesticides and the IS were prepared in ACN with 0.05% (v/v) of formic acid to yield 25, 200 and 400 μg/kg sample equivalents for the pesticides and 200 μg/kg for the IS. For matrix-matched calibration purposes (spiking after the extraction procedure), mixtures of the pesticides and IS were prepared in the same way to yield 5, 10, 25, 75, 200, 400 and 600 μg/kg, and 200 μg/kg, respectively. For QC purposes, a TPP solution was also prepared in ACN with 0.05% (v/v) of formic acid and added to all final extracts just prior to GC–MS/MS analyses to yield a concentration of 200 μg/kg in the sample. A mix of analytes protectants containing 100 g/L of ethylglycerol, 10 g/L of gulonolactone, 10 g/L of D-sorbitol and 5 g/L of shikimic acid was prepared in 4/1 (v/v) ACN/water with 0.5% (v/v) of formic acid and was also added just before the injection.

Solvents including GC–MS-grade ACN, toluene, GC-ECD/FID-grade methanol, ethyl acetate and glacial acetic acid were acquired from Merck (Darmstadt, Germany). Extraction salts including anhydrous magnesium sulphate, sodium acetate, sodium chloride, sodium hydrogencitrate sesquihydrate and sodium citrate tribasic dehydrate were purchased from Sigma-Aldrich. Finally, other salts used in the dispersive solid-phase extraction (dSPE) clean-up step as primary secondary amine (PSA) and octadecylsilane (C_{18}) were obtained from Supelco (Bellefonte, PA, USA).

2.2. Samples

Dried fruits including strawberry, blackberry, passion fruit, pineapple and grapes were purchased separately from local food stores in Bogota, Colombia, and all of them, which were initially analyzed, were free of the target pesticides residues. As required, since the dried fruits were already milled and homogenized, approximately 1 kg of each were directly used or previously mixed.

2.3. GC-QqQ-MS/MS conditions

GC–MS/MS analyses in multiple reaction monitoring (MRM) mode were carried out using a Shimadzu GCMS-TQ8040 triple-quadrupole (QqQ) mass spectrometer with an electron ionisation interface and an autosampler AOC 20i/s. Chromatographic separation was achieved on a SH-Rxi-5Sil MS column (30 m × 0.25 mm i.d., 0.25 μm) from Shimadzu. The oven temperature program of the GC was as follows: 50 °C (for 1 min), 25 °C/min ramp to 180 °C, then 5 °C/min ramp to 230 °C and finally 25 °C/min ramp to 290 °C and held for 5 min. Total analysis time was 24.6 min. Helium was employed as the carrier gas at 1.2 mL/min. The rest of the parameters were set as follows: MS interface, 250 °C; ion source, 300 °C; injection temperature in the splitless mode, 250 °C; injection volume, 1 μL. After 1 min of the injection, the split was opened. An auto-tune of the MS parameters was insured before each injection sequence and the syringe was washed with successive but individual rinses of methanol, ethyl acetate and ACN between injections. Table 1 of the Supplementary Material shows the retention times (t_R) and the MRM parameters of the selected pesticides, IS and TPP.

2.4. Sample preparation

In this work, three different methods were compared: A) Original QuEChERS method (unbuffered); B) AOAC 2007.01 official method (buffered); and C) CEN 15,662 official method (buffered). These 3 methods consisted of the following steps: 1) 5 g of a mixture of dried fruits composed of strawberry, blackberry, passion fruit, pineapple and grapes, or each of them separately, were introduced in a polypropylene falcon tube of 50 mL. For recovery purposes, spikes were made to yield 25, 200 and 400 µg/kg for the pesticides, and 200 µg/kg for the IS, in the sample. 2). Thereafter, 10 mL of ACN were added for both the original and CEN 15,662 methods, or 10 mL of ACN with 1% (v/v) of acetic acid for the AOAC 2007.01 method, and 10 mL of water for all methods. Then, the sample was thoroughly shaken employing an automated shaker for 1 h. 3) Next, 4 g of anhydrous magnesium sulphate and 1 g of sodium chloride were added for the original version, or 6 g of anhydrous magnesium sulphate and 1.5 g of sodium acetate for the AOAC 2007.01 version, or 4 g of anhydrous magnesium sulphate, 1 g of sodium chloride, 1 g of sodium citrate tribasic dehydrate and 0.5 g of sodium hydrogencitrate sesquihydrate for the CEN version. Then, the sample was vigorously shaken for 5 min by hand and centrifugated for 5 min at 4400 rpm. 4) 1 mL of the supernatant was transferred to a 2 mL tube containing 150 mg of anhydrous magnesium sulphate, 50 mg of PSA and 50 mg of C_{18} for the original and AOAC 2007.01 methods, or 150 mg of anhydrous magnesium sulphate, 25 mg of PSA and 25 mg of C_{18} for the CEN 15,662 method. Then, the tube was vortexed for 30 s and centrifuged at 4400 rpm for 5 min. 5) Afterwards, 200 µL of the supernatant were transferred to the appropriately labeled autosampler vials and 50 µL of the TPP solution to yield 200 µg/kg (for calibration purposes, this solution included the standards to yield 5, 10, 25, 75, 200, 400 and 600 µg/kg and the IS to yield 200 µg/kg) and 20 µL of the analytes protectants mixture, both in ACN, were added. 6) Finally, 1 µL was injected in the GC-QqQ-MS/MS system.

For co-extracted material determination, an aliquot of 1 mL of the supernatant after applying each of the 3 methods before and after of their corresponding clean-up steps were collected in a test tube. This extract was evaporated to dryness using a water bath at 40 °C under a stream of nitrogen and the tube was cooled in a desiccator and weighted after being on the stove at 120 °C for 1 h. This procedure was carried out in triplicate.

The performance of each method was compared using a "*t* test two-sample assuming equal variances" which was carried out using Microsoft Excel software.

2.5. *Matrix effect assessment*

Matrix effect (ME) was calculated as % ME = [(slope of matrix-matched calibration-slope of pure solvent calibration)/(slope of solvent calibration)] × 100 as previously developed (Kwon, Lehotay, & Geis-Asteggiante, 2012). A soft ME is considered when its values range between −20% and 0% (suppression) or between 0% and 20% (enhancement). When the ME values range between −50% and −20% or between 20% and 50%, it is considered a medium effect. Finally, if the ME values are below −50% or above 50%, it is considered to be a strong effect of signal suppression or enhancement, respectively (Kmellár et al., 2008).

3. Results and discussion

3.1. *GC-QqQ-MS/MS analysis*

As shown in Table 1 of the Supplementary Material, a group of 40 targeted analytes including 38 pesticides, atrazine-d_5 as procedural IS and TPP as QC were monitored by GC-QqQ-MS/MS using three MS/MS transitions, one for quantitation and two for confirmation. These pesticides represent the most important chemical families of pesticides and they have been widely used in fruit crops. In fact, all these pesticides have been frequently studied in different works devoted to the analysis of pesticides in fresh fruits (Fernandes et al., 2014; Koesukwiwat, Lehotay, & Leepipatpiboon, 2011; Varela-Martínez, González-Curbelo, González-Sálamo, & Hernández-Borges, 2019). However, beyond the MRM conditions reported by other authors for these analytes, the transitions and their corresponding collision energies were determined from the most abundant ions in the range 5–40 V in 5 V intervals by running each individual pesticide. In this sense, it should be noted that, for many pesticides, the higher mass ion was selected with the objective of minimizing background interferences (Kochman, Gordin, Goldshlag, Lehotay, & Amirav, 2002). Thus, the molecular ion as precursor ion was used when possible (i.e. atrazine, chlorpropham, dicloran, fenamiphos, fenitrothion, fenthion, parathion-methyl) in order to achieve a higher selectivity and lower detection levels in the matrices studied which are of a high complexity. Finally, the most intense transition was selected as the quantifier transition and the second and third strongest transitions worked as the qualifier transitions, although not always from the same precursor ion because a second or third transition was weaker than when another precursor ion was used. All of the above allowed to reach levels as low as 5 µg/kg for all pesticides both in pure solvent and in the matrices, as required by the standard maximum residue limit (MRL) established in 10 µg/kg to realize monitoring in food applications (Regulation (EC) NO 396/2005, 2005).

3.2. *Comparison of different versions of the QuEChERS method for the analysis of a mixture of dried fruits*

3.2.1. *Co-extracted material determination*

Although buffering the extraction media around pH 4 or 5 in QuEChERS has shown to yield higher extraction efficiency of pH-dependent pesticides independently of the sample pH (Lehotay, Mastovská, & Lightfield, 2005), as it happens in the official AOAC 2007.01 (Lehotay, 2007) and CEN 15,662 (Payá et al., 2007) methods, other aspects should be considered. In this sense, the reduction of the amount of co-extracted material is an important task because it can negatively affect the recovery values and increase the need for equipment maintenance so as not to lose instrument performance (Maštovská, Dorweiler, Lehotay, Wegscheid, & Szpylka, 2010). Therefore, and since this is the first time that any QuEChERS method is applied to these matrices, the two official methods and the original version (Anastassiades, Lehotay, Stajnbaher, & Schenck, 2003) were investigated in a mixture of dried fruits conformed by equal amounts of strawberry, blackberry, passion fruit, pineapple and grapes.

As explained, a swelling of the sample should be included to obtain high extraction efficiency from dried fruits (Rasche et al., 2015; Liu et al., 2016; González-Curbelo et al., 2015). In our case, it was carried out for all versions of the method by adding 10 mL of water to 5 g of sample, together with 10 mL of ACN, and subsequent agitation during 1 h before co-extracted material determination (see Section 2.4). Table 1 shows the amount of co-extracted material per mL of extract before and after the application of the dSPE procedure. As can be seen,

Table 1
Amount and percentage of co-extracted material of a dried fruit mixture when different QuEChERS methods were used (data is shown as a mean of three determinations and the standard deviation).

	AOAC 2007.01	CEN	ORIGINAL
Amount of co-extracted material before the dSPE (mg/mL)	8.8 ± 0.3	15.2 ± 0.4	20.5 ± 0.8
Amount of co-extracted material after the dSPE (mg/mL)	5.3 ± 0.1	7.6 ± 0.8	7.1 ± 0.6
Percentage of co-extracts eliminated in the dSPE step (%)	40.9	50.7	65.4
Amount matrix co-extractives (µg) injected in 1 µL	3.9	5.6	5.3

dSPE: dispersive solid-phase extraction.

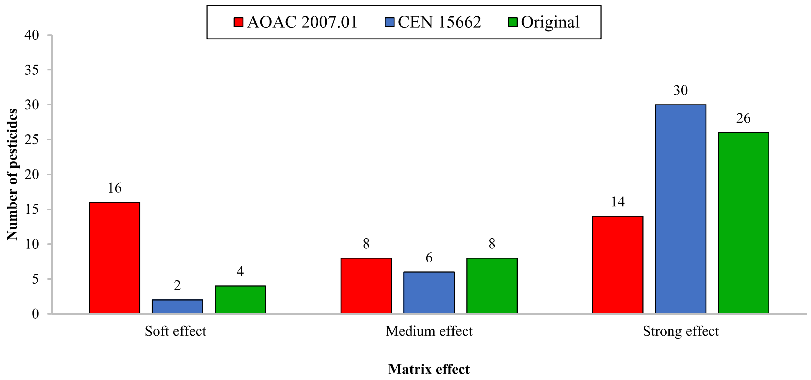

Fig. 1. Matrix effect distributions for the 38 studied pesticides in the mixture of dried fruits applying the AOAC 2007.01, CEN 15,662 and original QuEChERS methods prior to GC–MS/MS analysis.

the employment of the dSPE clean-up step decreased this negative amount between 40.9 and 65.4%. However, the application of the AOAC 2007.1 version provided the highest reduction and, consequently, the smallest amount of co-extracted material per injection: only 3.9 µg/µL considering 200 µL of extract and a final volume of 270 µL.

Concerning the amount of co-extracted material before the application of the dSPE procedure, when a statistical comparison was carried out between each two pairs of them, it was found that their variances did not differ significantly but when a *t* test two-sample assuming equal variances was run, it was found that they were statistically different. On the contrary, when the amount of co-extracted material after the application of the dSPE procedure was statistically compared, it was also found that their variances did not also differ significantly and that when a *t* test two-sample assuming equal variances was run, only the mean values of the CEN and the original methods were not statistically different from each other. Judging from these results, and in terms of coextracted material, both the CEN and the original method provide the same results. However, the best option for the removal of matrix components of the mixture of dried fruits is still the AOAC method and, as it will be later shown, also concerning consistent recovery values for most of the studied analytes.

3.2.2. *Linearity and matrix effect*

The three versions of the QuEChERS method were also studied in terms of linearity and ME changing the inlet liner and septum between injection sequences (one per applied method). The obtained matrix-matched calibration and standard calibration data including the determination coefficients (R^2) and ME results are presented in Table 2 of the Supplementary Material. As can be observed, linearity was achieved in the range 5–600 µg/kg (the limits of quantification were < 5 ng/g for all pesticides, which was the lowest calibrated level, LCL) for all three methods, obtaining for all pesticides R^2 values higher than 0.9900, except for carbaryl using the original method, which was 0.9870. ME were slightly different between methods.

ME is considered one of the most important and most common problems that can adversely affect quantification in pesticides analysis, particularly when analyzing complex samples in GC analysis (Kwon et al., 2012). To compensate this effect, in addition to the use of an IS and matrix-matched calibration, the use of a mixture of analyte protectants formed by ethylglycerol, gulonolactone, D-sorbitol and shikimic acid was incorporated as the best combination to effectively interact with and mask active sites in the GC system as previously demonstrated (Anastassiades, Mastovská, & Lehotay, 2003; Payá et al., 2007; Varela-Martínez et al., 2019). However, these measures are not usually enough to fully compensate the ME, even when large amounts of analyte protectants are used, and therefore its determination is necessary (Čajka, Maštovská, Lehotay, & Hajšlová, 2005). Fig. 1 shows the ME distributions for the 38 pesticides studied applying the AOAC 2007.01, CEN 15,662 and original methods to the mixture of dried fruits. Although the number of pesticides that show a medium ME is quite similar when the three methods were applied, almost half of the analytes studied presented a soft ME for the AOAC 2007.1 version, 14 of 38, while this number is much smaller for the other two versions. Coherently, the number of pesticides that suffer a strong ME is much lower for the AOAC 2007.1 method (14 pesticides) than for the others (30 for the CEN15662 method and 26 for the original method). Therefore, the AOAC 2007.01 method was able to compensate the ME for a greater extent.

3.2.3. *Trueness and precision*

To test the recovery and repeatability of the three versions of the QuEChERS method studied, the mixture of the dried fruits was spiked at 25, 200 and 400 µg/kg (n = 5 each). Fig. 2 shows the overall recovery percentages and relative standard deviations (RSDs) for all pesticides and spiking levels (n = 15) -the detailed results are presented in Table 3 of the Supplementary Material-. Fig. 2 evidences that most of the pesticides studied presented overall recovery values in the range 70–120 % with RSD ≤ 20% for all methods, as established by the acceptance criteria (SANTE Guidance, 2017), but some pesticides did not meet this criteria (outside the box): only iprodione (128%) applying the AOAC 2007.01 version, propoxur (164%), carbofuran (149%), triadimefon (139%) and carbaryl (60%) applying the CEN 15,662 version, and propoxur (143%), carbofuran (139%), triadimefon (136%), carbaryl (123%) and propiconazole (122%) applying the original version. Moreover, the last two methods provided less consistency in the results (RSDs ≥ 20% for 11 and 7 pesticides for CEN and original methods, respectively) than the AOAC 2007.01 method (overall RSDs ≤ 21% for all pesticides), accordingly to the higher level of co-extracted material and greater ME. Therefore, based on all these aspects, the AOAC 2007.01 official method was selected as the best QuEChERS version to analyze multiclass pesticides in the selected dried fruits.

3.3. *Validation of the AOAC 2007.01 method for the analysis of individual dried fruits*

To fully demonstrate the applicability of the AOAC 2007.01 official method to the extraction of the same group of 38 pesticides from the

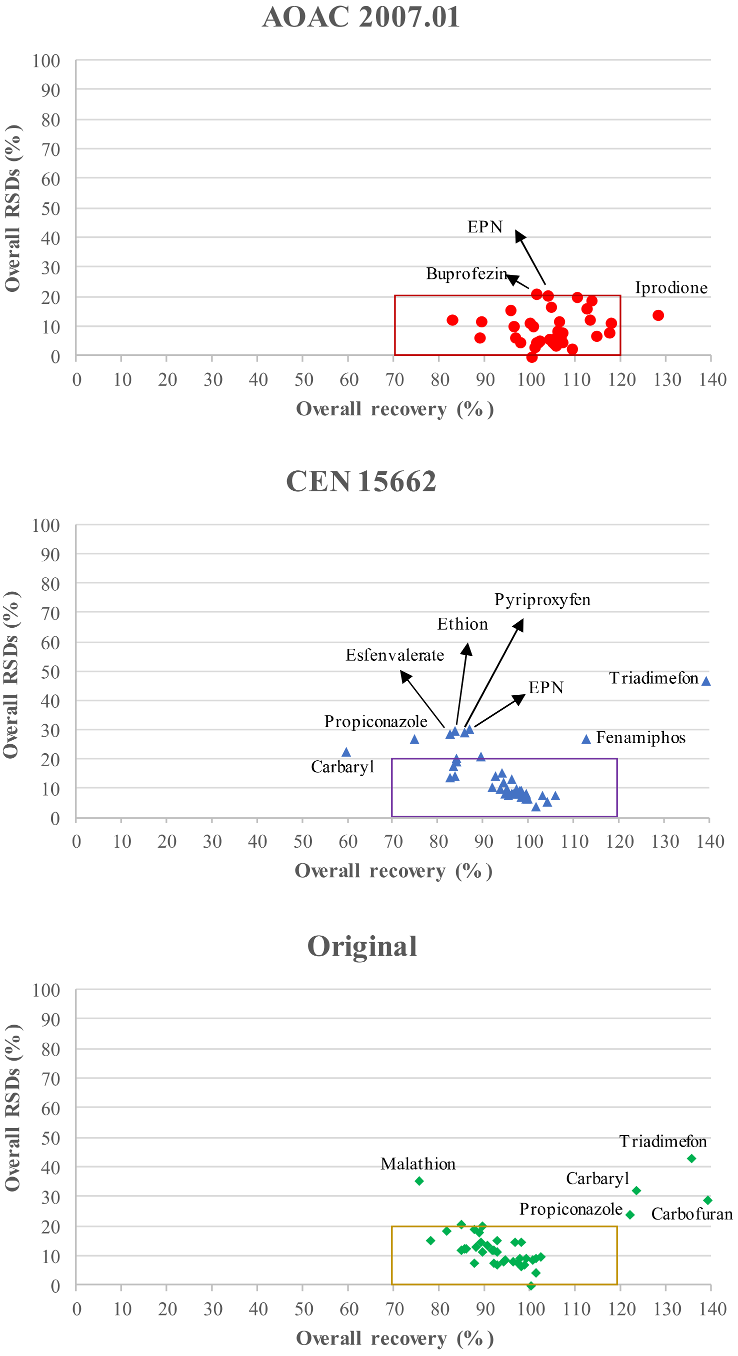

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Fig. 2. Overall recovery and RSD values for the 38 spiked pesticides in the mixture of dried fruits (strawberry, blackberry, passion fruit, pineapple and grapes) by GC-QqQ-MS/MS in the AOAC 2007.01, CEN 15,662 and original QuEChERS methods after spiking 25, 200 and 400 μg/kg (n = 15). The pesticides within the acceptable recovery and RSD are into the box.

Table 2
Average recovery and RSD values of the selected pesticides from different dried fruits after applying the QuEChERS AOAC 2007.01 method (n = 5 at each spiking level). Bold text indicates recovery outside the 70–120% range or RSD values > 20%.

	Strawberry			Blackberry			Passion fruit			Pineapple			Grape		
Pesticide	25 μg/kg	200 μg/kg	400 μg/kg	25 μg/kg	200 μg/kg	400 μg/kg	25 μg/kg	200 μg/kg	400 μg/kg	25 μg/kg	200 μg/kg	400 μg/kg	25 μg/kg	200 μg/kg	400 μg/kg
Propoxur	**61** (16)	91 (7)	105 (4)	96 (20)	114 (16)	101 (14)	104 (8)	99 (9)	117 (4)	92 (8)	95 (6)	97 (4)	107 (12)	120 (5)	108 (2)
Carbofuran	73 (14)	93 (7)	116 (7)	91 (16)	114 (16)	99 (7)	115 (12)	95 (8)	110 (2)	87 (13)	103 (6)	100 (4)	88 (20)	**122** (12)	76 (7)
Carbaryl	72 (14)	92 (4)	102 (7)	103 (18)	107 (17)	88 (10)	118 (17)	101 (6)	74 (10)	92 (5)	92 (4)	93 (2)	118 (11)	114 (4)	98 (3)
Diphenylamine	80 (9)	97 (4)	107 (4)	91 (18)	103 (17)	85 (8)	102 (9)	97 (6)	106 (1)	85 (3)	91 (4)	94 (3)	87 (11)	104 (4)	90 (3)
Chlorpropham	78 (4)	103 (3)	108 (3)	86 (12)	96 (13)	77 (12)	105 (4)	95 (5)	105 (3)	105 (4)	98 (5)	100 (4)	100 (9)	102 (4)	87 (3)
Dicloran	88 (15)	100 (5)	108 (16)	93 **(21)**	75 (16)	**69** (13)	89 (8)	99 (3)	101 (3)	83 (11)	107 (3)	92 (1)	87 (19)	87 (3)	77 (4)
Atrazine	91 (8)	97 (3)	103 (5)	89 (12)	96 (6)	93 (8)	101 (7)	102 (4)	99 (3)	99 (6)	98 (3)	99 (0)	79 (12)	113 (5)	96 (3)
Lindane	96 (9)	108 (3)	109 (4)	103 **(22)**	101 (11)	104 (10)	110 (6)	106 (4)	95 (3)	108 (15)	107 (4)	102 (3)	72 (14)	76 (5)	82 (6)
Propyzamide	92 (7)	101 (3)	108 (5)	78 (15)	93 (10)	96 (11)	101 (2)	97 (3)	103 (2)	98 (2)	101 (3)	100 (2)	96 (7)	112 (3)	96 (2)
Chlorpyrifos-methyl	107 (7)	106 (3)	106 (4)	78 **(24)**	89 (9)	81 (9)	109 (4)	101 (3)	98 (4)	111 (5)	108 (4)	104 (3)	105 (9)	104 (3)	83 (4)
Parathion-methyl	102 (8)	118 (2)	116 (6)	**134** (17)	**61 (21)**	**64** (20)	**121** (9)	**122** (6)	99 (7)	120 (11)	111 (5)	112 (2)	81 (17)	91 (6)	87 (4)
Alachlor	89 (9)	106 (2)	109 (4)	83 (19)	106 (7)	106 (10)	109 (6)	100 (2)	104 (1)	98 (3)	102 (3)	101 (2)	100 (8)	104 (3)	95 (2)
Tolclofos-methyl	89 (5)	103 (3)	110 (3)	80 (9)	97 (10)	96 (9)	104 (5)	101 (2)	103 (3)	108 (4)	105 (4)	99 (3)	93 (18)	97 (4)	88 (1)
Metalaxyl	84 (16)	96 (3)	102 (5)	110 (18)	112 (7)	108 (8)	91 (4)	96 (3)	98 (2)	104 (11)	98 (4)	98 (1)	113 (11)	100 (5)	102 (5)
Pirimiphos-methyl	93 (8)	102 (4)	110 (5)	73 (18)	99 (6)	105 (12)	106 (5)	98 (2)	104 (1)	105 (2)	103 (3)	102 (3)	102 (12)	99 (4)	91 (2)
Fenitrothion	119 (11)	119 (3)	116 (5)	112 (17)	70 (8)	70 (21)	115 (14)	114 (4)	102 (5)	81 (5)	117 (3)	113 (2)	93 (10)	103 (3)	88 (5)
Malathion	83 (6)	117 (3)	112 (8)	**154** (19)	117 (15)	117 (14)	**121** (6)	117 (6)	105 (4)	77 (12)	87 (7)	112 (5)	92 (17)	109 (3)	95 (2)
Chlorpyrifos	89 (6)	97 (3)	108 (4)	81 (10)	101 (7)	93 (10)	103 (5)	94 (2)	99 (1)	109 (5)	101 (4)	101 (2)	107 (5)	111 (4)	92 (2)
Fenthion	112 (4)	110 (2)	110 (5)	80 (13)	92 (10)	85 (7)	112 (3)	107 (2)	103 (2)	110 (1)	109 (3)	106 (2)	96 (16)	113 (4)	91 (4)
Triadimefon	106 **(21)**	104 (3)	103 (14)	99 (18)	103 (11)	91 (7)	103 (17)	99 (3)	104 (2)	92 (12)	114 (14)	93 (11)	**131** (9)	116 (7)	105 (2)
Pirimiphos-ethyl	81 (8)	107 (5)	107 (3)	**47** (12)	97 (7)	101 (12)	81 (5)	97 (3)	99 (3)	94 (4)	104 (3)	101 (2)	73 (19)	105 (5)	89 (2)
Penconazole	80 (8)	97 (3)	92 (19)	77 (21)	100 (9)	86 (8)	107 (4)	92 (3)	93 (3)	89 (4)	94 (3)	94 (2)	94 (19)	111 (6)	95 (3)
Triflumizole	95 (6)	98 (3)	102 (4)	73 (12)	118 (5)	110 (11)	92 (4)	97 (2)	96 (3)	92 (4)	98 (3)	95 (1)	99 (5)	102 (5)	94 (3)
Methidathion	89 (15)	116 (6)	115 (5)	105 (19)	71 (15)	71 (9)	**125** (15)	114 (8)	90 (9)	118 (9)	120 (6)	111 (3)	99 (6)	111 (3)	87 (5)
Fenamiphos	120 (11)	112 (3)	110 (5)	118 (15)	94 (16)	72 (15)	104 (9)	**65** (15)	**56** (4)	100 (3)	105 (3)	100 (1)	72 (26)	119 (3)	104 (4)
Myclobutanil	84 (6)	101 (4)	110 (5)	91 (19)	108 (9)	93 (10)	107 (5)	99 (2)	99 (2)	96 (1)	101 (2)	99 (1)	84 (17)	120 (6)	103 (4)
Dieldrin	94 (6)	97 (3)	103 (4)	99 **(25)**	99 (8)	99 (6)	91 (12)	83 (5)	87 (2)	74 (10)	94 (4)	94 (2)	74 **(25)**	86 (7)	76 (4)
Oxyfluorfen	108 (9)	107 (4)	109 (5)	103 (18)	76 (18)	95 (16)	86 (7)	96 (3)	100 (3)	90 (4)	107 (3)	108 (2)	79 (20)	96 (6)	81 (4)
Buprofezin	87 (5)	93 (3)	102 (4)	72 **(27)**	100 (9)	92 (6)	81 (15)	88 (1)	92 (3)	89 **(22)**	100 (3)	97 (2)	107 (2)	100 (8)	86 (2)
Endrin	100 (9)	99 (4)	105 (4)	**53** (10)	100 (6)	97 (7)	84 (11)	80 (4)	84 (2)	91 (12)	94 (4)	95 (1)	95 (5)	84 (8)	71 (5)
Ethion	101 (7)	107 (4)	110 (4)	84 **(24)**	84 (15)	96 (19)	88 (11)	102 (4)	98 (2)	107 (6)	107 (3)	105 (2)	98 (15)	110 (3)	86 (3)
Propiconazole	108 (7)	103 (5)	118 (5)	78 (7)	86 (15)	84 (20)	97 (16)	113 (7)	120 (4)	113 (11)	119 (9)	99 (1)	80 (20)	**121** (19)	113 (5)
Tebuconazole	87 (6)	98 (5)	107 (5)	115 (19)	103 (9)	84 (11)	95 (5)	96 (3)	102 (2)	94 (1)	98 (2)	98 (1)	114 (11)	116 (6)	106 (3)
Iprodione	108 (20)	106 (5)	110 (20)	113 **(21)**	89 (14)	71 (16)	116 (12)	85 (8)	79 (14)	102 (13)	104 (9)	103 (7)	75 (3)	106 (18)	94 (16)
EPN	87 (16)	118 (2)	111 (6)	70 **(24)**	72 (13)	74 (14)	105 (18)	92 (8)	83 (8)	82 (12)	114 (3)	113 (2)	103 (13)	103 (6)	75 (2)
Pyriproxyfen	**123** (6)	107 (4)	110 (6)	113 (20)	85 (17)	**69** (12)	95 (18)	99 (7)	95 (2)	75 (9)	94 (3)	94 (1)	95 (13)	110 (5)	85 (5)
Fenvalerate	97 (7)	105 (3)	107 (6)	112 (19)	74 (11)	71 (13)	87 (11)	89 (14)	89 (3)	106 (4)	109 (4)	107 (1)	99 (11)	95 (4)	71 (7)
Esfenvalerate	92 (8)	107 (4)	108 (6)	112 (20)	74 (19)	70 (9)	82 (12)	87 (14)	84 (17)	112 (3)	110 (4)	105 (3)	82 (10)	94 (3)	72 (7)

individual dried fruits, namely strawberry, blackberry, passion fruit, pineapple and grapes, it was validated in terms of matrix-matched calibration, ME, recovery and repeatability. This validation was carried out under the same conditions previously established for its application in the mixture of dried fruits. Initially, matrix-matched calibration curves were obtained for each sample matrix at seven concentration levels in the range 5–600 μg/kg (see Table 4 of the Supplementary Material). R^2 values were higher than 0.9900 for all pesticides and matrices. Regarding ME, and despite the use of the different strategies already mentioned, it was evident for a large number of the pesticides analysed. Fig. 1 of the Supplementary Material shows the ME distributions for the 38 pesticides studied applying the AOAC 2007.01 method to each individual fruit. As can be seen, ME for dried blackberries were higher than for the rest of the matrices. In particular, 34 pesticides showed a strong ME. Concerning dried grapes, ME were also high, with 28 pesticides having also a strong ME. The rest of the matrices showed similar effects, though they were in general strong for nearly half of the pesticides.

Finally, a recovery study was also developed at 25, 200 and 400 μg/kg for each dried fruit sample (n = 5 for each level and sample). As can be seen in Table 2, the vast majority of mean recovery and RSD values were within the criterion indicated above (97% of the possible combinations), which clearly demonstrated the effectiveness and repeatability of the selected method.

3.4. Analysis of real samples

With the aim of studying the possible pesticide content of different dried fruit samples, 15 samples marketed in several locations of the city of Bogotá (Colombia) were collected and analyzed in duplicate in September 2018 using the AOAC 2007.1 official method previously validated. The results are shown in Table 3. To ensure the unambiguous identification of the residues found, a maximum deviation of the retention time of ± 0.2 min was considered with respect to the reference standard and three MS/MS transitions (see Table 1 of the Supplementary Material).

It should be remarked that MRLs have been established for dried grapes by the Codex Alimentarius (Codex Alimentarius, 2018), but not for the rest of the dried fruits analysed in this work. Regarding the 38 pesticides analyzed, the MRLs established in dried grapes are the

Table 3
Pesticide content of several dried fruits samples analyzed by the QuEChERS AOAC 20017.01- GC-QqQ-MS/MS method.

Dried fruits	Sample	Zone	Date of collection	Pesticides detected	Concentration (μg/kg)[a]	Codex Alimentarius MRLs (μg/kg)
Strawberry	1	Las ferias (Bogotá)	Sept-18	–	–	–
	2	Nogal (Bogotá)	Sept-18	Metalaxyl	< LCL	n.e.
	3	Colina Campestre (Bogotá)	Sept-18	Metalaxyl	< LCL	n.e.
Blackberrry	1	Las ferias (Bogotá)	Sept-18	–	–	
	2	Nogal (Bogotá)	Sept-18	–	–	
	3	Colina Campestre (Bogotá)	Sept-18	Chlorpyrifos	400 ± 2	n.e.
Passion fruit	1	Las ferias (Bogotá)	Sept-18	–	–	
	2	Nogal (Bogotá)	Sept-18	–	–	
	3	Colina Campestre (Bogotá)	Sept-18	–	–	
Pineapple	1	Las ferias (Bogotá)	Sept-18	–	–	
	2	Nogal (Bogotá)	Sept-18	–	–	
	3	Colina Campestre (Bogotá)	Sept-18	–	–	
Grape	1	Las ferias (Bogotá)	Sept-18	Chlorpyrifos	9.4 ± 2.5	100
				Iprodione	135 ± 1	10000[b]
	2	Nogal (Bogotá)	Sept-18	–	–	
	3	Colina Campestre (Bogotá)	Sept-18	–	–	

(−) Pesticides not detected. n.e.: not established by the Codex Alimentarius.
[a] Mean of three determinations.
[b] Established for fresh fruits.

following: Buprofezin (2 mg/kg), chlorpyrifos (0.1 mg/kg), myclobutanil (6 mg/kg), parathion-methyl (1 mg/kg), penconazole (0.5 mg/kg), tebuconazole (7 mg/kg) and triadimefon (1 mg/kg); being slightly higher in all cases compared to the MRLs reported for fresh grapes except for chlorpyrifos (0.5 mg/kg). Therefore, the residual level of chlorpyrifos found in the dried grapes sample was lower than the limit set by this legislation: 9.4 μg/kg vs. 0.1 mg/kg. Regarding iprodione, as well as for the rest of the 38 pesticides, no MRLs have been reported in dried grapes by the Codex Alimentarius. However, the MRL value for the fresh fruit could be used as a reference. In such case, iprodione has a MRL value of 10 mg/kg which is much higher than the concentration found (135 μg/kg). Regarding the rest of the pesticide residues found, there are no MRL values for metalaxyl in fresh strawberry (metalaxyl was detected in two of the dried strawberry samples but below the LCL set at 5 μg/kg.) nor for chlorpyrifos in fresh strawberries (chlorpyrifos was found at a concentration of 400 μg/kg in one of the dried blackberry samples).

4. Conclusions

Trends in food sample preparation are focused on the development of faster, easier, more confident and cost-efficient methods, being the QuEChERS method the most used modern method for pesticide analysis. In this work, it is demonstrated that the AOAC 2007.01 official method provides the best results in terms of co-extracted material, ME and extraction efficiency than the original method and the CEN 15,662 official method for the determination of 38 multiclass pesticides in a mixture of selected dried fruits. Additionally, the AOAC 2007.01 official method was successfully applied for the first time for the analysis of pesticide residues in individual dried fruits (strawberry, blackberry, passion fruit, pineapple and grapes), obtaining good linearity and recovery values for almost all analytes in all matrices. The analysis of 15 commercialized dried fruit samples from Colombia revealed the presence of metalaxyl, chlorpyrifos, and iprodione in 4 of the samples but below the MRLs set by the Codex Alimentarius, which is the applicable legislation in the country.

Declaration of Competing Interest

Authors declare no conflict of interest.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.foodchem.2019.124961.

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SUPPLEMENTARY MATERIAL

Analysis of multiclass pesticides in dried fruits using gas chromatography tandem mass spectrometry

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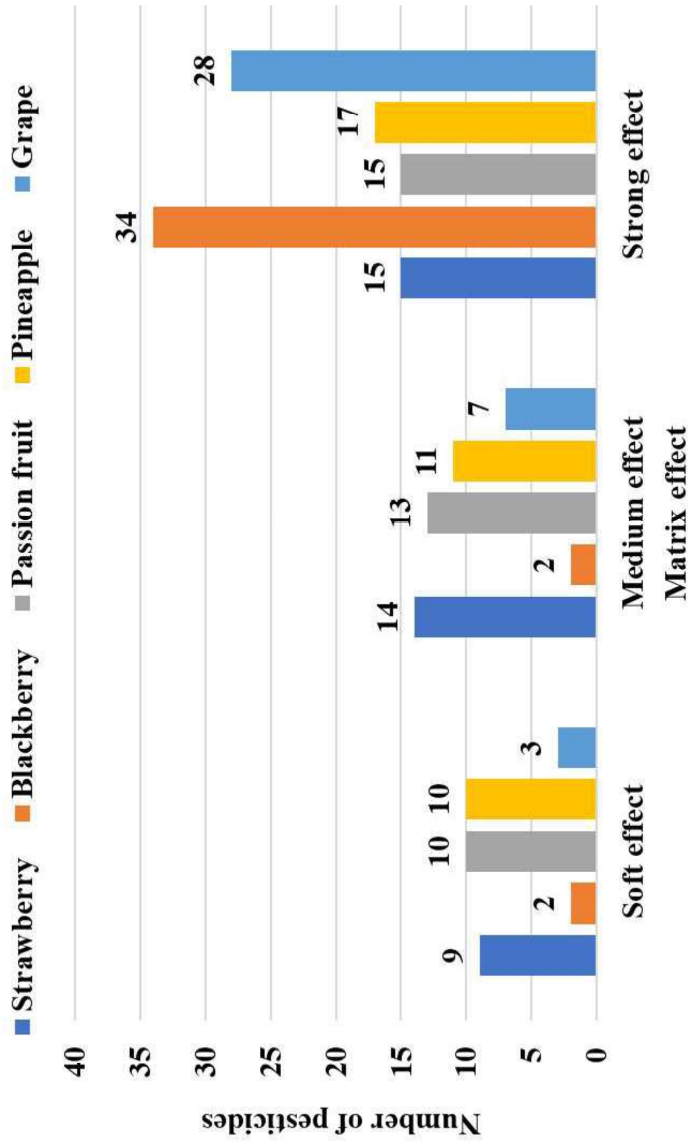

Varela-Martínez et al., Figure 1S

Table 1S.- Retention times, quantifier and qualifier transitions in the GC-QqQ-MS/MS analyses of the selected analytes.

Analyte	Retention time (min)	Quantifier transition (m/z)	Colision energy (V)	Qualifier transition (m/z)	Colision energy (V)	Qualifier transition (m/z)	Colision energy (V)
Propoxur	5.47	110.00→64.00	20	152.00→110.00	10	110.00→82.00	15
Carbofuran	6.25	164.00→149.00	10	149.00→103.00	15	149.00→103.00	15
Carbaryl	7.68	116.00→115.00	5	144.00→115.00	25	144.00→116.00	5
Diphenylamine	8.60	168.00→167.00	10	169.00→168.00	5	169.00→167.00	5
Chlorpropham	8.78	213.00→171.00	5	213.00→127.00	15	127.00→90.00	15
Dicloran	9.57	206.00→176.00	10	124.00→97.00	10	176.00→124.00	10
Atrazine-d5 (IS)	9.68	205.00→127.00	10	220.00→178.00	5	205.00→178.00	10
Atrazine	9.71	215.00→173.00	5	215.00→200.00	10	200.00→173.00	10
Lindane	10.03	183.00→181.00	5	219.00→181.00	10	181.00→111.00	10
Propyzamide	10.08	173.00→145.00	15	175.00→173.00	5	173.00→109.00	10
Chlorpyrifos-methyl	11.27	288.00→286.00	5	286.00→93.00	25	286.00→125.00	25
Parathion-methyl	11.43	263.00→109.00	15	109.00→79.00	10	263.00→125.00	10
Alachlor	11.45	188.00→160.00	10	160.00→132.00	15	188.00→146.00	10
Tolclofos-methyl	11.45	265.00→250.00	15	267.00→265.00	5	265.00→125.00	5
Metalaxyl	11.61	206.00→132.00	20	160.00→146.00	10	206.00→160.00	15
Primiphos-methyl	11.95	290.00→233.00	10	305.00→290.00	10	290.00→276.00	10
Fenitrothion	12.07	277.00→260.00	5	277.00→109.00	20	125.00→109.00	15
Malathion	12.25	127.00→99.00	5	173.00→127.00	5	125.00→93.00	5
Chlorpyrifos	12.48	314.00→258.00	15	199.00→171.00	15	197.00→97.00	15
Fenthion	12.58	278.00→109.00	20	278.00→137.00	10	278.00→245.00	10
Triamidefon	12.78	208.00→181.00	10	208.00→128.00	15	128.00→85.00	10
Pirimiphos-ethyl	13.05	333.00→168.00	25	333.00→318.00	10	318.00→180.00	10
Penconazole	13.59	161.00→159.00	5	248.00→159.00	25	248.00→161.00	5

Table 1S.-(Continued)

Analyte	Retention time (min)	Quantifier transition (m/z)	Colision energy (V)	Qualifier transition (m/z)	Colision energy (V)	Qualifier transition (m/z)	Colision energy (V)
Trifumizole	14.07	278.00→73.00	5	278.00→206.00	20	278.00→179.00	5
Methidathion	14.33	145.00→85.00	10	145.00→58.00	15	145.00→93.00	10
Fenamiphos	14.97	303.00→288.00	10	303.00→154.00	20	303.00→217.00	10
Myclobutanil	15.6	179.00→125.00	15	179.00→150.00	10	179.00→82.00	10
Dieldrin	15.67	263.00→191.00	30	263.00→193.00	30	263.00→81.00	35
Oxyfluorfen	15.67	361.00→300.00	15	252.00→223.00	15	300.00→252.00	15
Buprofezin	15.85	172.00→57.00	20	175.00→172.00	5	105.00→83.00	10
Endrin	16.32	263.00→193.00	30	263.00→228.00	20	263.00→228.00	20
Ethion	16.73	153.00→97.00	10	153.00→125.00	5	231.00→153.00	5
Propiconazole	17.55	175.00→173.00	5	259.00→69.00	10	259.00→173.00	10
Tebuconazole	17.82	250.00→125.00	20	250.00→70.00	10	125.00→70.00	10
Tryphenylphosphate (QC)	17.89	326.00→325.00	5	326.00→169.00	25	326.00→215.00	10
Iprodione	18.25	314.00→56.00	25	314.00→187.00	5	314.00→245.00	5
EPN	18.39	185.00→157.00	5	169.00→157.00	5	157.00→141.00	10
Pyriproxyfen	19.02	136.00→107.00	10	136.00→96.00	15	136.00→78.00	15
Fenvalerate	21.64	167.00→125.00	10	181.00→152.00	25	225.00→125.00	25
Esfenvalerate	21.91	167.00→125.00	10	225.00→167.00	20	225.00→181.00	20

Table 2S.- Matrix-matched calibration data of the selected pesticides and matrix effect (ME) percentage when different QuEChERS versions were applied to a dried fruit mixture.

Analyte	Sample	Studied linear range (µg/kg)	Regression equation (n=5)		$s_{y/x}$	R^2	ME (%)
			$b \pm s_b \cdot t_{(0.05;7)}$	$a \pm s_a \cdot t_{(0.05;7)}$			
Propoxur	AOAC 2007.01	5-600	$4.30\cdot10^{-2} \pm 6.91\cdot10^{-4}$	$9.00\cdot10^{-2} \pm 1.97\cdot10^{-3}$	$1.52\cdot10^{-3}$	0.9998	3
	CEN 15662	5-600	$2.89\cdot10^{-3} \pm 2.74\cdot10^{-4}$	$6.53\cdot10{-}^{2} \pm 7.80\cdot10^{-2}$	$6.03\cdot10^{-2}$	0.9932	-93
	Original	5-600	$7.21\cdot10^{-3} \pm 1.66\cdot10^{-4}$	$7.61\cdot10^{-2} \pm 4.72\cdot10^{-2}$	$3.65\cdot10^{-2}$	0.9996	-82
	Standard calibration	5-600	$4.15\cdot10^{-2} \pm 2.10\cdot10^{-3}$	$3.46\cdot10^{-3} \pm 5.98\cdot10^{-3}$	$4.62\cdot10^{-3}$	0.9981	-
Carbofuran	AOAC 2007.01	5-600	$9.55\cdot10^{-3} \pm 5.31\cdot10^{-4}$	$1.52\cdot10^{-3} \pm 1.51\cdot10^{-3}$	$1.17\cdot10^{-3}$	0.9977	4
	CEN 15662	5-600	$1.41\cdot10^{-3} \pm 1.17\cdot10^{-4}$	$7.63\cdot10^{-2} \pm 3.32\cdot10^{-2}$	$2.56\cdot10^{-2}$	0.9948	-84
	Original	5-600	$3.43\cdot10^{-3} \pm 2.71\cdot10^{4}$	$1.56\cdot10^{-3} \pm 7.71\cdot10^{-2}$	$5.96\cdot10^{-2}$	0.9953	-62
	Standard calibration	5-600	$9.18\cdot10^{-3} \pm 4.65\cdot10^{-4}$	$6.53\cdot10^{-2} \pm 1.32\cdot10^{-3}$	$1.02\cdot10^{-3}$	0.9981	-
Carbaryl	AOAC 2007.01	5-600	$5.90\cdot10^{-2} \pm 4.01\cdot10^{-3}$	$0.16\cdot10 \pm 0.14\cdot10$	$8.82\cdot10^{-3}$	0.9965	43
	CEN 15662	5-600	$3.20\cdot10^{-2} \pm 1.87\cdot10^{-3}$	$5.74\cdot10^{-1} \pm 5.31\cdot10^{-3}$	$4.11\cdot10^{-3}$	0.9977	$^{-}22$
	Original	5-600	$3.86\cdot10^{-2} \pm 5.10\cdot10^{-3}$	$5.74\cdot10^{-3} \pm 0.14\cdot10$	$0.11\cdot10$	0.9870	-5
	Standard calibration	5-600	$4.10\cdot10^{-2} \pm 2.77\cdot10^{-3}$	$-6.18\cdot10^{-3} \pm 7.88\cdot10^{-3}$	$6.09\cdot10^{-3}$	0.9966	-
Diphenylamine	AOAC 2007.01	5-600	$2.44\cdot10^{-3} \pm 3.78\cdot10^{-3}$	$-8.10\cdot10^{-2} \pm 0.10\cdot10$	$8.31\cdot10^{-3}$	0.9998	40
	CEN 15662	5-600	$2.39\cdot10^{-3} \pm 1.16\cdot10^{-2}$	$-8.55\cdot10^{-3} \pm 0.32\cdot10$	$0.25\cdot10$	0.9982	38
	Original	5-600	$2.47\cdot10^{-3} \pm 6.59\cdot10^{-3}$	$7.29\cdot10^{-3} \pm 0.18\cdot10$	$0.14\cdot10$	0.9995	42
	Standard calibration	5-600	$1.73\cdot10^{-3} \pm 4.92\cdot10^{-3}$	$5.16\cdot10^{-3} \pm 0.14\cdot10$	$0.10\cdot10$	0.9994	-
Chlorpropham	AOAC 2007.01	5-600	$9.51\cdot10^{-3} \pm 1.50\cdot10^{-4}$	$-3.79\cdot10^{-2} \pm 4.27\cdot10^{-2}$	$3.30\cdot10^{-2}$	0.9998	18
	CEN 15662	5-600	$1.21\cdot10^{-2} \pm 5.23\cdot10^{4}$	$-5.91\cdot10^{-2} \pm 1.49\cdot10^{-3}$	$1.15\cdot10^{-3}$	0.9986	50
	Original	5-600	$1.23\cdot10^{-2} \pm 2.82\cdot10^{4}$	$-2.89\cdot10^{-2} \pm 8.03\cdot10^{-2}$	$6.21\cdot10^{-2}$	0.9996	52
	Standard calibration	5-600	$8.04\cdot10^{-3} \pm 1.66\cdot10^{-4}$	$-3.57\cdot10^{-2} \pm 4.73\cdot10^{-2}$	$3.65\cdot10^{-2}$	0.9997	-
Dicloran	AOAC 2007.01	5-600	$5.76\cdot10^{-3} \pm 3.64\cdot10^{-4}$	$_{-2}.84\cdot10^{-2} \pm 1.04\cdot10^{-3}$	$8.00\cdot10^{-2}$	0.9970	75
	CEN 15662	5-600	$1.24\cdot10^{-2} \pm 7.89\cdot10^{-4}$	$-8.95\cdot10^{-2} \pm 2.24\cdot10^{-3}$	$1.74\cdot10^{-3}$	0.9970	278
	Original	5-600	$9.51\cdot10^{-3} \pm 3.41\cdot10^{-4}$	$-4.67\cdot10^{-2} \pm 9.70\cdot10^{-2}$	$7.50\cdot10^{-2}$	0.9990	189
	Standard calibration	5-600	$3.28\cdot10^{-3} \pm 1.75\cdot10^{-4}$	$-3.78\cdot10^{-2} \pm 4.98\cdot10^{-2}$	$3.85\cdot10^{-2}$	0.9979	-

Table 2S.-(Continued).

Analyte	Sample	Studied linear range (µg/kg)	Regression equation (n=5)		$s_{y/x}$	R^2	ME (%)
			$b \pm s_b \cdot t_{(0.05;7)}$	$a \pm s_a \cdot t_{(0.05;7)}$			
Atrazine	AOAC 2007.01	5-600	$2.85\cdot10^{-3} \pm 4.25\cdot10^{-5}$	$4.61\cdot10^{-3} \pm 1.21\cdot10^{-2}$	$9.35\cdot10^{-3}$	0.9998	12
	CEN 15662	5-600	$2.83\cdot10^{-3} \pm 1.88\cdot10^{-5}$	$8.81\cdot10^{-3} \pm 5.35\cdot10^{-3}$	$4.14\cdot10^{-3}$	0.9999	11
	Original	5-600	$3.03\cdot10^{-3} \pm 5.92\cdot10^{-5}$	$2.86\cdot10^{-3} \pm 1.68\cdot10^{-2}$	$1.30\cdot10^{-2}$	0.9997	20
	Standard calibration	5-600	$2.53\cdot10^{-3} \pm 8.05\cdot10^{-5}$	$-5.78\cdot10^{-3} \pm 2.29\cdot10^{-2}$	$1.77\cdot10^{-2}$	0.9992	-
Lindane	AOAC 2007.01	5-600	$9.67\cdot10^{-3} \pm 5.93\cdot10^{-4}$	$4.19\cdot10^{-3} \pm 1.69\cdot10^{-3}$	$1.30\cdot10^{-3}$	0.9972	-46
	CEN 15662	5-600	$2.14\cdot10^{-2} \pm 1.62\cdot10^{-3}$	$6.68\cdot10^{-3} \pm 4.60\cdot10^{-3}$	$3.56\cdot10^{-3}$	0.9957	19
	Original	5-600	$2.02\cdot10^{-2} \pm 9.99\cdot10^{-4}$	$1.37\cdot10^{-3} \pm 2.84\cdot10^{-3}$	$2.20\cdot10^{-3}$	0.9982	12
	Standard calibration	5-600	$1.80\cdot10^{-2} \pm 1.01\cdot10^{-3}$	$1.54\cdot10^{-3} \pm 2.87\cdot10^{-3}$	$2.22\cdot10^{-3}$	0.9976	-
Propyzamide	AOAC 2007.01	5-600	$5.75\cdot10^{-2} \pm 7.81\cdot10^{4}$	$2.55\cdot10^{-3} \pm 2.22\cdot10^{-3}$	$1.72\cdot10^{-3}$	0.9999	56
	CEN 15662	5-600	$7.10\cdot10^{-2} \pm 2.17\cdot10^{-3}$	$-3.76\cdot10^{-3} \pm 6.17\cdot10^{-3}$	$4.77\cdot10^{-3}$	0.9993	93
	Original	5-600	$6.69\cdot10^{-2} \pm 1.87\cdot10^{-3}$	$-4.45\cdot10^{-2} \pm 5.31\cdot10^{-3}$	$4.10\cdot10^{-3}$	0.9994	82
	Standard calibration	5-600	$3.67\cdot10^{-2} \pm 6.31\cdot10^{-4}$	$-9.05\cdot10^{-2} \pm 1.80\cdot10^{-3}$	$1.39\cdot10^{-3}$	0.9998	-
Chlorpyrifos-methyl	AOAC 2007.01	5-600	$1.27\cdot10^{-2} \pm 1.27\cdot10^{-4}$	$2.08\cdot10^{-2} \pm 3.61\cdot10^{-2}$	$2.79\cdot10^{-2}$	0.9999	-33
	CEN 15662	5-600	$3.21\cdot10^{-2} \pm 1.15\cdot10^{-3}$	$-3.52\cdot10^{-3} \pm 3.27\cdot10^{-3}$	$2.53\cdot10^{-3}$	0.9990	67
	Original	5-600	$3.17\cdot10^{-2} \pm 8.99\cdot10^{-4}$	$-8.90\cdot10^{-2} \pm 2.56\cdot10^{-3}$	$1.98\cdot10^{-3}$	0.9994	64
	Standard calibration	5-600	$1.92\cdot10^{-2} \pm 2.96\cdot10^{-4}$	$-4.60\cdot10^{-2} \pm 8.42\cdot10^{-2}$	$6.51\cdot10^{-2}$	0.9998	-
Parathion-methyl	AOAC 2007.01	5-600	$4.24\cdot10^{-3} \pm 2.10\cdot10^{-4}$	$2.77\cdot10^{-2} \pm 5.97\cdot10^{-2}$	$4.61\cdot10^{-2}$	0.9982	-9
	CEN 15662	5-600	$1.65\cdot10^{-2} \pm 4.35\cdot10^{-4}$	$-2.44\cdot10^{-2} \pm 1.24\cdot10^{-3}$	$9.56\cdot10^{-2}$	0.9995	252
	Original	5-600	$1.29\cdot10^{-2} \pm 3.19\cdot10^{-4}$	$-2.38\cdot10^{-2} \pm 9.06\cdot10^{-2}$	$7.00\cdot10^{-2}$	0.9995	173
	Standard calibration	5-600	$4.69\cdot10^{-3} \pm 1.68\cdot10^{4}$	$-5.36\cdot10^{-2} \pm 4.77\cdot10^{-2}$	$3.69\cdot10^{-2}$	0.9990	-
Alachlor	AOAC 2007.01	5-600	$1.51\cdot10^{-2} \pm 1.95\cdot10^{-4}$	$4.41\cdot10^{-2} \pm 5.54\cdot10^{-2}$	$4.28\cdot10^{-2}$	0.9999	-13
	CEN 15662	5-600	$2.64\cdot10^{-2} \pm 8.96\cdot10^{4}$	$-3.08\cdot10^{-3} \pm 2.55\cdot10^{-3}$	$1.97\cdot10^{-3}$	0.9991	51
	Original	5-600	$2.44\cdot10^{-2} \pm 5.13\cdot10^{-4}$	$-6.68\cdot10^{-2} \pm 1.46\cdot10^{-3}$	$1.13\cdot10^{-3}$	0.9997	40
	Standard calibration	5-600	$1.74\cdot10^{-2} \pm 3.60\cdot10^{-4}$	$1.69\cdot10^{-3} \pm 1.02\cdot10^{-3}$	$7.91\cdot10^{-2}$	0.9997	-

Table 2S.-(Continued).

Analyte	Sample	Studied linear range (μg/kg)	Regression equation (n=5)		$s_{y/x}$	R^2	ME (%)
			$b \pm s_b\cdot t_{(0.05;7)}$	$a \pm s_a\cdot t_{(0.05;7)}$			
Tolclofos-Methyl	AOAC 2007.01	5-600	$2.03\cdot10^{-2} \pm 3.54\cdot10^{-4}$	$7.01\cdot10^{-2} \pm 1.01\cdot10^{-3}$	$7.78\cdot10^{-2}$	0.9998	ˉ20
	CEN 15662	5-600	$3.65\cdot10^{-2} \pm 1.49\cdot10^{-3}$	$-3.22\cdot10^{-3} \pm 4.24\cdot10^{-3}$	$3.27\cdot10^{-3}$	0.9987	42
	Original	5-600	$3.17\cdot10^{-2} \pm 5.67\cdot10^{4}$	$-6.70\cdot10^{-3} \pm 1.61\cdot10^{-3}$	$1.25\cdot10^{-3}$	0.9998	24
	Standard calibration	5-600	$2.56\cdot10^{-2} \pm 5.78\cdot10^{-4}$	$7.39\cdot10^{-2} \pm 1.65\cdot10^{-3}$	$1.27\cdot10^{-3}$	0.9996	-
Metalaxyl	AOAC 2007.01	5-600	$7.37\cdot10^{-3} \pm 1.32\cdot10^{4}$	$2.69\cdot10^{-3} \pm 3.77\cdot10^{-2}$	$2.91\cdot10^{-2}$	0.9998	32
	CEN 15662	5-600	$1.04\cdot10^{-2} \pm 3.64\cdot10^{-4}$	$3.44\cdot10^{-3} \pm 1.04\cdot10^{-3}$	$8.01\cdot10^{-2}$	0.9991	86
	Original	5-600	$9.85\cdot10^{-3} \pm 3.44\cdot10^{-4}$	$3.03\cdot10^{-3} \pm 9.80\cdot10^{-2}$	$7.57\cdot10^{-2}$	0.9991	77
	Standard calibration	5-600	$5.56\cdot10^{-3} \pm 3.23\cdot10^{-4}$	$9.92\cdot10^{-4} \pm 9.19\cdot10^{-2}$	$7.10\cdot10^{-2}$	0.9975	-
Pirimiphos-methyl	AOAC 2007.01	5-600	$8.41\cdot10^{-3} \pm 1.86\cdot10^{-4}$	$-3.07\cdot10^{-2} \pm 5.29\cdot10^{-2}$	$4.09\cdot10^{-2}$	0.9996	-5
	CEN 15662	5-600	$1.31\cdot10^{-2} \pm 4.82\cdot10^{-4}$	$-6.78\cdot10^{-2} \pm 1.37\cdot10^{-3}$	$1.06\cdot10^{-3}$	0.9990	47
	Original	5-600	$1.20\cdot10^{-2} \pm 2.29\cdot10^{-4}$	$-3.21\cdot10^{-2} \pm 6.53\cdot10^{-2}$	$5.05\cdot10^{-2}$	0.9997	35
	Standard calibration	5-600	$8.88\cdot10^{-3} \pm 8.20\cdot10^{-5}$	$-3.42\cdot10^{-2} \pm 2.33\cdot10^{-2}$	$1.80\cdot10^{-2}$	0.9999	-
Fenitrothion	AOAC 2007.01	5-600	$5.07\cdot10^{-3} \pm 1.44\cdot10^{-4}$	$-8.40\cdot10^{-3} \pm 4.09\cdot10^{-2}$	$3.16\cdot10^{-2}$	0.9994	-4
	CEN 15662	5-600	$1.72\cdot10^{-2} \pm 6.03\cdot10^{-4}$	$-8.04\cdot10^{-2} \pm 1.72\cdot10^{-3}$	$1.33\cdot10^{-3}$	0.9991	224
	ORIGINAL	5-600	$1.43\cdot10^{-2} \pm 5.40\cdot10^{-4}$	$-7.61\cdot10^{-2} \pm 1.54\cdot10^{-3}$	$1.19\cdot10^{-3}$	0.9989	169
	Standard calibration	5-600	$5.29\cdot10^{-3} \pm 1.06\cdot10^{-4}$	$-5.30\cdot10^{-2} \pm 3.00\cdot10^{-2}$	$2.32\cdot10^{-2}$	0.9997	-
Malathion	AOAC 2007.01	5-600	$1.28\cdot10^{-2} \pm 4.48\cdot10^{-4}$	$9.67\cdot10^{-2} \pm 1.28\cdot10^{-3}$	$9.86\cdot10^{-2}$	0.9991	15
	CEN 15662	5-600	$3.97\cdot10^{-2} \pm 4.30\cdot10^{-3}$	$0.12\cdot10 \pm 0.12\cdot10$	$9.45\cdot10^{-3}$	0.9912	257
	Original	5-600	$3.78\cdot10^{-2} \pm 2.44\cdot10^{-3}$	$2.18 \pm 6.93\cdot10^{-3}$	$5.36\cdot10^{-3}$	0.9969	239
	Standard calibration	5-600	$1.11\cdot10^{-2} \pm 4.19\cdot10^{-4}$	$-3.13\cdot10^{-3} \pm 1.19\cdot10^{-3}$	$9.21\cdot10^{-2}$	0.9989	-
Chlorpyrifos	AOAC 2007.01	5-600	$1.34\cdot10^{-2} \pm 2.58\cdot10^{-4}$	$0.13\cdot10 \pm 7.35\cdot10^{-2}$	$5.68\cdot10^{-2}$	0.9997	-7
	CEN 15662	5-600	$2.21\cdot10^{-2} \pm 1.03\cdot10^{-3}$	$0.23\cdot10 \pm 2.92\cdot10^{-3}$	$2.26\cdot10^{-3}$	0.9984	52
	Original	5-600	$1.98\cdot10^{-2} \pm 5.00\cdot10^{-4}$	$0.15\cdot10 \pm 1.42\cdot10^{-3}$	$1.10\cdot10^{-3}$	0.9995	36
	Standard calibration	5-600	$1.45\cdot10^{-2} \pm 2.98\cdot10^{-4}$	$-4.60\cdot10^{-3} \pm 8.47\cdot10^{-2}$	$6.55\cdot10^{-2}$	0.9997	-

Table 2S.-(Continued).

Analyte	Sample	Studied linear range (µg/kg)	Regression equation (n=5)		$s_{y/x}$	R^2	ME (%)
			$b \pm s_b \cdot t_{(0.05;7)}$	$a \pm s_a \cdot t_{(0.05;7)}$			
Fenthion	AOAC 2007.01	5-600	$1.63 \cdot 10^{-2} \pm 4.12 \cdot 10^{-4}$	$7.30 \cdot 10^{-3} \pm 1.17 \cdot 10^{-3}$	$9.06 \cdot 10^{-2}$	0.9995	-6
	CEN 15662	5-600	$3.40 \cdot 10^{-2} \pm 1.03 \cdot 10^{-3}$	$-3.33 \cdot 10^{-3} \pm 2.94 \cdot 10^{-3}$	$2.28 \cdot 10^{-3}$	0.9993	93
	Original	5-600	$3.06 \cdot 10^{-2} \pm 6.75 \cdot 10^{-4}$	$-3.16 \cdot 10^{-3} \pm 1.92 \cdot 10^{-3}$	$1.48 \cdot 10^{-3}$	0.9996	74
	Standard calibration	5-600	$1.75 \cdot 10^{-2} \pm 2.91 \cdot 10^{-4}$	$-4.58 \cdot 10^{-2} \pm 8.28 \cdot 10^{-2}$	$6.40 \cdot 10^{-2}$	0.9998	-
Triadimefon	AOAC 2007.01	5-600	$1.71 \cdot 10^{-2} \pm 5.50 \cdot 10^{-4}$	$5.44 \cdot 10^{-2} \pm 1.56 \cdot 10^{-3}$	$1.21 \cdot 10^{-3}$	0.9992	52
	CEN 15662	5-600	$2.02 \cdot 10^{-2} \pm 1.17 \cdot 10^{-3}$	$-6.11 \cdot 10^{-2} \pm 3.33 \cdot 10^{-3}$	$2.57 \cdot 10^{-3}$	0.9975	81
	Original	5-600	$1.84 \cdot 10^{-2} \pm 1.93 \cdot 10^{-3}$	$-3.64 \cdot 10^{-2} \pm 5.48 \cdot 10^{-3}$	$4.23 \cdot 10^{-3}$	0.9918	65
	Standard calibration	5-600	$1.12 \cdot 10^{-2} \pm 2.53 \cdot 10^{-4}$	$-2.92 \cdot 10^{-2} \pm 7.20 \cdot 10^{-2}$	$5.56 \cdot 10^{-2}$	0.9996	-
Pirimiphos-ethyl	AOAC 2007.01	5-600	$4.11 \cdot 10^{-3} \pm 5.74 \cdot 10^{-5}$	$-3.41 \cdot 10^{-2} \pm 1.63 \cdot 10^{-2}$	$1.26 \cdot 10^{-2}$	0.9999	18
	CEN 15662	5-600	$5.34 \cdot 10^{-3} \pm 1.59 \cdot 10^{-4}$	$-3.43 \cdot 10^{-2} \pm 4.52 \cdot 10^{-2}$	$3.50 \cdot 10^{-2}$	0.9993	53
	Original	5-600	$5.16 \cdot 10^{-3} \pm 1.35 \cdot 10^{-4}$	$-4.07 \cdot 10^{-2} \pm 3.84 \cdot 10^{-2}$	$2.97 \cdot 10^{-2}$	0.9995	48
	Standard calibration	5-600	$3.48 \cdot 10^{-3} \pm 1.44 \cdot 10^{-4}$	$-8.15 \cdot 10^{-3} \pm 4.11 \cdot 10^{-2}$	$3.18 \cdot 10^{-2}$	0.9987	-
Penconazole	AOAC 2007.01	5-600	$3.53 \cdot 10^{-2} \pm 1.01 \cdot 10^{-3}$	$-9.25 \cdot 10^{-3} \pm 2.87 \cdot 10^{-3}$	$2.22 \cdot 10^{-3}$	0.9994	74
	CEN 15662	5-600	$4.66 \cdot 10^{-2} \pm 2.21 \cdot 10^{-3}$	$-3.18 \cdot 10^{-3} \pm 6.28 \cdot 10^{-3}$	$4.85 \cdot 10^{-3}$	0.9983	130
	Original	5-600	$4.13 \cdot 10^{-2} \pm 1.45 \cdot 10^{-3}$	$-3.17 \cdot 10^{-3} \pm 4.12 \cdot 10^{-3}$	$3.18 \cdot 10^{-3}$	0.9991	104
	Standard calibration	5-600	$2.02 \cdot 10^{-2} \pm 3.75 \cdot 10^{4}$	$-6.85 \cdot 10^{-3} \pm 1.07 \cdot 10^{-3}$	$8.25 \cdot 10^{-2}$	0.9997	-
Triflumizole	AOAC 2007.01	5-600	$9.19 \cdot 10^{-3} \pm 1.17 \cdot 10^{-4}$	$-3.06 \cdot 10^{-2} \pm 3.34 \cdot 10^{-2}$	$2.58 \cdot 10^{-2}$	0.9999	124
	CEN 15662	5-600	$8.22 \cdot 10^{-3} \pm 1.25 \cdot 10^{-4}$	$-2.84 \cdot 10^{-2} \pm 3.56 \cdot 10^{-2}$	$2.75 \cdot 10^{-2}$	0.9998	100
	Original	5-600	$9.94 \cdot 10^{-3} \pm 1.96 \cdot 10^{-4}$	$-4.46 \cdot 10^{-2} \pm 5.59 \cdot 10^{-2}$	$4.32 \cdot 10^{-2}$	0.9997	143
	Standard calibration	5-600	$4.09 \cdot 10^{-3} \pm 9.70 \cdot 10^{-5}$	$-4.16 \cdot 10^{-2} \pm 2.76 \cdot 10^{-2}$	$2.13 \cdot 10^{-2}$	0.9996	-
Methidathion	AOAC 2007.01	5-600	$1.19 \cdot 10^{-2} \pm 1.02 \cdot 10^{-3}$	$1.55 \cdot 10^{-3} \pm 2.89 \cdot 10^{-3}$	$2.24 \cdot 10^{-3}$	0.9945	-3
	CEN 15662	5-600	$5.69 \cdot 10^{-2} \pm 4.61 \cdot 10^{-4}$	$1.26 \cdot 10^{-3} \pm 1.31 \cdot 10^{-3}$	$1.01 \cdot 10^{-3}$	0.9999	362
	Original	5-600	$4.11 \cdot 10^{-2} \pm 8.87 \cdot 10^{-4}$	$-6.16 \cdot 10^{-2} \pm 2.52 \cdot 10^{-3}$	$1.95 \cdot 10^{-3}$	0.9996	233
	Standard calibration	5-600	$1.23 \cdot 10^{-2} \pm 8.92 \cdot 10^{-4}$	$-2.12 \cdot 10^{-3} \pm 2.54 \cdot 10^{-3}$	$1.96 \cdot 10^{-3}$	0.9960	-

Table 2S.-(Continued).

Analyte	Sample	Studied linear range (µg/kg)	Regression equation (n=5)		$s_{y/x}$	R^2	ME (%)
			b ± $s_b\cdot t_{(0.05;7)}$	a ± $s_a\cdot t_{(0.05;7)}$			
Fenamiphos	AOAC 2007.01	5-600	$4.55\cdot10^{-3} \pm 8.92\cdot10^{-5}$	$-2.19\cdot10^{-2} \pm 2.54\cdot10^{-2}$	$1.96\cdot10^{-2}$	0.9997	5687
	CEN 15662	5-600	$9.84\cdot10^{-3} \pm 3.18\cdot10^{-4}$	$-3.71\cdot10^{-2} \pm 9.05\cdot10^{-2}$	$7.00\cdot10^{-2}$	0.9992	12411
	Original	5-600	$8.13\cdot10^{-3} \pm 2.07\cdot10^{-4}$	$-4.05\cdot10^{-2} \pm 5.89\cdot10^{-2}$	$4.56\cdot10^{-2}$	0.9995	10237
	Standard calibration	5-600	$7.87\cdot10^{-5} \pm 3.98\cdot10^{-6}$	$9.09\cdot10^{-4} \pm 1.13\cdot10^{-3}$	$8.75\cdot10^{-4}$	0.9981	-
Myclobutanil	AOAC 2007.01	5-600	$3.13\cdot10^{-2} \pm 1.04\cdot10^{-3}$	$3.25\cdot10^{-3} \pm 2.95\cdot10^{-3}$	$2.28\cdot10^{-3}$	0.9992	142
	CEN 15662	5-600	$4.44\cdot10^{-2} \pm 1.68\cdot10^{-3}$	$2.75\cdot10^{-3} \pm 4.79\cdot10^{-3}$	$3.70\cdot10^{-3}$	0.9989	243
	Original	5-600	$4.06\cdot10^{-2} \pm 7.74\cdot10^{-4}$	$3.48\cdot10^{-3} \pm 2.20\cdot10^{-3}$	$1.70\cdot10^{-3}$	0.9997	214
	Standard calibration	5-600	$1.29\cdot10^{-2} \pm 1.19\cdot10^{-3}$	$-2.29\cdot10^{-3} \pm 3.39\cdot10^{-3}$	$2.62\cdot10^{-3}$	0.9936	-
Dieldrin	AOAC 2007.01	5-600	$3.86\cdot10^{-3} \pm 9.61\cdot10^{-5}$	$2.44\cdot10^{-3} \pm 2.73\cdot10^{-2}$	$2.11\cdot10^{-2}$	0.9995	-3
	CEN 15662	5-600	$5.07\cdot10^{-3} \pm 1.34\cdot10^{-4}$	$-3.89\cdot10^{-3} \pm 3.81\cdot10^{-2}$	$2.94\cdot10^{-2}$	0.9995	26
	Original	5-600	$4.52\cdot10^{-3} \pm 1.30\cdot10^{-4}$	$-3.33\cdot10^{-2} \pm 3.70\cdot10^{-2}$	$2.86\cdot10^{-2}$	0.9994	12
	Standard calibration	5-600	$4.02\cdot10^{-3} \pm 2.32\cdot10^{-4}$	$8.75\cdot10^{-3} \pm 6.59\cdot10^{-2}$	$5.09\cdot10^{-2}$	0.9975	-
Oxyfluorfen	AOAC 2007.01	5-600	$3.17\cdot10^{-3} \pm 1.43\cdot10^{-4}$	$-2.97\cdot10^{-2} \pm 4.06\cdot10^{-2}$	$3.14\cdot10^{-2}$	0.9985	157
	CEN 15662	5-600	$5.17\cdot10^{-3} \pm 1.74\cdot10^{-4}$	$-3.95\cdot10^{-2} \pm 4.95\cdot10^{-2}$	$3.82\cdot10^{-2}$	0.9991	319
	Original	5-600	$4.32\cdot10^{-3} \pm 1.75\cdot10^{-4}$	$-4.21\cdot10^{-2} \pm 4.97\cdot10^{-2}$	$3.84\cdot10^{-2}$	0.9988	250
	Standard calibration	5-600	$1.23\cdot10^{-3} \pm 7.93\cdot10^{-5}$	$-3.43\cdot10^{-2} \pm 2.25\cdot10^{-2}$	$1.74\cdot10^{-2}$	0.9974	-
Buprofezin	AOAC 2007.01	5-600	$1.02\cdot10^{-2} \pm 1.20\cdot10^{-4}$	$1.48\cdot10^{-2} \pm 3.41\cdot10^{-2}$	$2.64\cdot10^{-2}$	0.9999	30
	CEN 15662	5-600	$1.25\cdot10^{-2} \pm 3.70\cdot10^{-4}$	$-3.90\cdot10^{-2} \pm 1.05\cdot10^{-3}$	$8.14\cdot10^{-2}$	0.9993	59
	Original	5-600	$1.18\cdot10^{-2} \pm 4.03\cdot10^{-4}$	$-7.24\cdot10^{-3} \pm 1.15\cdot10^{-3}$	$8.86\cdot10^{-2}$	0.9991	50
	Standard calibration	5-600	$7.84\cdot10^{-3} \pm 1.83\cdot10^{-4}$	$-2.32\cdot10^{-2} \pm 5.22\cdot10^{-2}$	$4.03\cdot10^{-2}$	0.9996	-
Endrin	AOAC 2007.01	5-600	$2.54\cdot10^{-3} \pm 6.74\cdot10^{-5}$	$-2.05\cdot10^{-2} \pm 1.92\cdot10^{-2}$	$1.48\cdot10^{-2}$	0.9995	9
	CEN 15662	5-600	$3.77\cdot10^{-3} \pm 1.21\cdot10^{-4}$	$-3.15\cdot10^{-2} \pm 3.44\cdot10^{-2}$	$2.66\cdot10^{-2}$	0.9992	63
	Original	5-600	$3.20\cdot10^{-3} \pm 1.06\cdot10^{-4}$	$-3.23\cdot10^{-2} \pm 3.01\cdot10^{-2}$	$2.33\cdot10^{-2}$	0.9992	38
	Standard calibration	5-600	$2.31\cdot10^{-3} \pm 5.91\cdot10^{-5}$	$-3.16\cdot10^{-2} \pm 1.68\cdot10^{-2}$	$1.30\cdot10^{-2}$	0.9995	-

Table 2S.-(Continued).

Analyte	Sample	Studied linear range (μg/kg)	Regression equation (n=5)		$s_{y/x}$	R^2	ME (%)
			$b \pm s_b \cdot t_{(0.05;7)}$	$a \pm s_a \cdot t_{(0.05;7)}$			
Ethion	AOAC 2007.01	5-600	$2.05\cdot10^{-2} \pm 4.61\cdot10^{-4}$	$5.98\cdot10^{-2} \pm 1.31\cdot10^{-3}$	$1.01\cdot10^{-3}$	0.9996	45
	CEN 15662	5-600	$3.95\cdot10^{-2} \pm 1.21\cdot10^{-3}$	$-8.75\cdot10^{-2} \pm 3.43\cdot10^{-3}$	$2.65\cdot10^{-3}$	0.9993	181
	Original	5-600	$3.60\cdot10^{-2} \pm 1.22\cdot10^{-3}$	$-3.14\cdot10^{-3} \pm 3.46\cdot10^{-3}$	$2.68\cdot10^{-3}$	0.9991	156
	Standard calibration	5-600	$1.41\cdot10^{-2} \pm 3.50\cdot10^{-4}$	$-3.01\cdot10^{-3} \pm 9.94\cdot10^{-2}$	$7.69\cdot10^{-2}$	0.9995	-
Propiconazole	AOAC 2007.01	5-600	$1.29\cdot10^{-2} \pm 5.70\cdot10^{-4}$	$3.70\cdot10^{-3} \pm 1.62\cdot10^{-3}$	$1.25\cdot10^{-3}$	0.9985	68
	CEN 15662	5-600	$2.08\cdot10^{-2} \pm 2.12\cdot10^{-3}$	$0.26\cdot10 \pm 6.03\cdot10^{-3}$	$4.66\cdot10^{-3}$	0.9922	171
	Original	5-600	$1.38\cdot10^{-2} \pm 8.36\cdot10^{-4}$	$1.55\cdot10^{-3} \pm 2.38\cdot10^{-3}$	$1.84\cdot10^{-3}$	0.9972	80
	Standard calibration	5-600	$7.65\cdot10^{-3} \pm 3.05\cdot10^{-4}$	$-3.70\cdot10^{-3} \pm 8.67\cdot10^{-2}$	$6.70\cdot10^{-2}$	0.9988	-
Tebuconazole	AOAC 2007.01	5-600	$1.60\cdot10^{-2} \pm 5.85\cdot10^{-4}$	$4.09\cdot10^{-3} \pm 1.66\cdot10^{-3}$	$1.29\cdot10^{-3}$	0.9990	156
	CEN 15662	5-600	$2.38\cdot10^{-2} \pm 1.06\cdot10^{-3}$	$5.72\cdot10^{-3} \pm 3.02\cdot10^{-3}$	$2.34\cdot10^{-3}$	0.9985	281
	Original	5-600	$2.05\cdot10^{-2} \pm 6.29\cdot10^{-4}$	$4.88\cdot10^{-3} \pm 1.79\cdot10^{-3}$	$1.38\cdot10^{-3}$	0.9993	228
	Standard calibration	5-600	$6.24\cdot10^{-3} \pm 4.23\cdot10^{-4}$	$-5.35\cdot10^{-2} \pm 1.20\cdot10^{-3}$	$9.30\cdot10^{-2}$	0.9965	-
Iprodione	AOAC 2007.01	5-600	$2.73\cdot10^{-4} \pm 3.09\cdot10^{-5}$	$1.78\cdot10^{-2} \pm 8.79\cdot10^{-3}$	$6.80\cdot10^{-3}$	0.9904	103
	CEN 15662	5-600	$5.29\cdot10^{-3} \pm 1.77\cdot10^{-4}$	$2.55\cdot10^{-3} \pm 5.04\cdot10^{-2}$	$3.89\cdot10^{-2}$	0.9992	3835
	Original	5-600	$3.53\cdot10^{-3} \pm 8.08\cdot10^{-5}$	$1.31\cdot10^{-3} \pm 2.30\cdot10^{-2}$	$1.78\cdot10^{-2}$	0.9996	2522
	Standard calibration	5-600	$1.35\cdot10^{-4} \pm 4.17\cdot10^{-5}$	$-3.41\cdot10^{-3} \pm 1.19\cdot10^{-2}$	$9.18\cdot10^{-3}$	0.9918	-
EPN	AOAC 2007.01	5-600	$4.79\cdot10^{-3} \pm 3.54\cdot10^{-4}$	$7.27\cdot10^{-2} \pm 1.01\cdot10^{-3}$	$7.79\cdot10^{-2}$	0.9959	38
	CEN 15662	5-600	$2.06\cdot10^{-2} \pm 8.93\cdot10^{-4}$	$6.36\cdot10^{-2} \pm 2.54\cdot10^{-3}$	$1.96\cdot10^{-3}$	0.9986	496
	Original	5-600	$1.55\cdot10^{-2} \pm 4.07\cdot10^{-4}$	$3.05\cdot10^{-2} \pm 1.16\cdot10^{-3}$	$8.94\cdot10^{-2}$	0.9995	347
	Standard calibration	5-600	$3.46\cdot10^{-3} \pm 3.05\cdot10^{-4}$	$-3.86\cdot10^{-2} \pm 8.67\cdot10^{-2}$	$6.70\cdot10^{-2}$	0.9941	-
Pyriproxyfen	AOAC 2007.01	5-600	$2.05\cdot10^{-2} \pm 5.57\cdot10^{-4}$	$4.72\cdot10^{-2} \pm 1.58\cdot10^{-3}$	$1.23\cdot10^{-3}$	0.9994	145
	CEN 15662	5-600	$2.98\cdot10^{-2} \pm 1.11\cdot10^{-3}$	$0.17\cdot10 \pm 3.16\cdot10^{-3}$	$2.44\cdot10^{-3}$	0.9990	256
	Original	5-600	$2.77\cdot10^{-2} \pm 9.34\cdot10^{-4}$	$4.40\cdot10^{-3} \pm 2.66\cdot10^{-3}$	$2.05\cdot10^{-3}$	0.9991	231
	Standard calibration	5-600	$8.35\cdot10^{-3} \pm 2.52\cdot10^{-4}$	$-4.64\cdot10^{-3} \pm 7.16\cdot10^{-2}$	$5.54\cdot10^{-2}$	0.9993	-

Table 2S.-(Continued).

Analyte	Sample	Studied linear range (µg/kg)	Regression equation (n=5)		$s_{y/x}$	R^2	ME (%)
			$b \pm s_b \cdot t_{(0.05;7)}$	$a \pm s_a \cdot t_{(0.05;7)}$			
Fenvalerate	AOAC 2007.01	5-600	$1.57\cdot10^{-2} \pm 4.30\cdot10^{-4}$	$3.15\cdot10^{-2} \pm 1.22\cdot10^{-3}$	$9.46\cdot10^{-2}$	0.9994	276
	CEN 15662	5-600	$4.18\cdot10^{-2} \pm 1.56\cdot10^{-3}$	$-9.07\cdot10^{-2} \pm 4.44\cdot10^{-3}$	$3.43\cdot10^{-3}$	0.9989	902
	Original	5-600	$3.93\cdot10^{-2} \pm 1.18\cdot10^{-3}$	$-5.73\cdot10^{-2} \pm 3.35\cdot10^{-3}$	$2.59\cdot10^{-3}$	0.9993	842
	Standard calibration	5-600	$4.17\cdot10^{-3} \pm 3.11\cdot10^{-4}$	$-8.76\cdot10^{-2} \pm 8.84\cdot10^{-2}$	$6.83\cdot10^{-2}$	0.9958	-
Esfenvalerate	AOAC 2007.01	5-600	$1.34\cdot10^{-2} \pm 3.87\cdot10^{-4}$	$1.94\cdot10^{-2} \pm 1.10\cdot10^{-3}$	$8.52\cdot10^{-2}$	0.9994	403
	CEN 15662	5-600	$5.27\cdot10^{-2} \pm 1.79\cdot10^{-3}$	$-4.51\cdot10^{-2} \pm 5.09\cdot10^{-3}$	$3.94\cdot10^{-3}$	0.9991	1874
	Original	5-600	$4.53\cdot10^{-2} \pm 1.28\cdot10^{-3}$	$-3.08\cdot10^{-3} \pm 3.65\cdot10^{-3}$	$2.82\cdot10^{-3}$	0.9994	1598
	Standard calibration	5-600	$2.67\cdot10^{-3} \pm 2.43\cdot10^{-4}$	$-3.48\cdot10^{-2} \pm 6.90\cdot10^{-2}$	$5.33\cdot10^{-2}$	0.9948	-

b: Slope; S_b: Standard deviation of the slope; a: intercept; S_a: Standard deviation of the intercept; R^2: determination coefficient; $s_{y/x}$: Standard deviation of the estimate. ^{a}Calculated following the equation used by Kwon *et al.* (Kwon, Lehotay, & Geis-Asteggiante, 2012).

Table 3S.- Average recoveries (RSDs) of the selected pesticides in a mixture of dried fruits after applying three versions of the QuEChERS method (n=5 at each spiking level). Bold text indicates recovery outside the 70-120 % range.

Pesticide	**AOAC**			**CEN**			**ORIGINAL**		
	25 µg/kg	**200 µg/kg**	**400 µg/kg**	**25 µg/kg**	**200 µg/kg**	**400 µg/kg**	**25 µg/kg**	**200 µg/kg**	**400 µg/kg**
Propoxur	102 (8)	101 (5)	85 (2)	**141** (14)	**180** (12)	120 (7)	**190** (18)	**135** (15)	103 (7)
Carbofuran	112 (8)	107 (5)	93 (2)	110 (6)	**131** (12)	**127** (5)	112 (10)	118 (5)	98 (6)
Carbaryl	109 (4)	114 (4)	95 (2)	119 (15)	114 (9)	100 (5)	102 (18)	119 (3)	108 (7)
Diphenylamine	112 (2)	101 (3)	88 (2)	99 (6)	115 (6)	100 (5)	102 (5)	102 (2)	100 (6)
Chlorpropham	106 (2)	104 (3)	94 (2)	91 (6)	108 (4)	97 (7)	88 (9)	102 (1)	103 (7)
Dicloran	95 (13)	103 (3)	106 (4)	77 (14)	103 (3)	94 (6)	76 (14)	96 (2)	105 (6)
Atrazine	104 (7)	102 (4)	98 (1)	91 (12)	101 (1)	98 (2)	110 (10)	97 (2)	96 (4)
Lindane	104 (8)	91 (5)	102 (1)	72 (8)	97 (4)	90 (6)	84 (20)	101 (6)	99 (5)
Propyzamide	105 (2)	103 (3)	95 (1)	93 (6)	105 (3)	98 (6)	92 (7)	101 (2)	103 (5)
Chlorpyrifos-methyl	106 (6)	100 (2)	108 (1)	90 (6)	103 (4)	97 (6)	79 (9)	97 (2)	99 (6)
Parathion-methyl	95 (10)	107 (3)	119 (2)	77 (13)	102 (1)	100 (7)	74 (14)	94 (3)	99 (6)
Alachlor	102 (8)	101 (3)	102 (1)	93 (9)	105 (3)	97 (6)	91 (13)	103 (2)	102 (6)
Tolclofos-Methyl	110 (3)	103 (2)	103 (2)	89 (5)	105 (4)	96 (6)	91 (10)	100 (1)	100 (5)
Metalaxyl	106 (5)	108 (2)	101 (2)	89 (10)	101 (3)	95 (6)	95 (12)	101 (2)	106 (6)
Pirimiphos-methyl	102 (4)	99 (3)	102 (2)	86 (7)	105 (3)	97 (5)	80 (9)	98 (3)	100 (5)
Fenitrothion	117 (6)	107 (2)	120 (4)	81 (12)	104 (2)	100 (7)	74 (16)	93 (2)	102 (6)
Malathion	119 (4)	104 (3)	120 (1)	87 (2)	**143** (5)	**138** (8)	71 (19)	106 (3)	110 (4)
Chlorpyrifos	114 (3)	104 (2)	101 (2)	86 (6)	102 (4)	93 (6)	94 (11)	100 (1)	100 (5)
Fenthion	102 (3)	103 (2)	112 (1)	93 (6)	105 (3)	96 (6)	89 (11)	99 (2)	100 (6)
Triadimefon	111 (12)	96 (4)	92 (1)	94 (20)	118 (12)	95 (5)	83 (10)	94 (3)	99 (8)

Table 3S.-(Continued).

Pesticide	AOAC			CEN			ORIGINAL		
	25 µg/kg	200 µg/kg	400 µg/kg	25 µg/kg	200 µg/kg	400 µg/kg	25 µg/kg	200 µg/kg	400 µg/kg
Pirimiphos-ethyl	99 (9)	99 (3)	92 (1)	83 (8)	102 (2)	93 (6)	87 (7)	93 (4)	98 (5)
Penconazole	102 (6)	98 (3)	90 (2)	80 (8)	98 (1)	94 (7)	79 (13)	93 (2)	96 (6)
Triflumizole	102 (4)	98 (3)	92 (2)	104 (7)	105 (2)	100 (3)	82 (8)	88 (4)	93 (3)
Methidathion	113 (4)	106 (3)	120 (5)	89 (12)	101 (2)	100 (5)	76 (12)	91 (2)	98 (7)
Fenamiphos	110 (2)	106 (2)	111 (1)	82 (15)	106 (3)	94 (6)	89 (11)	94 (1)	100 (6)
Myclobutanil	112 (3)	106 (3)	102 (1)	89 (10)	102 (4)	96 (7)	87 (5)	95 (5)	93 (11)
Dieldrin	73 (15)	93 (2)	82 (3)	70 (14)	92 (4)	86 (5)	87 (17)	86 (3)	90 (7)
Oxyfluorfen	107 (10)	102 (4)	107 (3)	76 (14)	102 (3)	98 (6)	73 (12)	93 (3)	102 (5)
Buprofezin	88 (20)	94 (3)	88 (2)	93 (6)	101 (3)	94 (6)	75 (16)	87 (2)	92 (5)
Endrin	95 (5)	87 (4)	84 (2)	73 (14)	89 (2)	85 (5)	81 (18)	82 (3)	87 (5)
Ethion	97 (6)	106 (4)	109 (1)	76 (10)	101 (2)	96 (6)	78 (8)	95 (2)	100 (6)
Propiconazole	112 (19)	100 (3)	94 (3)	106 (15)	96 (7)	99 (5)	111 (17)	93 (6)	95 (4)
Tebuconazole	115 (4)	104 (3)	100 (1)	88 (9)	104 (2)	94 (6)	87 (9)	95 (1)	100 (5)
Iprodione	119 (18)	119 (7)	**146** (5)	82 (12)	103 (3)	95 (5)	73 (12)	94 (3)	104 (4)
EPN	103 (17)	93 (2)	**125** (4)	79 (13)	101 (2)	97 (6)	79 (15)	91 (2)	98 (5)
Pyriproxyfen	77 (14)	96 (2)	95 (2)	80 (11)	99 (5)	92 (7)	90 (7)	93 (2)	96 (6)
Fenvalerate	101 (5)	102 (3)	118 (4)	85 (8)	103 (4)	94 (5)	73 (8)	88 (1)	96 (4)
Esfenvalerate	99 (19)	103 (2)	116 (4)	80 (11)	98 (3)	92 (7)	72 (13)	86 (2)	95 (6)

Table 4S.- Matrix-matched calibration data of the selected pesticides and matrix effect (ME) percentage when different QuEChERS versions were applied to a dried fruit mixture.

Analyte	Sample	Studied linear range (µg/kg)	Regression equation (n=7)		$s_{y/x}$	R^2	ME (%)
			$b \pm s_b \cdot t_{(0.05;5)}$	$a \pm s_a \cdot t_{(0.05;5)}$			
Propoxur	Strawberry	5-600	$2.70\cdot10^{-2} \pm 5.81\cdot10^{-4}$	$2.75\cdot10^{-1} \pm 1.65\cdot10^{-1}$	1.28·10-1	0.9997	-34
	Blackberry	5-600	$7.23\cdot10^{-2} \pm 3.45\cdot10^{-3}$	$-3.97\cdot10^{-1} \pm 9.81\cdot10^{-1}$	7.58·10-1	0.9983	74
	Passion fruit'	5-600	$2.60\cdot10^{-2} \pm 5.86\cdot10^{-4}$	$6.65\cdot10^{-2} \pm 1.67\cdot10^{-1}$	1.29·10-1	0.9996	-37
	Pineapple	5-600	$1.96\cdot10^{-2} \pm 3.85\cdot10^{-4}$	$-2.35\cdot10^{-2} \pm 1.10\cdot10^{-1}$	$8.47\cdot10^{-2}$	0.9997	-52
	Grape	5-600	$7.55\cdot10^{-2} \pm 3.30\cdot10^{-3}$	$-2.54\cdot10^{-1} \pm 9.40\cdot10^{-1}$	7.27·10-1	0.9986	82
	Standard calibration	5-600	$4.15\cdot10^{-2} \pm 2.10\cdot10^{-3}$	$3.46\cdot10^{-1} \pm 5.98\cdot10^{-1}$	4.62·10-1	0.9981	-
Carbofuran	Strawberry	5-600	$7.13\cdot10^{-3} \pm 3.59\cdot10^{-4}$	$0.10\cdot10 \pm 1.02\cdot10^{-1}$	$7.89\cdot10^{-2}$	0.9981	-22
	Blackberry	5-600	$1.85\cdot10^{-2} \pm 1.37\cdot10^{-3}$	$6.87\cdot10^{-1} \pm 3.89\cdot10^{-1}$	$3.01\cdot10^{-1}$	0.9959	101
	Passion fruit'	5-600	$6.64\cdot10^{-3} \pm 3.78\cdot10^{-4}$	$1.60\cdot10^{-1} \pm 1.08\cdot10^{-1}$	$8.31\cdot10^{-2}$	0.9976	-27
	Pineapple	5-600	$5.64\cdot10^{-3} \pm 1.48\cdot10^{-4}$	$6.80\cdot10^{-3} \pm 4.22\cdot10^{-2}$	$3.26\cdot10^{-2}$	0.9995	-38
	Grape	5-600	$1.67\cdot10^{-2} \pm 1.83\cdot10^{-3}$	$0.23\cdot10 \pm 5.22\cdot10^{-1}$	$4.03\cdot10^{-1}$	0.9910	82
	Standard calibration	5-600	$6.64\cdot10^{-3} \pm 4.65\cdot10^{-4}$	$6.53\cdot10^{-2} \pm 1.32\cdot10^{-1}$	$1.02\cdot10^{-1}$	0.9981	-
Carbaryl	Strawberry	5-600	$5.99\cdot10^{-2} \pm 2.46\cdot10^{-3}$	$7.64\cdot10^{-1} \pm 7.01\cdot10^{-1}$	$5.42\cdot10^{-1}$	0.9987	46
	Blackberry	5-600	$1.69\cdot10^{-1} \pm 5.99\cdot10^{-3}$	$0.68\cdot10 \pm 0.17\cdot10$	$0.13\cdot10$	0.9991	312
	Passion fruit'	5-600	$5.91\cdot10^{-2} \pm 4.22\cdot10^{-3}$	$1.91\cdot10^{-1} \pm 0.12\cdot10$	$9.28\cdot10^{-1}$	0.9961	44
	Pineapple	5-600	$4.97\cdot10^{-2} \pm 1.18\cdot10^{-3}$	$6.27\cdot10^{-1} \pm 3.36\cdot10^{-1}$	$2.60\cdot10^{-1}$	0.9996	21
	Grape	5-600	$1.32\cdot10^{-1} \pm 8.90\cdot10^{-3}$	$0.11\cdot10 \pm 0.25\cdot10$	$0.19\cdot10$	0.9966	221
	Standard calibration	5-600	$4.10\cdot10^{-2} \pm 2.77\cdot10^{-3}$	$-6.18\cdot10^{-1} \pm 7.88\cdot10^{-1}$	$6.09\cdot10^{-1}$	0.9966	-
Diphenylamine	Strawberry	5-600	$1.59\cdot10^{-1} \pm 1.57\cdot10^{-3}$	$0.11\cdot10 \pm 4.46\cdot10^{-1}$	$3.45\cdot10^{-1}$	0.9999	-8
	Blackberry	5-600	$5.18\cdot10^{-1} \pm 9.93\cdot10^{-3}$	$-6.06\cdot10^{-1} \pm 0.28\cdot10$	$0.21\cdot10$	0.9997	198
	Passion fruit'	5-600	$1.33\cdot10^{-1} \pm 3.79\cdot10^{-3}$	$-6.96\cdot10^{-2} \pm 0.10\cdot10$	$8.33\cdot10^{-1}$	0.9994	-23
	Pineapple	5-600	$1.37\cdot10^{-1} \pm 2.19\cdot10^{-3}$	$0.10\cdot10 \pm 6.23\cdot10^{-1}$	$4.82\cdot10^{-1}$	0.9998	-20
	Grape	5-600	$3.95\cdot10^{-1} \pm 2.12\cdot10^{-2}$	$-0.16\cdot10 \pm 0.60\cdot10$	$0.46\cdot10$	0.9978	128
	Standard calibration	5-600	$1.73\cdot10^{-1} \pm 4.92\cdot10^{-3}$	$5.16\cdot10^{-1} \pm 0.14\cdot10$	$0.10\cdot10$	0.9994	-

Table 4S.-(Continued).

Analyte	Sample	Studied linear range (µg/kg)	Regression equation (n=7)		$s_{y/x}$	R^2	ME (%)
			$b \pm s_b{\cdot}t_{(0.05;5)}$	$a \pm s_a{\cdot}t_{(0.05;5)}$			
Chlorpropham	Strawberry	5-600	$7.33\cdot10^{-3} \pm 8.25\cdot10^{-5}$	$1.30\cdot10^{-2} \pm 2.35\cdot10^{-2}$	$1.81\cdot10^{-2}$	0.9999	-8
	Blackberry	5-600	$2.35\cdot10^{-2} \pm 6.46\cdot10^{-4}$	$1.27\cdot10^{-2} \pm 1.84\cdot10^{-1}$	1.42·10-1	0.9994	192
	Passion fruit'	5-600	$7.42\cdot10^{-3} \pm 2.19\cdot10^{-4}$	$-1.23\cdot10^{-2} \pm 6.23\cdot10^{-2}$	$4.82\cdot10^{-2}$	0.9993	-7
	Pineapple	5-600	$7.44\cdot10^{-3} \pm 1.37\cdot10^{-4}$	$-2.97\cdot10^{-2} \pm 3.91\cdot10^{-2}$	$3.02\cdot10^{-2}$	0.9997	-7
	Grape	5-600	$1.55\cdot10^{-2} \pm 5.09\cdot10^{-4}$	$-4.28\cdot10^{-2} \pm 1.45\cdot10^{-1}$	1.12·10-1	0.9992	92
	Standard calibration	5-600	$8.04\cdot10^{-3} \pm 1.66\cdot10^{-4}$	$-3.57\cdot10^{-2} \pm 4.73\cdot10^{-2}$	$3.65\cdot10^{-2}$	0.9997	-
Dicloran	Strawberry	5-600	$6.20\cdot10^{-3} \pm 2.70\cdot10^{-4}$	$-2.99\cdot10^{-2} \pm 7.67\cdot10^{-2}$	$5.93\cdot10^{-2}$	0.9986	89
	Blackberry	5-600	$1.74\cdot10^{-2} \pm 6.62\cdot10^{-4}$	$-8.70\cdot10^{-2} \pm 1.88\cdot10^{-1}$	$1.46\cdot10^{-1}$	0.9989	428
	Passion fruit'	5-600	$5.00\cdot10^{-3} \pm 1.59\cdot10^{-4}$	$-3.16\cdot10^{-2} \pm 4.53\cdot10^{-2}$	$3.50\cdot10^{-2}$	0.9992	52
	Pineapple	5-600	$6.00\cdot10^{-3} \pm 3.84\cdot10^{-4}$	$-6.25\cdot10^{-2} \pm 1.09\cdot10^{-1}$	$3.50\cdot10^{-2}$	0.9969	82
	Grape	5-600	$1.25\cdot10^{-2} \pm 7.84\cdot10^{-4}$	$2.60\cdot10^{-2} \pm 2.23\cdot10^{-1}$	$3.50\cdot10^{-2}$	0.9970	280
	Standard calibration	5-600	$3.28\cdot10^{-3} \pm 1.75\cdot10^{-4}$	$-1.78\cdot10^{-2} \pm 4.98\cdot10^{-2}$	$3.50\cdot10^{-2}$	0.9979	-
Atrazine	Strawberry	5-600	$2.63\cdot10^{-3} \pm 6.72\cdot10^{-5}$	$1.66\cdot10^{-2} \pm 1.91\cdot10^{-2}$	$1.48\cdot10^{-2}$	0.9995	4
	Blackberry	5-600	$2.18\cdot10^{-3} \pm 1.63\cdot10^{-4}$	$6.32\cdot10^{-2} \pm 4.64\cdot10^{-2}$	$3.59\cdot10^{-2}$	0.9958	-13
	Passion fruit'	5-600	$2.93\cdot10^{-3} \pm 8.28\cdot10^{-5}$	$-7.59\cdot10^{-3} \pm 2.36\cdot10^{-2}$	$1.82\cdot10^{-2}$	0.9994	16
	Pineapple	5-600	$2.91\cdot10^{-3} \pm 7.31\cdot10^{-5}$	$1.47\cdot10^{-2} \pm 2.08\cdot10^{-2}$	$1.61\cdot10^{-2}$	0.9994	15
	Grape	5-600	$2.97\cdot10^{-3} \pm 1.77\cdot10^{-4}$	$-1.32\cdot10^{-2} \pm 5.05\cdot10^{-2}$	$3.90\cdot10^{-2}$	0.9994	17
	Standard calibration	5-600	$2.53\cdot10^{-3} \pm 8.05\cdot10^{-5}$	$-5.78\cdot10^{-3} \pm 2.29\cdot10^{-2}$	$1.77\cdot10^{-2}$	0.9994	-
Lindane	Strawberry	5-600	$8.96\cdot10^{-3} \pm 1.74\cdot10^{-4}$	$1.50\cdot10^{-1} \pm 4.96\cdot10^{-2}$	$3.83\cdot10^{-2}$	0.9991	-50
	Blackberry	5-600	$2.07\cdot10^{-2} \pm 1.41\cdot10^{-3}$	$3.86\cdot10^{-1} \pm 4.00\cdot10^{-1}$	$3.10\cdot10^{-1}$	0.9965	15
	Passion fruit'	5-600	$5.55\cdot10^{-3} \pm 1.96\cdot10^{-4}$	$7.86\cdot10^{-1} \pm 5.56\cdot10^{-2}$	$4.30\cdot10^{-2}$	0.9991	-69
	Pineapple	5-600	$8.03\cdot10^{-3} \pm 2.07\cdot10^{-4}$	$9.17\cdot10^{-2} \pm 5.89\cdot10^{-2}$	$4.55\cdot10^{-2}$	0.9995	-55
	Grape	5-600	$1.67\cdot10^{-2} \pm 1.50\cdot10^{-3}$	$6.62\cdot10^{-1} \pm 4.28\cdot10^{-1}$	$3.30\cdot10^{-1}$	0.9939	-6
	Standard calibration	5-600	$1.80\cdot10^{-2} \pm 1.01\cdot10^{-3}$	$1.54\cdot10^{-1} \pm 2.87\cdot10^{-1}$	$2.22\cdot10^{-1}$	0.9976	-69

Table 4S.-(Continued).

Analyte	Sample	Studied linear range (µg/kg)	Regression equation (n=7)		$s_{y/x}$	R^2	ME (%)
			$b \pm s_b \cdot t_{(0.05;5)}$	$a \pm s_a \cdot t_{(0.05;5)}$			
Propyzamide	Strawberry	5-600	$4.76\cdot10^{-2} \pm 5.81\cdot10^{-4}$	$1.51\cdot10^{-1} \pm 1.65\cdot10^{-1}$	$1.28\cdot10^{-1}$	0.9999	29
	Blackberry	5-600	$8.44\cdot10^{-2} \pm 7.57\cdot10^{-4}$	$2.49\cdot10^{-1} \pm 2.15\cdot10^{-1}$	$1.66\cdot10^{-1}$	0.9999	130
	Passion fruit'	5-600	$5.27\cdot10^{-2} \pm 8.50\cdot10^{-4}$	$1.31\cdot10^{-1} \pm 2.42\cdot10^{-1}$	$1.87\cdot10^{-1}$	0.9998	43
	Pineapple	5-600	$4.75\cdot10^{-2} \pm 7.85\cdot10^{-4}$	$2.56\cdot10^{-3} \pm 2.23\cdot10^{-1}$	$1.73\cdot10^{-1}$	0.9998	29
	Grape	5-600	$6.62\cdot10^{-2} \pm 2.46\cdot10^{-3}$	$6.13\cdot10^{-2} \pm 6.98\cdot10^{-1}$	$5.40\cdot10^{-1}$	0.9990	80
	Standard calibration	5-600	$3.67\cdot10^{-2} \pm 6.31\cdot10^{-4}$	$-9.05\cdot10^{-2} \pm 1.80\cdot10^{-1}$	$1.39\cdot10^{-1}$	0.9998	-
Chlorpyrifos-methyl	Strawberry	5-600	$1.48\cdot10^{-2} \pm 2.67\cdot10^{-4}$	$2.42\cdot10^{-2} \pm 7.59\cdot10^{-2}$	$5.86\cdot10^{-2}$	0.9998	-23
	Blackberry	5-600	$3.15\cdot10^{-2} \pm 4.63\cdot10^{-4}$	$-7.67\cdot10^{-2} \pm 1.32\cdot10^{-1}$	$1.02\cdot10^{-1}$	0.9998	63
	Passion fruit'	5-600	$1.06\cdot10^{-2} \pm 1.34\cdot10^{-4}$	$8.18\cdot10^{-3} \pm 3.81\cdot10^{-2}$	$2.95\cdot10^{-2}$	0.9999	-44
	Pineapple	5-600	$1.45\cdot10^{-2} \pm 5.09\cdot10^{-4}$	$3.74\cdot10^{-2} \pm 1.45\cdot10^{-1}$	$1.12\cdot10^{-1}$	0.9991	-24
	Grape	5-600	$2.63\cdot10^{-2} \pm 1.40\cdot10^{-3}$	$-1.64\cdot10^{-1} \pm 3.98\cdot10^{-1}$	$3.07\cdot10^{-1}$	0.9979	36
	Standard calibration	5-600	$1.92\cdot10^{-2} \pm 2.96\cdot10^{-4}$	$-4.60\cdot10^{-2} \pm 8.42\cdot10^{-2}$	$6.51\cdot10^{-2}$	0.9998	-
Parathion-methyl	Strawberry	5-600	$5.23\cdot10^{-3} \pm 6.74\cdot10^{-5}$	$9.05\cdot10^{-3} \pm 1.92\cdot10^{-2}$	$1.48\cdot10^{-2}$	0.9999	11
	Blackberry	5-600	$8.87\cdot10^{-3} \pm 8.26\cdot10^{-5}$	$1.63\cdot10^{-2} \pm 2.35\cdot10^{-2}$	$1.82\cdot10^{-2}$	0.9999	89
	Passion fruit'	5-600	$3.45\cdot10^{-3} \pm 1.63\cdot10^{-4}$	$-1.05\cdot10^{-2} \pm 4.64\cdot10^{-2}$	$3.59\cdot10^{-2}$	0.9983	-26
	Pineapple	5-600	$4.92\cdot10^{-3} \pm 2.26\cdot10^{-4}$	$4.06\cdot10^{-2} \pm 6.43\cdot10^{-2}$	$4.97\cdot10^{-2}$	0.9984	4
	Grape	5-600	$8.33\cdot10^{-3} \pm 2.33\cdot10^{-4}$	$-3.72\cdot10^{-2} \pm 6.63\cdot10^{-2}$	$5.12\cdot10^{-2}$	0.9994	77
	Standard calibration	5-600	$4.69\cdot10^{-3} \pm 1.68\cdot10^{-4}$	$-5.36\cdot10^{-2} \pm 4.77\cdot10^{-2}$	$3.69\cdot10^{-2}$	0.9990	-
Alachlor	Strawberry	5-600	$1.29\cdot10^{-2} \pm 1.18\cdot10^{-4}$	$5.18\cdot10^{-2} \pm 3.34\cdot10^{-2}$	$2.58\cdot10^{-2}$	0.9999	-25
	Blackberry	5-600	$2.72\cdot10^{-2} \pm 1.15\cdot10^{-3}$	$-1.22\cdot10^{-2} \pm 3.27\cdot10^{-1}$	$2.53\cdot10^{-1}$	0.9987	56
	Passion fruit'	5-600	$1.38\cdot10^{-2} \pm 2.46\cdot10^{-4}$	$-1.19\cdot10^{-2} \pm 6.99\cdot10^{-2}$	$5.40\cdot10^{-2}$	0.9998	-20
	Pineapple	5-600	$1.39\cdot10^{-2} \pm 4.22\cdot10^{-4}$	$2.85\cdot10^{-2} \pm 1.20\cdot10^{-1}$	$9.28\cdot10^{-2}$	0.9993	-20
	Grape	5-600	$2.17\cdot10^{-2} \pm 4.52\cdot10^{-4}$	$-1.95\cdot10^{-2} \pm 1.29\cdot10^{-1}$	$9.94\cdot10^{-2}$	0.9997	24
	Standard calibration	5-600	$1.74\cdot10^{-2} \pm 3.60\cdot10^{-4}$	$1.69\cdot10^{-3} \pm 1.02\cdot10^{-1}$	$7.91\cdot10^{-2}$	0.9997	-

Table 4S.-(Continued).

Analyte	Sample	Studied linear range (µg/kg)	Regression equation (n=7)		$s_{y/x}$	R^2	ME (%)
			$b \pm s_b \cdot t_{(0.05;5)}$	$a \pm s_a \cdot t_{(0.05;5)}$			
Tolclofos-Methyl	Strawberry	5-600	$1.70\cdot10^{-2} \pm 2.52\cdot10^{-4}$	$4.79\cdot10^{-2} \pm 7.17\cdot10^{-2}$	$5.54\cdot10^{-2}$	0.9998	-33
	Blackberry	5-600	$3.71\cdot10^{-2} \pm 1.11\cdot10^{-3}$	$7.65\cdot10^{-2} \pm 3.16\cdot10^{-1}$	$2.44\cdot10^{-1}$	0.9993	44
	Passion fruit'	5-600	$1.53\cdot10^{-2} \pm 2.10\cdot10^{-4}$	$2.61\cdot10^{-2} \pm 5.98\cdot10^{-2}$	$4.63\cdot10^{-2}$	0.9999	-40
	Pineapple	5-600	$1.77\cdot10^{-2} \pm 6.86\cdot10^{-4}$	$1.50\cdot10^{-2} \pm 1.95\cdot10^{-1}$	$1.51\cdot10^{-1}$	0.9989	-30
	Grape	5-600	$3.02\cdot10^{-2} \pm 5.38\cdot10^{-4}$	$1.27\cdot10^{-2} \pm 1.53\cdot10^{-1}$	$1.18\cdot10^{-1}$	0.9998	17
	Standard calibration	5-600	$2.56\cdot10^{-2} \pm 5.78\cdot10^{-4}$	$7.39\cdot10^{-2} \pm 1.65\cdot10^{-1}$	$1.27\cdot10^{-1}$	0.9996	-
Metalaxyl	Strawberry	5-600	$7.05\cdot10^{-3} \pm 1.03\cdot10^{-4}$	$3.75\cdot10^{-2} \pm 2.93\cdot10^{-2}$	$2.27\cdot10^{-2}$	0.9998	26
	Blackberry	5-600	$1.58\cdot10^{-2} \pm 1.88\cdot10^{-3}$	$0.17\cdot10 \pm 5.36\cdot10^{-1}$	$4.14\cdot10^{-1}$	0.9914	184
	Passion fruit'	5-600	$7.90\cdot10^{-3} \pm 1.64\cdot10^{-4}$	$2.30\cdot10^{-2} \pm 4.66\cdot10^{-2}$	$3.60\cdot10^{-2}$	0.9997	42
	Pineapple	5-600	$6.98\cdot10^{-3} \pm 1.08\cdot10^{-4}$	$-6.00\cdot10^{-3} \pm 3.07\cdot10^{-2}$	$2.37\cdot10^{-2}$	0.9998	25
	Grape	5-600	$9.55\cdot10^{-3} \pm 5.11\cdot10^{-4}$	$5.58\cdot10^{-1} \pm 1.45\cdot10^{-1}$	$1.12\cdot10^{-1}$	0.9978	71
	Standard calibration	5-600	$5.56\cdot10^{-3} \pm 3.23\cdot10^{-4}$	$9.92\cdot10^{-4} \pm 9.19\cdot10^{-2}$	$7.10\cdot10^{-2}$	0.9975	-
Pirimiphos-methyl	Strawberry	5-600	$6.75\cdot10^{-3} \pm 1.07\cdot10^{-4}$	$-8.11\cdot10^{-3} \pm 3.05\cdot10^{-2}$	$2.36\cdot10^{-2}$	0.9998	-23
	Blackberry	5-600	$1.19\cdot10^{-2} \pm 2.28\cdot10^{-4}$	$-6.10\cdot10^{-2} \pm 6.50\cdot10^{-2}$	$5.02\cdot10^{-2}$	0.9997	34
	Passion fruit'	5-600	$6.80\cdot10^{-3} \pm 1.45\cdot10^{-4}$	$^{-1}.95\cdot10^{-2} \pm 4.12\cdot10^{-2}$	$3.18\cdot10^{-2}$	0.9997	-23
	Pineapple	5-600	$7.12\cdot10^{-3} \pm 1.54\cdot10^{-4}$	$-3.02\cdot10^{-3} \pm 4.38\cdot10^{-2}$	$3.39\cdot10^{-2}$	0.9996	-19
	Grape	5-600	$1.08\cdot10^{-2} \pm 1.99\cdot10^{-4}$	$-6.45\cdot10^{-2} \pm 5.67\cdot10^{-2}$	$4.38\cdot10^{-2}$	0.9997	2
	Standard calibration	5-600	$8.88\cdot10^{-3} \pm 8.20\cdot10^{-5}$	$-1.42\cdot10^{-2} \pm 2.33\cdot10^{-2}$	$1.80\cdot10^{-2}$	0.9999	-
Fenitrothion	Strawberry	5-600	$6.35\cdot10^{-3} \pm 1.12\cdot10^{-4}$	$-2.33\cdot10^{-2} \pm 3.20\cdot10^{-2}$	$2.47\cdot10^{-2}$	0.9998	20
	Blackberry	5-600	$1.10\cdot10^{-2} \pm 1.43\cdot10^{-4}$	$-4.00\cdot10^{-2} \pm 4.06\cdot10^{-2}$	$3.14\cdot10^{-2}$	0.9999	107
	Passion fruit'	5-600	$4.42\cdot10^{-3} \pm 1.51\cdot10^{-4}$	$-2.87\cdot10^{-2} \pm 4.29\cdot10^{-2}$	$3.31\cdot10^{-2}$	0.9991	-16
	Pineapple	5-600	$6.25\cdot10^{-3} \pm 1.70\cdot10^{-4}$	$-6.20\cdot10^{-4} \pm 4.82\cdot10^{-2}$	$3.73\cdot10^{-2}$	0.9994	17
	Grape	5-600	$9.76\cdot10^{-3} \pm 3.76\cdot10^{-4}$	$-9.90\cdot10^{-2} \pm 1.07\cdot10^{-1}$	$8.27\cdot10^{-2}$	0.9989	84
	Standard calibration	5-600	$5.29\cdot10^{-3} \pm 1.06\cdot10^{-4}$	$-5.30\cdot10^{-2} \pm 3.00\cdot10^{-2}$	$2.32\cdot10^{-2}$	0.9997	-

Table 4S.-(Continued).

Analyte	Sample	Studied linear range (µg/kg)	Regression equation (n=7)		$s_{y/x}$	R^2	ME (%)
			$b \pm s_b \cdot t_{(0.05;5)}$	$a \pm s_a \cdot t_{(0.05;5)}$			
Malathion	Strawberry	5-600	$1.65 \cdot 10^{-2} \pm 2.85 \cdot 10^{-4}$	$0.10 \cdot 10 \pm 8.12 \cdot 10^{-2}$	$6.28 \cdot 10^{-2}$	0.9998	48
	Blackberry	5-600	$4.80 \cdot 10^{-2} \pm 5.46 \cdot 10^{-3}$	$0.11 \cdot 10 \pm 0.15 \cdot 10$	$0.12 \cdot 10$	0.9903	332
	Passion fruit'	5-600	$1.19 \cdot 10^{-2} \pm 4.85 \cdot 10^{-4}$	$1.87 \cdot 10^{-1} \pm 1.38 \cdot 10^{-1}$	$1.07 \cdot 10^{-1}$	0.9987	6
	Pineapple	5-600	$1.73 \cdot 10^{-2} \pm 1.67 \cdot 10^{-3}$	$2.48 \cdot 10^{-1} \pm 4.76 \cdot 10^{-1}$	$3.68 \cdot 10^{-1}$	0.9929	55
	Grape	5-600	$2.25 \cdot 10^{-2} \pm 4.93 \cdot 10^{-4}$	$1.93 \cdot 10^{-1} \pm 1.40 \cdot 10^{-1}$	$1.08 \cdot 10^{-1}$	0.9996	102
	Standard calibration	5-600	$1.11 \cdot 10^{-2} \pm 4.19 \cdot 10^{-4}$	$-1.13 \cdot 10^{-1} \pm 1.19 \cdot 10^{-1}$	$9.21 \cdot 10^{-2}$	0.9989	-
Chlorpyrifos	Strawberry	5-600	$1.08 \cdot 10^{-2} \pm 5.72 \cdot 10^{-4}$	$0.24 \cdot 10 \pm 1.63 \cdot 10^{-1}$	$1.26 \cdot 10^{-1}$	0.9979	-25
	Blackberry	5-600	$2.42 \cdot 10^{-2} \pm 9.81 \cdot 10^{-4}$	$0.16 \cdot 10 \pm 2.79 \cdot 10^{-1}$	$2.16 \cdot 10^{-1}$	0.9988	66
	Passion fruit'	5-600	$1.06 \cdot 10^{-2} \pm 2.91 \cdot 10^{-4}$	$3.94 \cdot 10^{-2} \pm 8.27 \cdot 10^{-2}$	$6.39 \cdot 10^{-2}$	0.9994	-27
	Pineapple	5-600	$1.15 \cdot 10^{-2} \pm 2.76 \cdot 10^{-4}$	$2.83 \cdot 10^{-2} \pm 7.84 \cdot 10^{-2}$	$6.06 \cdot 10^{-2}$	0.9996	-21
	Grape	5-600	$2.00 \cdot 10^{-2} \pm 1.93 \cdot 10^{-3}$	$0.89 \cdot 10 \pm 5.49 \cdot 10^{-1}$	$4.24 \cdot 10^{-1}$	0.9936	37
	Standard calibration	5-600	$1.45 \cdot 10^{-2} \pm 2.98 \cdot 10^{-4}$	$-4.60 \cdot 10^{-3} \pm 8.47 \cdot 10^{-2}$	$6.55 \cdot 10^{-2}$	0.9997	-
Fenthion	Strawberry	5-600	$1.65 \cdot 10^{-2} \pm 1.61 \cdot 10^{-4}$	$1.11 \cdot 10^{-2} \pm 4.59 \cdot 10^{-2}$	$3.55 \cdot 10^{-2}$	0.9999	-5
	Blackberry	5-600	$3.54 \cdot 10^{-2} \pm 3.61 \cdot 10^{-4}$	$-4.64 \cdot 10^{-2} \pm 1.03 \cdot 10^{-1}$	$7.95 \cdot 10^{-2}$	0.9999	101
	Passion fruit'	5-600	$1.43 \cdot 10^{-2} \pm 1.67 \cdot 10^{-4}$	$-6.24 \cdot 10^{-3} \pm 4.74 \cdot 10^{-2}$	$3.66 \cdot 10^{-2}$	0.9999	-18
	Pineapple	5-600	$1.69 \cdot 10^{-2} \pm 4.35 \cdot 10^{-4}$	$1.79 \cdot 10^{-2} \pm 1.24 \cdot 10^{-1}$	$9.56 \cdot 10^{-2}$	0.9995	-3
	Grape	5-600	$2.82 \cdot 10^{-2} \pm 1.47 \cdot 10^{-3}$	$-2.25 \cdot 10^{-1} \pm 4.18 \cdot 10^{-1}$	$3.23 \cdot 10^{-1}$	0.9979	60
	Standard calibration	5-600	$1.75 \cdot 10^{-2} \pm 2.91 \cdot 10^{-4}$	$-4.58 \cdot 10^{-2} \pm 8.28 \cdot 10^{-2}$	$6.40 \cdot 10^{-2}$	0.9998	-
Triadimefon	Strawberry	5-600	$1.52 \cdot 10^{-2} \pm 2.99 \cdot 10^{-4}$	$1.66 \cdot 10^{-1} \pm 8.49 \cdot 10^{-2}$	$6.57 \cdot 10^{-2}$	0.9997	36
	Blackberry	5-600	$3.76 \cdot 10^{-2} \pm 8.41 \cdot 10^{-4}$	$2.20 \cdot 10^{-1} \pm 2.39 \cdot 10^{-1}$	$1.85 \cdot 10^{-1}$	0.9996	236
	Passion fruit'	5-600	$1.75 \cdot 10^{-2} \pm 5.96 \cdot 10^{-4}$	$8.50 \cdot 10^{-2} \pm 1.69 \cdot 10^{-1}$	$1.31 \cdot 10^{-1}$	0.9991	56
	Pineapple	5-600	$1.66 \cdot 10^{-2} \pm 1.42 \cdot 10^{-3}$	$2.83 \cdot 10^{-1} \pm 4.03 \cdot 10^{-1}$	$3.11 \cdot 10^{-1}$	0.9945	48
	Grape	5-600	$2.65 \cdot 10^{-2} \pm 1.22 \cdot 10^{-3}$	$5.43 \cdot 10^{-2} \pm 3.48 \cdot 10^{-1}$	$2.69 \cdot 10^{-1}$	0.9984	136
	Standard calibration	5-600	$1.12 \cdot 10^{-2} \pm 2.53 \cdot 10^{-4}$	$-2.92 \cdot 10^{-2} \pm 7.20 \cdot 10^{-2}$	$5.56 \cdot 10^{-2}$	0.9996	-

Table 4S.-(Continued).

Analyte	Sample	Studied linear range (µg/kg)	Regression equation (n=7)		$s_{y/x}$	R^2	ME (%)
			$b \pm s_b\cdot t_{(0.05;5)}$	$a \pm s_a\cdot t_{(0.05;5)}$			
Pirimiphos-ethyl	Strawberry	5-600	$3.33\cdot10^{-3} \pm 8.48\cdot10^{-5}$	$-1.40\cdot10^{-2} \pm 2.41\cdot10^{-2}$	$1.87\cdot10^{-2}$	0.9995	-4
	Blackberry	5-600	$5.84\cdot10^{-3} \pm 3.34\cdot10^{-4}$	$-5.41\cdot10^{-2} \pm 9.51\cdot10^{-2}$	$7.35\cdot10^{-2}$	0.9975	67
	Passion fruit'	5-600	$3.64\cdot10^{-3} \pm 4.80\cdot10^{-5}$	$-1.94\cdot10^{-2} \pm 1.37\cdot10^{-2}$	$1.06\cdot10^{-2}$	0.9999	4
	Pineapple	5-600	$3.38\cdot10^{-3} \pm 5.64\cdot10^{-5}$	$-1.38\cdot10^{-2} \pm 1.60\cdot10^{-2}$	$1.24\cdot10^{-2}$	0.9998	-2
	Grape	5-600	$5.09\cdot10^{-3} \pm 2.19\cdot10^{-4}$	$-5.22\cdot10^{-2} \pm 6.23\cdot10^{-2}$	$4.82\cdot10^{-2}$	0.9986	46
	Standard calibration	5-600	$3.48\cdot10^{-3} \pm 1.44\cdot10^{-4}$	$-8.15\cdot10^{-3} \pm 4.11\cdot10^{-2}$	$3.18\cdot10^{-2}$	0.9987	-
Penconazole	Strawberry	5-600	$3.62\cdot10^{-2} \pm 6.92\cdot10^{-4}$	$1.66\cdot10^{-1} \pm 1.97\cdot10^{-1}$	$1.52\cdot10^{-1}$	0.9997	79
	Blackberry	5-600	$8.26\cdot10^{-2} \pm 1.36\cdot10^{-3}$	$3.80\cdot10^{-1} \pm 3.86\cdot10^{-1}$	$2.98\cdot10^{-1}$	0.9998	308
	Passion fruit'	5-600	$3.87\cdot10^{-2} \pm 1.56\cdot10^{-3}$	$-2.12\cdot10^{-1} \pm 4.44\cdot10^{-1}$	$3.43\cdot10^{-1}$	0.9988	91
	Pineapple	5-600	$3.34\cdot10^{-2} \pm 6.99\cdot10^{-4}$	$-7.21\cdot10^{-2} \pm 1.99\cdot10^{-1}$	$1.54\cdot10^{-1}$	0.9997	65
	Grape	5-600	$6.10\cdot10^{-2} \pm 3.48\cdot10^{-3}$	$-5.74\cdot10^{-1} \pm 9.89\cdot10^{-1}$	$7.65\cdot10^{-1}$	0.9975	201
	Standard calibration	5-600	$2.02\cdot10^{-2} \pm 3.75\cdot10^{-4}$	$-6.85\cdot10^{-3} \pm 1.07\cdot10^{-1}$	$8.25\cdot10^{-2}$	0.9997	-
Triflumizole	Strawberry	5-600	$9.12\cdot10^{-3} \pm 9.02\cdot10^{-5}$	$-2.78\cdot10^{-3} \pm 2.57\cdot10^{-2}$	$1.98\cdot10^{-2}$	0.9999	123
	Blackberry	5-600	$8.88\cdot10^{-3} \pm 6.39\cdot10^{-4}$	$-6.50\cdot10^{-2} \pm 1.82\cdot10^{-1}$	$1.40\cdot10^{-1}$	0.9961	117
	Passion fruit'	5-600	$1.04\cdot10^{-2} \pm 1.69\cdot10^{-4}$	$-3.53\cdot10^{-2} \pm 4.81\cdot10^{-2}$	$3.72\cdot10^{-2}$	0.9998	154
	Pineapple	5-600	$8.89\cdot10^{-3} \pm 1.88\cdot10^{-4}$	$-1.14\cdot10^{-2} \pm 5.36\cdot10^{-2}$	$4.14\cdot10^{-2}$	0.9997	117
	Grape	5-600	$1.18\cdot10^{-2} \pm 3.49\cdot10^{-4}$	$-9.83\cdot10^{-2} \pm 9.92\cdot10^{-2}$	$7.67\cdot10^{-2}$	0.9993	189
	Standard calibration	5-600	$4.09\cdot10^{-3} \pm 9.70\cdot10^{-5}$	$-4.16\cdot10^{-2} \pm 2.76\cdot10^{-2}$	$2.13\cdot10^{-2}$	0.9996	-
Methidathion	Strawberry	5-600	$2.01\cdot10^{-2} \pm 5.24\cdot10^{-4}$	$1.17\cdot10^{-1} \pm 1.49\cdot10^{-1}$	$1.15\cdot10^{-1}$	0.9995	63
	Blackberry	5-600	$2.50\cdot10^{-2} \pm 1.35\cdot10^{-3}$	$-3.40\cdot10^{-2} \pm 3.83\cdot10^{-1}$	$2.96\cdot10^{-1}$	0.9978	103
	Passion fruit'	5-600	$1.31\cdot10^{-2} \pm 6.26\cdot10^{-4}$	$-6.57\cdot10^{-2} \pm 1.78\cdot10^{-1}$	$1.38\cdot10^{-1}$	0.9983	6
	Pineapple	5-600	$1.94\cdot10^{-2} \pm 7.14\cdot10^{-4}$	$6.54\cdot10^{-2} \pm 2.03\cdot10^{-1}$	$1.57\cdot10^{-1}$	0.9990	5
	Grape	5-600	$2.31\cdot10^{-2} \pm 1.27\cdot10^{-3}$	$-1.56\cdot10^{-1} \pm 3.62\cdot10^{-1}$	$2.80\cdot10^{-1}$	0.9977	87
	Standard calibration	5-600	$1.23\cdot10^{-2} \pm 8.92\cdot10^{-4}$	$-2.12\cdot10^{-1} \pm 2.54\cdot10^{-1}$	$1.96\cdot10^{-1}$	0.9960	-

Table 4S.-(Continued).

Analyte	Sample	Studied linear range (µg/kg)	Regression equation (n=7)		$s_{y/x}$	R^2	ME (%)
			$b \pm s_b \cdot t_{(0.05;5)}$	$a \pm s_a \cdot t_{(0.05;5)}$			
Fenamiphos	Strawberry	5-600	$5.16 \cdot 10^{-3} \pm 7.30 \cdot 10^{-5}$	$-8.51 \cdot 10^{-3} \pm 2.08 \cdot 10^{-2}$	$1.60 \cdot 10^{-2}$	0.9998	6462
	Blackberry	5-600	$9.44 \cdot 10^{-3} \pm 1.87 \cdot 10^{-4}$	$-4.30 \cdot 10^{-2} \pm 5.32 \cdot 10^{-2}$	$4.11 \cdot 10^{-2}$	0.9997	11899
	Passion fruit'	5-600	$5.45 \cdot 10^{-3} \pm 1.05 \cdot 10^{-4}$	$-2.33 \cdot 10^{-2} \pm 2.99 \cdot 10^{-2}$	$2.31 \cdot 10^{-2}$	0.9997	6821
	Pineapple	5-600	$5.90 \cdot 10^{-3} \pm 9.35 \cdot 10^{-5}$	$-9.97 \cdot 10^{-3} \pm 2.66 \cdot 10^{-2}$	$2.06 \cdot 10^{-2}$	0.9998	7398
	Grape	5-600	$6.42 \cdot 10^{-3} \pm 3.94 \cdot 10^{-4}$	$-8.80 \cdot 10^{-2} \pm 1.12 \cdot 10^{-1}$	$8.66 \cdot 10^{-2}$	0.9972	8057
	Standard calibration	5-600	$7.87 \cdot 10^{-5} \pm 3.98 \cdot 10^{-6}$	$9.09 \cdot 10^{-4} \pm 1.13 \cdot 10^{-3}$	$8.75 \cdot 10^{-4}$	0.9981	-
Myclobutanil	Strawberry	5-600	$3.49 \cdot 10^{-2} \pm 9.64 \cdot 10^{-4}$	$7.99 \cdot 10^{-1} \pm 2.74 \cdot 10^{-1}$	$2.12 \cdot 10^{-1}$	0.9994	169
	Blackberry	5-600	$7.11 \cdot 10^{-2} \pm 7.44 \cdot 10^{-4}$	$7.26 \cdot 10^{-1} \pm 2.12 \cdot 10^{-1}$	$1.64 \cdot 10^{-1}$	0.9999	450
	Passion fruit'	5-600	$3.81 \cdot 10^{-2} \pm 9.05 \cdot 10^{-4}$	$-4.69 \cdot 10^{-2} \pm 2.57 \cdot 10^{-1}$	$1.99 \cdot 10^{-1}$	0.9996	194
	Pineapple	5-600	$3.25 \cdot 10^{-2} \pm 7.67 \cdot 10^{-4}$	$1.38 \cdot 10^{-2} \pm 2.18 \cdot 10^{-1}$	$1.69 \cdot 10^{-1}$	0.9996	151
	Grape	5-600	$5.23 \cdot 10^{-2} \pm 3.55 \cdot 10^{-3}$	$-3.81 \cdot 10^{-1} \pm 0.10 \cdot 10$	$7.81 \cdot 10^{-1}$	0.9965	305
	Standard calibration	5-600	$1.29 \cdot 10^{-2} \pm 1.19 \cdot 10^{-3}$	$-2.29 \cdot 10^{-1} \pm 3.39 \cdot 10^{-1}$	$2.62 \cdot 10^{-1}$	0.9936	-
Dieldrin	Strawberry	5-600	$3.31 \cdot 10^{-3} \pm 5.32 \cdot 10^{-5}$	$-7.77 \cdot 10^{-3} \pm 1.51 \cdot 10^{-2}$	$1.17 \cdot 10^{-2}$	0.9998	-17
	Blackberry	5-600	$6.69 \cdot 10^{-3} \pm 3.54 \cdot 10^{-4}$	$-3.43 \cdot 10^{-2} \pm 1.01 \cdot 10^{-1}$	$7.78 \cdot 10^{-2}$	0.9979	66
	Passion fruit'	5-600	$3.71 \cdot 10^{-3} \pm 5.87 \cdot 10^{-5}$	$7.46 \cdot 10^{-4} \pm 1.67 \cdot 10^{-2}$	$1.29 \cdot 10^{-2}$	0.9998	-7
	Pineapple	5-600	$3.16 \cdot 10^{-3} \pm 1.21 \cdot 10^{-4}$	$9.91 \cdot 10^{-3} \pm 3.43 \cdot 10^{-2}$	$2.65 \cdot 10^{-2}$	0.9989	-21
	Grape	5-600	$5.59 \cdot 10^{-3} \pm 3.62 \cdot 10^{-4}$	$-5.16 \cdot 10^{-2} \pm 1.03 \cdot 10^{-1}$	$7.96 \cdot 10^{-2}$	0.9968	39
	Standard calibration	5-600	$4.02 \cdot 10^{-3} \pm 2.32 \cdot 10^{-4}$	$8.75 \cdot 10^{-3} \pm 6.59 \cdot 10^{-2}$	$5.09 \cdot 10^{-2}$	0.9975	-
Oxyfluorfen	Strawberry	5-600	$3.15 \cdot 10^{-3} \pm 7.48 \cdot 10^{-5}$	$-2.67 \cdot 10^{-2} \pm 2.13 \cdot 10^{-2}$	$1.64 \cdot 10^{-2}$	0.9996	155
	Blackberry	5-600	$5.50 \cdot 10^{-3} \pm 1.75 \cdot 10^{-4}$	$-6.04 \cdot 10^{-2} \pm 4.96 \cdot 10^{-2}$	$3.84 \cdot 10^{-2}$	0.9992	346
	Passion fruit'	5-600	$3.36 \cdot 10^{-3} \pm 1.41 \cdot 10^{-4}$	$-2.82 \cdot 10^{-2} \pm 4.01 \cdot 10^{-2}$	$3.10 \cdot 10^{-2}$	0.9987	172
	Pineapple	5-600	$3.20 \cdot 10^{-3} \pm 6.92 \cdot 10^{-5}$	$-2.36 \cdot 10^{-2} \pm 1.97 \cdot 10^{-2}$	$1.52 \cdot 10^{-2}$	0.9996	159
	Grape	5-600	$4.67 \cdot 10^{-3} \pm 3.23 \cdot 10^{-4}$	$-7.45 \cdot 10^{-2} \pm 9.18 \cdot 10^{-2}$	$7.10 \cdot 10^{-2}$	0.9964	279
	Standard calibration	5-600	$1.23 \cdot 10^{-3} \pm 7.93 \cdot 10^{-5}$	$-1.43 \cdot 10^{-2} \pm 2.25 \cdot 10^{-2}$	$1.74 \cdot 10^{-2}$	0.9974	-

Table 4S.-(Continued).

Analyte	Sample	Studied linear range (µg/kg)	Regression equation (n=7)		$s_{y/x}$	R^2	ME (%)
			$b \pm s_b \cdot t_{(0.05;5)}$	$a \pm s_a \cdot t_{(0.05;5)}$			
Buprofezin	Strawberry	5-600	$9.50\cdot10^{-3} \pm 2.48\cdot10^{-4}$	$3.80\cdot10^{-2} \pm 7.05\cdot10^{-2}$	$5.45\cdot10^{-2}$	0.9995	21
	Blackberry	5-600	$1.73\cdot10^{-2} \pm 3.66\cdot10^{-4}$	$3.37\cdot10^{-2} \pm 1.04\cdot10^{-1}$	$8.04\cdot10^{-2}$	0.9997	120
	Passion fruit'	5-600	$1.03\cdot10^{-2} \pm 1.78\cdot10^{-4}$	$1.34\cdot10^{-2} \pm 5.06\cdot10^{-2}$	$3.91\cdot10^{-2}$	0.9998	31
	Pineapple	5-600	$8.66\cdot10^{-3} \pm 3.25\cdot10^{-4}$	$8.65\cdot10^{-2} \pm 9.23\cdot10^{-2}$	$7.14\cdot10^{-2}$	0.9989	10
	Grape	5-600	$1.42\cdot10^{-2} \pm 6.82\cdot10^{-4}$	$-8.34\cdot10^{-2} \pm 1.94\cdot10^{-1}$	$1.50\cdot10^{-1}$	0.9983	81
	Standard calibration	5-600	$7.84\cdot10^{-3} \pm 1.83\cdot10^{-4}$	$-2.32\cdot10^{-2} \pm 5.22\cdot10^{-2}$	$4.03\cdot10^{-2}$	0.9996	-
Endrin	Strawberry	5-600	$2.25\cdot10^{-3} \pm 6.28\cdot10^{-5}$	$-1.82\cdot10^{-2} \pm 1.79\cdot10^{-2}$	$1.38\cdot10^{-2}$	0.9994	-2
	Blackberry	5-600	$4.04\cdot10^{-3} \pm 3.05\cdot10^{-4}$	$-5.85\cdot10^{-2} \pm 8.67\cdot10^{-2}$	$6.71\cdot10^{-2}$	0.9957	74
	Passion fruit'	5-600	$2.58\cdot10^{-3} \pm 6.85\cdot10^{-5}$	$-2.19\cdot10^{-2} \pm 1.95\cdot10^{-2}$	$1.51\cdot10^{-2}$	0.9995	11
	Pineapple	5-600	$2.23\cdot10^{-3} \pm 7.87\cdot10^{-5}$	$-1.23\cdot10^{-2} \pm 2.24\cdot10^{-2}$	$1.73\cdot10^{-2}$	0.9991	-3
	Grape	5-600	$3.32\cdot10^{-3} \pm 2.33\cdot10^{-4}$	$-5.14\cdot10^{-2} \pm 6.62\cdot10^{-2}$	$5.12\cdot10^{-2}$	0.9963	43
	Standard calibration	5-600	$2.31\cdot10^{-3} \pm 5.91\cdot10^{-5}$	$-1.16\cdot10^{-2} \pm 1.68\cdot10^{-2}$	$1.30\cdot10^{-2}$	0.9995	-
Ethion	Strawberry	5-600	$2.43\cdot10^{-2} \pm 1.55\cdot10^{-4}$	$1.38\cdot10^{-2} \pm 4.41\cdot10^{-2}$	$3.41\cdot10^{-2}$	0.9999	73
	Blackberry	5-600	$3.88\cdot10^{-2} \pm 1.39\cdot10^{-3}$	$5.00\cdot10^{-2} \pm 3.95\cdot10^{-1}$	$3.05\cdot10^{-1}$	0.9990	175
	Passion fruit'	5-600	$2.22\cdot10^{-2} \pm 5.19\cdot10^{-4}$	$-2.19\cdot10^{-2} \pm 1.48\cdot10^{-1}$	$1.14\cdot10^{-1}$	0.9996	57
	Pineapple	5-600	$2.33\cdot10^{-2} \pm 7.94\cdot10^{-4}$	$2.55\cdot10^{-2} \pm 2.26\cdot10^{-1}$	$1.75\cdot10^{-1}$	0.9991	65
	Grape	5-600	$3.78\cdot10^{-2} \pm 2.11\cdot10^{-3}$	$-2.09\cdot10^{-1} \pm 5.99\cdot10^{-1}$	$4.63\cdot10^{-1}$	0.9977	169
	Standard calibration	5-600	$1.41\cdot10^{-2} \pm 3.50\cdot10^{-4}$	$-1.01\cdot10^{-1} \pm 9.94\cdot10^{-2}$	$7.69\cdot10^{-2}$	0.9995	-
Propiconazole	Strawberry	5-600	$1.25\cdot10^{-2} \pm 1.18\cdot10^{-3}$	$7.51\cdot10^{-1} \pm 3.35\cdot10^{-1}$	$2.59\cdot10^{-1}$	0.9933	63
	Blackberry	5-600	$3.11\cdot10^{-2} \pm 3.60\cdot10^{-3}$	$0.19\cdot10 \pm 0.10\cdot10$	$7.91\cdot10^{-1}$	0.9900	306
	Passion fruit'	5-600	$1.36\cdot10^{-2} \pm 1.27\cdot10^{-3}$	$7.99\cdot10^{-1} \pm 3.60\cdot10^{-1}$	$2.79\cdot10^{-1}$	0.9935	78
	Pineapple	5-600	$1.18\cdot10^{-2} \pm 6.57\cdot10^{-4}$	$3.09\cdot10^{-1} \pm 1.87\cdot10^{-1}$	$1.45\cdot10^{-1}$	0.9977	54
	Grape	5-600	$1.79\cdot10^{-2} \pm 2.27\cdot10^{-3}$	$0.20\cdot10 \pm 6.45\cdot10^{-1}$	$4.98\cdot10^{-1}$	0.9910	133
	Standard calibration	5-600	$7.65\cdot10^{-3} \pm 3.05\cdot10^{-4}$	$-3.70\cdot10^{-3} \pm 8.67\cdot10^{-2}$	$6.70\cdot10^{-2}$	0.9988	-

Table 4S.-(Continued).

Analyte	Sample	Studied linear range (µg/kg)	Regression equation (n=7)		$s_{y/x}$	R^2	ME (%)
			$b \pm s_b \cdot t_{(0.05;5)}$	$a \pm s_a \cdot t_{(0.05;5)}$			
Tebuconazole	Strawberry	5-600	$1.77 \cdot 10^{-2} \pm 5.91 \cdot 10^{-4}$	$0.16 \cdot 10 \pm 1.68 \cdot 10^{-1}$	$1.30 \cdot 10^{-1}$	0.9992	184
	Blackberry	5-600	$3.52 \cdot 10^{-2} \pm 7.48 \cdot 10^{-4}$	$0.13 \cdot 10 \pm 2.13 \cdot 10^{-1}$	$1.64 \cdot 10^{-1}$	0.9997	464
	Passion fruit'	5-600	$1.93 \cdot 10^{-2} \pm 9.01 \cdot 10^{-4}$	$2.72 \cdot 10^{-2} \pm 2.56 \cdot 10^{-1}$	$1.98 \cdot 10^{-1}$	0.9984	209
	Pineapple	5-600	$1.66 \cdot 10^{-2} \pm 2.44 \cdot 10^{-4}$	$1.44 \cdot 10^{-2} \pm 6.94 \cdot 10^{-2}$	$5.36 \cdot 10^{-2}$	0.9998	166
	Grape	5-600	$2.81 \cdot 10^{-2} \pm 1.36 \cdot 10^{-3}$	$-2.38 \cdot 10^{-1} \pm 3.87 \cdot 10^{-1}$	$2.99 \cdot 10^{-1}$	0.9982	350
	Standard calibration	5-600	$6.24 \cdot 10^{-3} \pm 4.23 \cdot 10^{-4}$	$-5.35 \cdot 10^{-2} \pm 1.20 \cdot 10^{-1}$	$9.30 \cdot 10^{-2}$	0.9965	-
Iprodione	Strawberry	5-600	$7.92 \cdot 10^{-4} \pm 6.28 \cdot 10^{-5}$	$2.18 \cdot 10^{-2} \pm 1.79 \cdot 10^{-2}$	$1.38 \cdot 10^{-2}$	0.9953	488
	Blackberry	5-600	$4.11 \cdot 10^{-3} \pm 4.22 \cdot 10^{-4}$	$6.29 \cdot 10^{-1} \pm 1.20 \cdot 10^{-1}$	$9.27 \cdot 10^{-2}$	0.9928	2958
	Passion fruit'	5-600	$3.48 \cdot 10^{-4} \pm 3.67 \cdot 10^{-5}$	$1.13 \cdot 10^{-2} \pm 1.04 \cdot 10^{-2}$	$8.07 \cdot 10^{-3}$	0.9926	158
	Pineapple	5-600	$6.65 \cdot 10^{-4} \pm 2.30 \cdot 10^{-5}$	$8.62 \cdot 10^{-3} \pm 6.54 \cdot 10^{-3}$	$5.06 \cdot 10^{-3}$	0.9992	394
	Grape	5-600	$2.90 \cdot 10^{-3} \pm 2.69 \cdot 10^{-4}$	$3.65 \cdot 10^{-1} \pm 7.66 \cdot 10^{-2}$	$5.92 \cdot 10^{-2}$	0.9945	2053
	Standard calibration	5-600	$1.35 \cdot 10^{-4} \pm 4.17 \cdot 10^{-5}$	$-3.41 \cdot 10^{-3} \pm 1.19 \cdot 10^{-2}$	$9.18 \cdot 10^{-3}$	0.9918	-
EPN	Strawberry	5-600	$7.68 \cdot 10^{-3} \pm 2.37 \cdot 10^{-4}$	$4.62 \cdot 10^{-2} \pm 6.74 \cdot 10^{-2}$	$5.21 \cdot 10^{-2}$	0.9993	122
	Blackberry	5-600	$1.13 \cdot 10^{-2} \pm 6.23 \cdot 10^{-4}$	$1.56 \cdot 10^{-1} \pm 1.77 \cdot 10^{-1}$	$1.37 \cdot 10^{-1}$	0.9977	226
	Passion fruit'	5-600	$4.48 \cdot 10^{-3} \pm 1.60 \cdot 10^{-4}$	$6.66 \cdot 10^{-2} \pm 4.56 \cdot 10^{-2}$	$3.53 \cdot 10^{-2}$	0.9992	29
	Pineapple	5-600	$7.16 \cdot 10^{-3} \pm 4.93 \cdot 10^{-4}$	$2.40 \cdot 10^{-1} \pm 1.40 \cdot 10^{-1}$	$1.08 \cdot 10^{-1}$	0.9970	107
	Grape	5-600	$1.14 \cdot 10^{-2} \pm 1.34 \cdot 10^{-3}$	$2.69 \cdot 10^{-1} \pm 3.82 \cdot 10^{-1}$	$2.95 \cdot 10^{-1}$	0.9913	230
	Standard calibration	5-600	$3.46 \cdot 10^{-3} \pm 3.05 \cdot 10^{-4}$	$-3.86 \cdot 10^{-2} \pm 8.67 \cdot 10^{-2}$	$6.70 \cdot 10^{-2}$	0.9941	-
Pyriproxyfen	Strawberry	5-600	$2.35 \cdot 10^{-2} \pm 2.68 \cdot 10^{-4}$	$-1.05 \cdot 10^{-2} \pm 7.63 \cdot 10^{-2}$	$5.90 \cdot 10^{-2}$	0.9999	181
	Blackberry	5-600	$5.07 \cdot 10^{-2} \pm 4.83 \cdot 10^{-4}$	$1.52 \cdot 10^{-1} \pm 1.37 \cdot 10^{-1}$	$1.06 \cdot 10^{-1}$	0.9999	507
	Passion fruit'	5-600	$2.55 \cdot 10^{-2} \pm 1.30 \cdot 10^{-3}$	$0.10 \cdot 10 \pm 3.71 \cdot 10^{-1}$	$2.86 \cdot 10^{-1}$	0.9980	205
	Pineapple	5-600	$2.28 \cdot 10^{-2} \pm 4.57 \cdot 10^{-4}$	$3.81 \cdot 10^{-1} \pm 1.30 \cdot 10^{-1}$	$1.00 \cdot 10^{-1}$	0.9997	173
	Grape	5-600	$3.59 \cdot 10^{-2} \pm 2.75 \cdot 10^{-3}$	$0.16 \cdot 10 \pm 7.82 \cdot 10^{-1}$	$6.04 \cdot 10^{-1}$	0.9956	330
	Standard calibration	5-600	$8.35 \cdot 10^{-3} \pm 2.52 \cdot 10^{-4}$	$-4.64 \cdot 10^{-3} \pm 7.16 \cdot 10^{-2}$	$5.54 \cdot 10^{-2}$	0.9993	-

Table 4S.-(Continued).

Analyte	Sample	Studied linear range (µg/kg)	Regression equation (n=7)		$s_{y/x}$	R^2	ME (%)
			$b \pm s_b \cdot t_{(0.05;5)}$	$a \pm s_a \cdot t_{(0.05;5)}$			
Fenvalerate	Strawberry	5-600	$2.45\cdot10^{-2} \pm 3.37\cdot10^{-4}$	$3.82\cdot10^{-2} \pm 9.58\cdot10^{-2}$	$7.40\cdot10^{-2}$	0.9999	487
	Blackberry	5-600	$4.74\cdot10^{-2} \pm 4.63\cdot10^{-3}$	$-2.92\cdot10^{-1} \pm 0.13\cdot10$	$0.10\cdot10$	0.9928	1037
	Passion fruit'	5-600	$1.26\cdot10^{-2} \pm 3.66\cdot10^{-4}$	$-2.18\cdot10^{-2} \pm 1.04\cdot10^{-1}$	$8.06\cdot10^{-2}$	0.9994	202
	Pineapple	5-600	$2.36\cdot10^{-2} \pm 6.20\cdot10^{-5}$	$1.32\cdot10^{-2} \pm 1.76\cdot10^{-2}$	$1.36\cdot10^{-2}$	0.9999	466
	Grape	5-600	$4.52\cdot10^{-2} \pm 3.08\cdot10^{-3}$	$-2.54\cdot10^{-1} \pm 8.77\cdot10^{-1}$	$6.78\cdot10^{-1}$	0.9965	984
	Standard calibration	5-600	$4.17\cdot10^{-3} \pm 3.11\cdot10^{-4}$	$-8.76\cdot10^{-2} \pm 8.84\cdot10^{-2}$	$6.83\cdot10^{-2}$	0.9958	-
Esfenvalerate	Strawberry	5-600	$2.44\cdot10^{-2} \pm 3.94\cdot10^{-4}$	$2.49\cdot10^{-2} \pm 1.12\cdot10^{-1}$	$8.67\cdot10^{-2}$	0.9998	814
	Blackberry	5-600	$4.71\cdot10^{-2} \pm 4.46\cdot10^{-3}$	$-2.42\cdot10^{-1} \pm 0.12\cdot10$	$9.81\cdot10^{-1}$	0.9932	1663
	Passion fruit'	5-600	$1.24\cdot10^{-2} \pm 3.50\cdot10^{-4}$	$1.25\cdot10^{-2} \pm 9.97\cdot10^{-2}$	$7.70\cdot10^{-2}$	0.9994	363
	Pineapple	5-600	$2.37\cdot10^{-2} \pm 2.31\cdot10^{-4}$	$-2.18\cdot10^{-2} \pm 6.58\cdot10^{-2}$	$5.09\cdot10^{-2}$	0.9999	787
	Grape	5-600	$4.56\cdot10^{-2} \pm 2.76\cdot10^{-3}$	$-2.42\cdot10^{-1} \pm 7.86\cdot10^{-1}$	$6.08\cdot10^{-1}$	0.9972	1607
	Standard calibration	5-600	$2.67\cdot10^{-3} \pm 2.43\cdot10^{-4}$	$-3.48\cdot10^{-2} \pm 6.90\cdot10^{-2}$	$5.33\cdot10^{-2}$	0.9948	-

b: Slope; Sb: Standard deviation of the slope; a: intercept; Sa: Standard deviation of the intercept; R^2: determination coefficient; Sy/x: standard deviation of the estimate. a Calculated following the equation used by Kwon et al. (Kwon, Lehotay, & Geis-Asteggiante, 2012).

IV.3.- Determination of pesticides in dried minor tropical fruits from Colombia using the *Quick, Easy, Cheap, Effective, Rugged* and *Safe* method-gas chromatography tandem mass spectrometry

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The aim of this work was to extend the application of the method previously studied and validated to the analysis of the same group of pesticides in the dried minor tropical fruits uchuva (*Physalis peruviana*), lulo (*Solanum quitoense*), guanabana (*Anona muricata*) and pitahaya (*Hylocereus undatus*) cultivated and exported from Colombia as well as to study matrix effects and to analyse several samples of each type.

Calibration curves using the peak areas ratio of the analytes and the IS of the method (atrazine d_5) were developed both in pure solvent and in the extracts of each dried fruit. In all cases, the same analytes protectants mixture of our previous manuscripts was used. Determination coefficients (R^2) higher than 0.99 were obtained for all the pesticides and samples. Concerning matrix effects, most pesticides showed a soft or medium matrix effect, except for guanabana, which showed a high matrix effect for a higher number of pesticides.

Satisfactory recovery (in the range 70-120 %) and intra-day precision (RSD < 20 %) was obtained for 92 % of the pesticides and matrix combinations after the development of the recovery study at three concentration levels. The LCL of the method was also 5 μg/kg for all pesticides and matrices.

Regarding the analysis of real samples (5 samples of each type bought at local markets of Bogotá), showed the presence of a single pesticide, tebuconazole, in two uchuva samples, one of them below the LCL of the method.

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RESEARCH ARTICLE

Determination of pesticides in dried minor tropical fruits from Colombia using the Quick, Easy, Cheap, Effective, Rugged, and Safe method-gas chromatography–tandem mass spectrometry

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The AOAC 2007.1 quick, easy, cheap, effective, rugged, and safe official method, together with gas chromatography coupled to a triple quadrupole mass spectrometer was applied for the analysis of 38 multiclass pesticides from dried fruits typically cultivated and exported from Colombia: uchuva (*Physalis peruviana*), lulo (*Solanum quitoense*), guanabana (*Anona muricata*), and pitahaya (*Hylocereus undatus*). The whole method was validated in terms of matrix-matched calibration, matrix effect, and recovery using atrazine-d_5 as internal standard, triphenylphosphate for quality control of the injection, and a proper mixture of analytes protectants. Matrix-matched calibration data were found satisfactory for all pesticides and dried fruits, reporting R^2 values above 0.99. Matrix effect values evidenced the existence of such effect in most cases. The applied procedure gave satisfactory recovery percentages (70–120%) and relative standard deviation values (< 20%) for 92% of the 456 combinations pesticide/fruit studied (spiked levels of 25, 200, and 400 μg/kg). Finally, 20 real dried fruit samples were analyzed and residues of tebuconazole were found in two samples of uchuva at a concentration below the lowest calibration level of the method for one of them and at 10.8 ± 1.6 μg/kg for the other, being below or similar to the general maximum residue level established for monitoring purposes in food applications.

KEYWORDS
dried fruits, gas chromatography, pesticide residues, tandem mass spectrometry, tropical fruits

1 | INTRODUCTION

Nowadays, it is clear that among the different contaminants that may be present in foods, pesticides have been mostly studied and regulated, probably because of their wide use worldwide, the health concerns that have arisen since their introduction and the extremely high world trade of foods. In fact, many countries around the world have set strict regulations concerning the authorization of pesticides, the establishment of maximum residue limits (MRLs), the development of regular pesticide monitoring programs, or even the compliance of official laboratories dedicated to pesticide residue analysis.

Pesticide residues determination in food commodities, though carried out in a good number of occasions, has a high interest [1–8]. On the one hand, it is important to suitably control the presence of pesticides in food samples (especially to guarantee food safety), to check the presence and

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Article Related Abbreviations: C_{18}, octadecylsilane; EPN, *O*-ethyl *O*-(4-nitrophenyl) phenylphosphonothioate; IS, internal standard; LCL, lowest calibration level; ME, matrix effect; MRL, maximum residue limit; PSA, primary secondary amine; QqQ, triple quadrupole; TPP, triphenylphosphate.

persistence of recently authorized pesticides and to find out if illegal practices are being developed [1,2]. On the other hand, it is also important to implement, improve, and extend existing analytical methods that would be used to address the previous issues [3–5].

Regarding the analysis of pesticide residues, the QuEChERS method, introduced in 2003 [9], is probably the most relevant and most applied in the field due to its simplicity, rapidity, low cost, effectivity, robustness, and safety. Its importance is such that it is indeed considered a "mega method" [10,11] since similar conditions are able to provide the simultaneous and effective extraction of a wide variety of compounds.

Despite such success, QuEChERS is still considered a "living" method since current trends in its development and improvement are focused on the automation of the procedure (which is an important issue), on the introduction of new clean-up and effective sorbents as well as on the extension of its applicability to the extraction of highly polar pesticides and highly complex matrices in which it has not been applied yet [5,11]. In this sense, its application to the analysis of minor tropical fruits (others different from mango, pineapple, banana, papaya, and avocado) has been limited since such fruits are less cultivated, there is a minor market of pesticides and, as a consequence, not enough attention is frequently paid to the development of analytical methods for the determination of pesticides in such matrices [12]. Besides that, other matrices in which the QuEChERS method has been less applied are dried fruits (which are nutritionally equivalent to fresh fruits in smaller serving sizes), probably as a result of their low water content and high amount of sugars. In fact, the number of previous works in which pesticides have been analyzed in dried fruits is really scarce [13–16]. As an example, Liu et al. [14] applied an unbuffered version of the QuEChERS method prior to GC–MS to determine 29 pesticides in dried red peppers, while Rasche et al. [13] applied the QuEChERS CEN 15662 method to three dried fruits (raisins, apples, and blackcurrant) prior to their determination by GC–MS/MS. Rutkowska et al. [16] also applied the CEN 15662 method for the determination of 236 pesticides in three dried herbs (*Centaurea cyanus* L., *Matricaria chamomilla* L., *and Thymus vulgaris* L.) and in dried fruit currants and chokeberry. Very recently, in a previous work carried out by our research group [15], we studied the application of three versions of the QuEChERS method (original, AOAC 2007.01, and CEN 15662) for the extraction of 38 multiclass pesticides from a mixture of five dried fruits: strawberry, blackberry, passion fruit, pineapple, and grapes. Since the AOAC 2007.01 method provided the best results in terms of lower amount of matrix co-extractives, matrix effect (ME), extraction efficiency, and precision, it was later applied to the analysis of the same pesticides in the individual dried fruits providing good recovery (between 70 and 120%) and relative standard deviation values (< 20%) for most pesticides at three spiked levels. Since the content of pesticide residues in these types of matrices is normally higher than in the same fresh products due to concentration effect, it is still necessary to extend these studies to other dried fruits.

The aim of this work is to extend the application of such version of the QuEChERS method to the analysis of pesticides in the dried minor tropical fruits uchuva (*Physalis peruviana*), lulo (*Solanum quitoense*), guanabana (*Anona muricata*), and pitahaya (*Hylocereus undatus*) cultivated and exported from Colombia, to study ME and to analyze several samples of each type. To the best of our knowledge, this is the first time of the QuEChERS method application in the extraction of pesticides from this type of dried fruits and one of the very few articles in the literature in applying the method to the extraction of dried fruits, also to these minor tropical fruits.

2 | MATERIALS AND METHODS

2.1 | Chemicals and samples

Pesticide analytical standards, atrazine-d_5 (as internal standard, IS), and triphenylphosphate (TPP), all with purity ≥ 95.9%, were obtained from Sigma–Aldrich (St. Louis, MO). Individual stock solutions of each analyte were prepared in toluene at approximately 1000 mg/L and stored in the dark at 4°C. For recovery studies, mixtures of pesticides and IS were prepared separately with ACN containing 0.05% (v/v) of formic acid to yield 25, 200, and 400 μg/kg for the pesticides and 200 μg/kg for the IS. For calibration studies, appropriate mixtures were prepared with the same solvent to yield 5, 10, 25, 75, 200, 400, and 600 μg/kg sample equivalents for the pesticides and 200 μg/kg for IS and TPP, all in the same solution. In addition, for quality control of the injection, another TPP solution was prepared in ACN with 0.05% (v/v) of formic acid to yield 200 μg/kg. The mix of analytes protectants contained ethylglycerol (100 g/L), gulonolactone (10 g/L), D-sorbitol (10 g/L), and shikimic acid (5 g/L) and was prepared in 4:1 (v/v) ACN/water also containing 0.5% (v/v) of formic acid. Each of them was obtained from Sigma–Aldrich with a purity ≥ 95.0%.

Toluene, GC–MS-grade ACN, GC-ECD/FID-grade methanol, ethyl acetate, and glacial acetic acid were obtained from Merck (Darmstadt, Germany). Anhydrous magnesium sulfate and sodium acetate were obtained from Sigma–Aldrich. Primary secondary amine (PSA) and octadecylsilane (C_{18}) were obtained from Supelco (Bellefonte, PA).

A total of 20 dried fruit samples already milled and homogenized of uchuva, lulo, guanabana, and pitahaya (five samples of each dried fruit and approximately 1 kg of each of them) were purchased from different conventional food stores in

Bogota, Colombia, and they were properly stored. At least one sample of each type of matrix, which was initially analyzed, was found to be free of the target analytes. Consequently, they were used as blank matrices for validation purposes. After validation, the rest of samples were analyzed.

2.2 | GC–MS/MS conditions

A Shimadzu GCMS-TQ8040 triple-quadrupole (QqQ) mass spectrometer, an autosampler AOC 20i/s and a SH-Rxi-5Sil MS column (30 m × 0.25 mm i.d., 0.25 μm) were used for analysis. Helium was employed as the carrier gas (2.0 mL/min). One microliter was injected in the splitless mode at 250°C (after 1 min of the injection, the split was opened) using the following column oven program: 50°C (for 1 min), then 25°C/min ramp to 180°C, then 5°C/min ramp to 230°C, and finally 25°C/min ramp to 290°C and held during 5 min. The MS interface and ion source were maintained at 250 and 300°C, respectively, and total run time was 24.6 min. Before each matrix validation, an auto-tune of the MS was performed, and the liner was changed. The 10 μL syringe was washed with a single rinse of methanol, ethyl acetate, and ACN between injections. Supporting Information Table S1 shows the retention times and quantifier and qualifier transitions of all the studied analytes.

2.3 | Sample preparation

Five grams of dried uchuva, dried lulo, dried guanabana, and dried pitahaya were properly spiked for recovery studies and slightly vortexed. Next, 10 mL of ACN with 1% (v/v) of acetic acid and 10 mL of water were added and the sample was shaken for 1 h employing an automated shaker. Then, 6 g of anhydrous magnesium sulfate and 1.5 g of sodium acetate were added, and the sample was hand-shaken for 5 min and centrifuged for 5 min at 4400 rpm. Subsequently, a dispersive solid-phase extraction step was carried out transferring 1 mL of the supernatant to a 2 mL tube containing 150 mg of anhydrous magnesium sulfate, 50 mg of PSA, and 50 mg of C_{18}. Immediately, the tube was vortexed for 30 s and centrifuged at 4400 rpm for 5 min. Afterward, 200 μL of the supernatant were transferred to the appropriate vials and 50 μL of the TPP solution and 20 μL of the mixture of analytes protectants were added (total volume of 270 μL). Finally, 1 μL was injected in the GC–QqQ–MS/MS equipment. For the calibration studies, the same previous steps were carried out; however, this time using blank extracts (without the addition of pesticides nor the IS at the beginning of the procedure) and the pesticides and IS together with the TPP as well as the mix of analytes protectants were added to the final extract (final volume of 270 μL), just before their injection in the GC–MS system.

3 | RESULTS AND DISCUSSION

In a previous study by our group [15], we demonstrated that the AOAC 2007.1 official QuEChERS method provided better results considering the amount of matrix co-extractives, ME, extraction efficiency, and precision than the original and CEN 15662 QuEChERS methods to extract a group of 38 multiclass pesticides from a mixture of five dried fruits (strawberry, blackberry, passion fruit, pineapple, and grapes) as well as from each dried fruit. Therefore, considering the importance of other dried minor tropical fruits widely cultivated and exported in Colombia, namely, uchuva, lulo, guanabana, and pitahaya, we extended this methodology to the analysis of the same group of pesticides from these dried fruits. For this purpose, a full validation was carried out in terms of matrix-matched calibration, ME, recovery, and precision in accordance with the requirements established by the Codex Alimentarius Commission Guidelines (CAC/GL 90–2017) [17]. In this sense, the samples under study were previously analyzed to corroborate the absence of any type of pesticide residue and/or chromatographic interferences. Finally, five samples of each dried fruit were analyzed to demonstrate the applicability of such method together with GC–QqQ–MS/MS for real sample analysis.

3.1 | Matrix-matched calibration and matrix effect

Calibration curves using the peak areas ratio of the analytes and the IS were developed following the established method in the range 5–600 μg/kg ($n = 7$) in triplicate, both in pure solvent and in the extracts of each dried fruit. As shown in Supporting Information Table S2, satisfactory linearity was achieved in all cases, with R^2 values > 0.99 (Supporting Information Figure S1 also shows the matrix-matched calibration curves for Guanabana as an example). It must be taken into account that the lowest calibration level (LCL, which was set at 5 μg/kg) was lower than the standard maximum residue limit (MRL) set at 10 μg/kg by the international legislation for the analysis of pesticides in agri-food matrices [18], which is higher than the LOQ values for all matrix/pesticide combination. In this sense, MRLs for pesticides have not been established for the studied commodities by the Codex Alimentarius [19], which is the applicable legislation in Colombia, not even for the corresponding fresh fruits.

Regarding ME, it was compensated by following the instructions of the previously commented guidelines (CAC/GL 90–2017), which indicate the possibility of using matrix-matched calibration, IS, and analytes protectants. In this last case, an appropriate mixture formed by ethylglycerol, gulonolactone, D-sorbitol, and shikimic acid was used as recommended by the parents of the QuEChERS method [20]. Although the above has demonstrated to provide significant

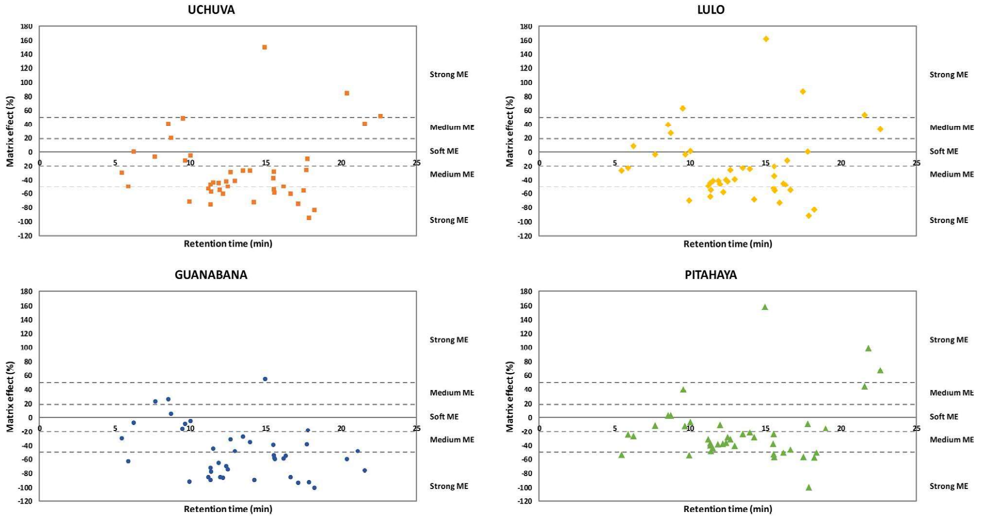

FIGURE 1 Distribution of the ME (%) versus retention time (min) for each analyzed dried fruit

improvements in reducing ME, Supporting Information Table S2 shows such effect calculated in percentage through the comparison of slopes of pure solvent-based and matrix-matched calibration curves. In particular, the following equation was used: ME (%) = (slope of matrix-matched calibration curve − slope of pure solvent-based calibration curve)/(slope of pure solvent-based calibration curve) × 100 [21]. In this sense, when the values move away from zero it means that the ME is greater, whether it is negative (suppression of the signal) or positive (enhancement of the signal). To clarify this point, Figure 1 shows the ME (%) distributions for the 38 pesticides studied in each of the dried fruits analyzed. As it can be appreciated, most pesticides showed a soft (range from –20 to 20%) or medium (range between –20 and –50% or between 20 and 50%) ME, except for guanabana, as will be shown in the next section.

3.2 | Recovery and precision

Method trueness was assessed in terms of recovery and repeatability (intraday precision) by application of the proposed QuEChERS–GC–QqQ–MS/MS method to extract the 38 pesticides from each dried fruit spiked at three different concentration levels (25, 200, and 400 μg/kg). In particular, mean recovery values were determined by comparing pesticide peak area/IS peak area ratios spiked before the application of the sample preparation method, with the ones obtained for blank extracts spiked after the application of the sample preparation method. Five consecutive replicates were injected three times each on the same day ($n = 5$). Results of the recovery study as well as the intraday precision expressed as average recovery percentages and RSD values, respectively, both in percentage, are summarized in Table 1. As can be observed, satisfactory recovery (in the range 70–120%) and intraday precision (RSD < 20%) was obtained for 92% of the cases, but if the requirements are extended to a range of 30–140% maintaining RSD values < 20%, as the SANTE/11813/2017 guidance document contemplates [22], the recovery values are acceptable for 97% of the cases (interday precision across 3 days of analysis expressed as RSD values were also < 20% for the same pesticides/matrix combination). Moreover, as it has been anticipated, it should be noted that the worst recovery values are obtained for guanabana. As an example, EPN presents recovery percentages > 120% at the three spiked levels, which is consistent with the strong ME that suffered. Analogously, the same happens for malathion, fenthion, methidathion, and fenamiphos in guanabana. In any case, the results are good in general terms that shows the high robustness of the applied method.

3.3 | Analysis of real samples

To confirm the applicability of the validated QuEChERS–GC–QqQ–MS/MS method, five samples of each dried fruit were collected from five food stores in Bogota (Colombia) and were analyzed in triplicate ($n = 3$). Table 2 shows that residues of most of the pesticides were undetected from all the samples, except tebuconazole in two samples with concentrations at 10.8 μg/kg and lower than the LCL (5 μg/kg). As already mentioned, there are no MRLs for any pesticide in the

TABLE 1 Average recovery and RSD (between parenthesis) values of the selected pesticides in representative matrices validation of the final method ($n = 5$ at each spiking level)

	UCHUVA			**LULO**			**GUANABANA**			**PITAHAYA**		
Pesticide	**25 μg/kg**	**200 μg/kg**	**400 μg/kg**	**25 μg/kg**	**200 μg/kg**	**400 μg/kg**	**25 μg/kg**	**200 μg/kg**	**400 μg/kg**	**25 μg/kg**	**200 μg/kg**	**400 μg/kg**
Propoxur	92 (7)	97 (3)	115 (4)	97 (9)	94 (2)	98 (3)	88 (6)	91 (1)	96 (2)	85 (9)	86 (5)	99 (3)
Carbofuran	**62** (17)	103 (14)	109 (4)	85 (7)	92 (6)	96 (3)	93 (17)	96 (4)	99 (2)	86 (18)	94 (7)	100 (4)
Carbaryl	118 (10)	73 (32)	**121** (4)	110 (4)	79 (1)	96 (4)	113 (11)	76 (6)	102 (7)	93 (17)	100 (4)	107 (6)
Diphenylamine	85 (3)	90 (3)	110 (3)	71 (13)	87 (2)	94 (1)	112 (12)	93 (2)	98 (1)	98 (4)	97 (2)	108 (3)
Chlorpropham	96 (4)	97 (4)	111 (4)	90 (8)	97 (1)	96 (1)	**60** (3)	93 (3)	103 (2)	103 (4)	99 (3)	104 (3)
Dicloran	107 (7)	93 (4)	107 (3)	96 (10)	88 (3)	101 (1)	**140** (12)	96 (13)	84 (18)	66 (15)	99 (3)	103 (3)
Atrazine	94 (15)	97 (2)	112 (4)	101 (**29**)	95 (2)	84 (12)	105 (9)	96 (3)	101 (1)	79 (9)	98 (1)	103 (3)
Lindane	118 (9)	105 (7)	111 (3)	107 (14)	94 (9)	97 (4)	104 (8)	116 (7)	116 (10)	99 (10)	94 (2)	104 (4)
Propyzamide	87 (4)	96 (3)	113 (2)	90 (3)	94 (2)	103 (2)	93 (2)	96 (2)	103 (1)	84 (6)	87 (0)	97 (4)
Chlorpyrifos-methyl	105 (9)	106 (2)	114 (3)	113 (5)	100 (4)	108 (3)	120 (3)	**142** (9)	**130** (7)	108 (5)	101 (2)	107 (3)
Parathion-methyl	112 (15)	120 (3)	119 (4)	110 (12)	112 (5)	120 (5)	109 (4)	**141** (9)	**139** (10)	112 (9)	101 (4)	107 (3)
Alachlor	99 (6)	98 (3)	111 (3)	88 (16)	99 (1)	108 (2)	114 (18)	120 (6)	118 (6)	101 (5)	96 (2)	102 (3)
Tolclofos-methyl	101 (7)	96 (1)	113 (2)	104 (10)	93 (2)	103 (2)	102 (11)	120 (7)	**121** (6)	93 (4)	96 (4)	101 (4)
Metalaxyl	112 (19)	89 (2)	108 (2)	110 (6)	97 (3)	102 (4)	81 (7)	93 (3)	99 (2)	84 (13)	95 (5)	104 (3)
Pirimiphos-methyl	95 (5)	96 (2)	112 (2)	92 (6)	96 (2)	105 (3)	96 (8)	118 (4)	111 (3)	102 (8)	95 (3)	104 (3)
Fenitrothion	102 (10)	111 (4)	117 (4)	92 (10)	114 (3)	120 (5)	114 (15)	**149** (10)	**137** (9)	117 (5)	100 (2)	109 (3)
Malathion	96 (19)	107 (3)	116 (3)	**166** (16)	110 (1)	113 (4)	**163** (12)	**143** (10)	**132** (9)	117 (16)	116 (2)	113 (4)
Chlorpyrifos	86 (2)	88 (1)	107 (3)	100 (3)	92 (2)	98 (2)	116 (10)	120 (6)	113 (6)	97 (5)	92 (2)	100 (3)
Fenthion	113 (3)	105 (1)	115 (2)	110 (3)	99 (2)	108 (3)	**175** (11)	**129** (7)	**127** (7)	101 (5)	100 (1)	105 (3)
Triadimefon	105 (8)	97 (3)	112 (3)	120 (4)	100 (3)	107 (2)	85 (6)	94 (1)	101 (1)	100 (7)	102 (2)	105 (4)
Pirimiphos-ethyl	83 (10)	88 (4)	108 (3)	85 (9)	89 (4)	102 (2)	89 (9)	91 (1)	100 (1)	87 (4)	93 (4)	96 (3)
Penconazole	78 (8)	87 (5)	105 (3)	85 (5)	90 (2)	99 (4)	93 (3)	86 (1)	97 (2)	80 (18)	91 (2)	97 (4)
Triflumizole	87 (3)	89 (3)	105 (3)	90 (4)	89 (2)	101 (2)	101 (5)	91 (2)	99 (2)	95 (4)	93 (2)	99 (3)
Methidathion	116 (9)	112 (4)	114 (5)	**168** (11)	120 (4)	121 (6)	**235** (19)	**138** (12)	**137** (12)	119 (5)	119 (3)	113 (3)
Fenamiphos	99 (5)	99 (2)	114 (2)	109 (3)	99 (1)	110 (3)	**172** (10)	**125** (6)	**122** (6)	119 (4)	104 (3)	110 (3)
Myclobutanil	92 (6)	95 (3)	113 (3)	88 (5)	95 (1)	105 (2)	96 (5)	94 (1)	104 (1)	99 (5)	99 (2)	105 (3)
Dieldrin	73 (9)	81 (5)	94 (3)	71 (11)	78 (4)	85 (2)	83 (14)	78 (4)	85 (2)	90 (10)	86 (3)	93 (4)
Oxyfluorfen	96 (9)	90 (6)	108 (3)	85 (10)	89 (3)	103 (2)	95 (10)	112 (4)	113 (7)	96 (10)	94 (4)	102 (5)
Buprofezin	72 (8)	85 (3)	102 (4)	77 (11)	85 (2)	97 (2)	89 (9)	86 (2)	93 (1)	76 (9)	91 (1)	98 (3)
Endrin	81 (17)	76 (4)	92 (3)	73 (8)	77 (3)	84 (1)	97 (11)	78 (2)	86 (4)	82 (8)	87 (3)	91 (4)
Ethion	86 (5)	98 (2)	109 (2)	117 (10)	96 (0)	105 (3)	**160** (15)	**129** (8)	119 (8)	93 (6)	97 (2)	102 (3)
Propiconazole	119 (17)	119 (7)	113 (2)	115 (9)	111 (6)	119 (4)	**172** (17)	**140** (5)	118 (9)	**163** (18)	**125** (4)	**139** (3)
Tebuconazole	91 (5)	92 (3)	108 (3)	100 (4)	101 (2)	107 (2)	106 (4)	99 (2)	104 (2)	97 (4)	93 (1)	101 (4)
Iprodione	102 (20)	109 (10)	113 (4)	119 (14)	116 (4)	113 (7)	87 (18)	117 (22)	**201** **(27)**	117 (8)	117 (7)	117 (4)
EPN	72 (12)	96 (5)	108 (2)	107 (13)	101 (5)	107 (5)	**220** (13)	**124** (5)	**126** (14)	90 (10)	99 (3)	101 (2)
Pyriproxyfen	71 (6)	93 (20)	98 (2)	**62** (20)	81 (5)	90 (3)	81 (**34**)	99 (**35**)	91 (6)	104 (19)	108 (10)	100 (2)
Fenvalerate	87 (6)	89 (4)	107 (3)	91 (3)	85 (2)	93 (2)	100 (7)	96 (4)	98 (10)	95 (1)	95 (1)	102 (4)
Esfenvalerate	79 (8)	88 (5)	107 (3)	89 (1)	88 (2)	91 (2)	107 (3)	98 (6)	98 (11)	99 (1)	98 (2)	103 (4)

Bold text indicates recovery outside the 70–120% range and/or RSD values higher than 20%.

studied dried fruits or when they are fresh. Despite this fact, it should be noted that in the pesticide database corresponding to the Codex Alimentarius [19], fresh uchuva, guanabana, and pitahaya already appear catalogued as "Assorted Tropical and Sub-Tropical Fruit - Inedible Peel." Therefore, it is possible that specific MRLs will be set in the near future soon. In any case, we rely on the standard MRL of 10 μg/kg established by the international legislation to carry out this work.

Regarding the pesticide content of dried fruits analyzed in previous works, Liu et al. [14] found residues of carbaryl,

TABLE 2 Pesticide content of several tropical fruits samples analysed by the proposed QuEChERS-GC-QqQ-MS/MS method

Dried fruits	Sample	Zone	Date of collection	Pesticides detected	Concentration (μg/kg)[a]
Uchuva	1	Chapinero (Bogota)	October 2018	–	–
	2	Nogal (Bogota)	October 2018	Tebuconazole	< LCL
	3	Colina campestre (Bogota)	October 2018	–	–
	4	Porciuncula (Bogota)	October 2018	–	–
	5	Las ferias (Bogota)	October 2018	Tebuconazole	10.8 ± 1.6
Lulo	1	Chapinero (Bogota)	October 2018	–	–
	2	Nogal (Bogota)	October 2018	–	–
	3	Colina campestre (Bogota)	October 2018	–	–
	4	Porciuncula (Bogota)	October 2018	–	–
	5	Las ferias (Bogota)	October 2018		
Guanabana	1	Chapinero (Bogota)	October 2018	–	–
	2	Nogal (Bogota)	October 2018	–	–
	3	Colina campestre (Bogota)	October 2018	–	–
	4	Porciuncula (Bogota)	October 2018	–	–
	5	Las ferias (Bogota)	October 2018	–	–
Pitahaya	1	Chapinero (Bogota)	October 2018	–	–
	2	Nogal (Bogota)	October 2018	–	–
	3	Colina campestre (Bogota)	October 2018	–	–
	4	Porciuncula (Bogota)	October 2018	–	–
	5	Las ferias (Bogota)	October 2018	–	–

(-) Pesticides were not detected.

[a]Mean of three determinations.

chlorpyrifos, and paclobutrazol in dried red pepper at concentrations as high as 710, 260, and 260 μg/kg, respectively, but all below the established MRLs, while Rutkowska et al. [16] found residues of trifloxystrobin in dried currants at 25 μg/kg. From our part [15], we recently found residues of chlorpyrifos and iprodione in a dried grape sample at 9.4 and 135 μg/kg, respectively, as well as residues of chlorpyrifos at 400 μg/kg in dried blackberry and metalaxyl in two dried strawberry samples, but these last ones below the LCL set at 5 μg/kg. These results, together with those obtained in this work, show the presence of pesticide residues in dried fruits, even after being subjected to drying processes. Therefore, it continues to be necessary to develop efficient and sensitive methodologies capable of guaranteeing food safety.

4 | CONCLUDING REMARKS

In this research, a group of 38 multiclass pesticides were analyzed for the first time in four dried tropical fruits (uchuva, lulo, guanabana, and pitahaya) using the AOAC 2007.1 official QuEChERS method in combination with GC–QqQ–MS/MS. For the very great majority of the combinations pesticide/matrix analyzed, the analytical performance of the method (i.e., matrix-matched calibration, recovery, and repeatability) was successful, with an LCL in accordance with the monitoring purposes worldwide in food applications. As expected, dried fruits are very complex matrices, even more than the corresponding fresh fruits, which was evidenced through the appreciable ME even when all the recommended measures were adopted to minimize such effect. The analysis of 20 samples collected at different food stores of Bogota revealed the presence of residues of tebuconazole, but at relatively low concentrations.

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CONFLICT OF INTEREST

The authors have declared no conflict of interest.

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SUPPORTING INFORMATION

Additional supporting information may be found online in the Supporting Information section at the end of the article.

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SUPPLEMENTARY MATERIAL

Determination of pesticides in dried minor tropical fruits from Colombia using the *Quick. Easy. Cheap. Effective. Rugged* and *Safe* method-gas chromatography tandem mass spectrometry

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Table S1.- Retention times and quantifier and qualifier transitions in GC-QqQ-MS/MS analyses of the selected pesticides.

Analyte	Retention time (min)	Quantifier transition (m/z)	Collision energy (V)	Qualifier transition (m/z)	Collision energy (V)	Qualifier transition (m/z)	Collision energy (V)
Propoxur	5.47	110.00→64.00	20	152.00→110.00	10	110.00→82.00	15
Carbofuran	6.25	164.00→149.00	10	149.00→103.00	15	149.00→103.00	15
Carbaryl	7.68	116.00→115.00	5	144.00→115.00	25	144.00→116.00	5
Diphenylamine	8.60	168.00→167.00	10	169.00→168.00	5	169.00→167.00	5
Chlorpropham	8.78	213.00→171.00	5	213.00→127.00	15	127.00→90.00	15
Dicloran	9.57	206.00→176.00	10	124.00→97.00	10	176.00→124.00	10
Atrazine-d_5	9.68	205.00→127.00	10	220.00→178.00	5	205.00→178.00	10
Atrazine	9.71	215.00→173.00	5	215.00→200.00	10	200.00→173.00	10
Lindane	10.03	183.00→181.00	5	219.00→181.00	10	181.00→111.00	10
Propyzamide	10.08	173.00→145.00	15	175.00→173.00	5	173.00→109.00	10
Chlorpyrifos-methyl	11.27	288.00→286.00	5	286.00→93.00	25	286.00→125.00	25
Parathion-methyl	11.43	263.00→109.00	15	109.00→79.00	10	263.00→125.00	10
Alachlor	11.45	188.00→160.00	10	160.00→132.00	15	188.00→146.00	10
Tolclofos-methyl	11.45	265.00→250.00	15	267.00→265.00	5	265.00→125.00	5
Metalaxyl	11.61	206.00→132.00	20	160.00→146.00	10	206.00→160.00	15
Primiphos-methyl	11.95	290.00→233.00	10	305.00→290.00	10	290.00→276.00	10
Fenitrothion	12.07	277.00→260.00	5	277.00→109.00	20	125.00→109.00	15
Malathion	12.25	127.00→99.00	5	173.00→127.00	5	125.00→93.00	5
Chlorpyrifos	12.48	314.00→258.00	15	199.00→171.00	15	197.00→97.00	15
Fenthion	12.58	278.00→109.00	20	278.00→137.00	10	278.00→245.00	10
Triamidefon	12.78	208.00→181.00	10	208.00→128.00	15	128.00→85.00	10
Pirimiphos-ethyl	13.05	333.00→168.00	25	333.00→318.00	10	318.00→180.00	10

Table S1.-(Continued).

Analyte	Retention time (min)	Quantifier transition (m/z)	Collision energy (V)	Qualifier transition (m/z)	Collision energy (V)	Qualifier transition (m/z)	Collision energy (V)
Penconazole	13.59	161.00→159.00	5	248.00→159.00	25	248.00→161.00	5
Triflumizole	14.07	278.00→73.00	5	278.00→206.00	20	278.00→179.00	5
Methidathion	14.33	145.00→85.00	10	145.00→58.00	15	145.00→93.00	10
Fenamiphos	14.97	303.00→288.00	10	303.00→154.00	20	303.00→217.00	10
Myclobutanil	15.60	179.00→125.00	15	179.00→150.00	10	179.00→82.00	10
Dieldrin	15.67	263.00→191.00	30	263.00→193.00	30	263.00→81.00	35
Oxyfluorfen	15.67	361.00→300.00	15	252.00→223.00	15	300.00→252.00	15
Buprofezin	15.85	172.00→57.00	20	175.00→172.00	5	105.00→83.00	10
Endrin	16.32	263.00→193.00	30	263.00→228.00	20	263.00→228.00	20
Ethion	16.73	153.00→97.00	10	153.00→125.00	5	231.00→153.00	5
Propiconazole	17.55	175.00→173.00	5	259.00→69.00	10	259.00→173.00	10
Tebuconazole	17.82	250.00→125.00	20	250.00→70.00	10	125.00→70.00	10
Triphenyl phosphate	17.89	326.00→325.00	5	326.00→169.00	25	326.00→215.00	10
Iprodiona	18.25	314.00→56.00	25	314.00→187.00	5	314.00→245.00	5
EPN	18.39	185.00→157.00	5	169.00→157.00	5	157.00→141.00	10
Pyriproxyfen	19.02	136.00→107.00	10	136.00→96.00	15	136.00→78.00	15
Fenvalerate	21.64	167.00→125.00	10	181.00→152.00	25	225.00→125.00	25
Esfenvalerate	21.91	167.00→125.00	10	225.00→167.00	20	225.00→181.00	20

Table S2.- Matrix-matched calibration data and matrix effect percentage of the selected pesticides.

Analyte	Sample	Studied linear range (µg/kg)	Regression equation (n=5)		$s_{y/x}$	LOQ (µg/kg)	R^2	ME (%)
			$b \pm s_b \cdot t_{(0.05;7)}$	$a \pm s_a \cdot t_{(0.05;7)}$				
Propoxur	Uchuva	5-600	$3.61\cdot10^{-2} \pm 2.98\cdot10^{-4}$	$1.59\cdot10^{-1} \pm 8.48\cdot10^{-2}$	$6.56\cdot10^{-2}$	0.28	0.9999	-29
	Lulo	5-600	$3.76\cdot10^{-2} \pm 1.12\cdot10^{-3}$	$-6.80\cdot10^{-3} \pm 3.19\cdot10^{-1}$	$2.47\cdot10^{-1}$	1.05	0.9993	-26
	Guanabana	5-600	$3.61\cdot10^{-2} \pm 6.68\cdot10^{-4}$	$-5.36\cdot10^{-2} \pm 1.90\cdot10^{-1}$	$1.47\cdot10^{-1}$	0.54	0.9997	-29
	Pitahaya	5-600	$2.37\cdot10^{-2} \pm 4.29\cdot10^{-4}$	$7.33\cdot10^{-2} \pm 1.22\cdot10^{-1}$	$9.43\cdot10^{-2}$	0.44	0.9998	-53
	Standard calibration	5-600	$5.09\cdot10^{-2} \pm 3.50\cdot10^{-3}$	$-5.15\cdot10^{-1} \pm 9.95\cdot10^{-1}$	$7.69\cdot10^{-1}$	1.50	0.9964	-
Carbofuran	Uchuva	5-600	$9.19\cdot10^{-3} \pm 1.03\cdot10^{-3}$	$4.74\cdot10^{-1} \pm 2.94\cdot10^{-1}$	$2.28\cdot10^{-1}$	0.02	0.9905	1
	Lulo	5-600	$9.93\cdot10^{-3} \pm 6.01\cdot10^{-4}$	$3.35\cdot10^{-1} \pm 1.71\cdot10^{-1}$	$1.32\cdot10^{-1}$	0.12	0.9972	9
	Guanabana	5-600	$8.46\cdot10^{-3} \pm 4.63\cdot10^{-4}$	$7.54\cdot10^{-2} \pm 1.32\cdot10^{-1}$	$1.02\cdot10^{-1}$	0.42	0.9977	-7
	Pitahaya	5-600	$6.69\cdot10^{-3} \pm 2.45\cdot10^{-4}$	$2.08\cdot10^{-1} \pm 6.97\cdot10^{-2}$	$5.39\cdot10^{-2}$	0.20	0.9990	-26
	Standard calibration	5-600	$9.10\cdot10^{-3} \pm 9.48\cdot10^{-4}$	$-1.57\cdot10^{-1} \pm 2.70\cdot10^{-1}$	$2.08\cdot10^{-1}$	4.98	0.9918	-
Carbaryl	Uchuva	5-600	$4.81\cdot10^{-2} \pm 2.02\cdot10^{-3}$	$7.89\cdot10^{-1} \pm 5.76\cdot10^{-1}$	$4.45\cdot10^{-1}$	0.10	0.9987	-6
	Lulo	5-600	$4.97\cdot10^{-2} \pm 4.73\cdot10^{-3}$	$3.48\cdot10^{-2} \pm 1.35\cdot10$	$1.04\cdot10$	0.34	0.9932	-2
	Guanabana	5-600	$6.31\cdot10^{-2} \pm 5.98\cdot10^{-3}$	$-8.84\cdot10^{-1} \pm 1.70\cdot10$	$1.31\cdot10$	0.32	0.9932	24
	Pitahaya	5-600	$4.54\cdot10^{-2} \pm 1.58\cdot10^{-3}$	$5.62\cdot10^{-1} \pm 4.50\cdot10^{-1}$	$3.48\cdot10^{-1}$	0.14	0.9991	-11
	Standard calibration	5-600	$5.10\cdot10^{-2} \pm 3.76\cdot10^{-3}$	$-4.36\cdot10^{-1} \pm 1.07\cdot10$	$8.28\cdot10^{-1}$	0.87	0.9959	-
Diphenylamine	Uchuva	5-600	$1.99\cdot10^{-1} \pm 2.01\cdot10^{-3}$	$1.48\cdot10 \pm 5.72\cdot10^{-1}$	$4.42\cdot10^{-1}$	0.13	0.9999	41
	Lulo	5-600	$1.98\cdot10^{-1} \pm 1.97\cdot10^{-3}$	$6.34\cdot10^{-2} \pm 5.62\cdot10^{-1}$	$4.34\cdot10^{-1}$	0.33	0.9999	40
	Guanabana	5-600	$1.79\cdot10^{-1} \pm 6.21\cdot10^{-3}$	$-1.02\cdot10 \pm 1.77\cdot10$	$1.36\cdot10$	0.20	0.9991	27
	Pitahaya	5-600	$1.46\cdot10^{-1} \pm 4.13\cdot10^{-3}$	$8.06\cdot10^{-1} \pm 1.17\cdot10$	$9.08\cdot10^{-1}$	0.15	0.9994	3
	Standard calibration	5-600	$1.41\cdot10^{-1} \pm 1.08\cdot10^{-2}$	$-1.56\cdot10 \pm 3.08\cdot10$	$2.38\cdot10$	1.23	0.9956	-

Table S2.-(Continued).

Analyte	Sample	Studied linear range (µg/kg)	Regression equation (n=5)		$s_{y/x}$	LOQ (µg/kg)	R^2	ME (%)
			$b \pm s_b \cdot t_{(0.05;7)}$	$a \pm s_a \cdot t_{(0.05;7)}$				
Chlorpropham	Uchuva	5-600	$8.59\cdot10^{-3} \pm 1.68\cdot10^{-4}$	$-3.91\cdot10^{-2} \pm 4.78\cdot10^{-2}$	$3.70\cdot10^{-2}$	3.92	0.9997	20
	Lulo	5-600	$9.07\cdot10^{-3} \pm 2.59\cdot10^{-4}$	$-4.73\cdot10^{-2} \pm 7.36\cdot10^{-2}$	$5.69\cdot10^{-2}$	4.03	0.9994	27
	Guanabana	5-600	$7.52\cdot10^{-3} \pm 2.51\cdot10^{-4}$	$2.64\cdot10^{-3} \pm 7.15\cdot10^{-2}$	$5.53\cdot10^{-2}$	3.96	0.9992	5
	Pitahaya	5-600	$7.36\cdot10^{-3} \pm 8.64\cdot10^{-5}$	$-2.68\cdot10^{-2} \pm 2.46\cdot10^{-2}$	$1.90\cdot10^{-2}$	3.02	0.9999	3
	Standard calibration	5-600	$7.13\cdot10^{-3} \pm 6.71\cdot10^{-4}$	$-1.47\cdot10^{-1} \pm 1.91\cdot10^{-1}$	$1.48\cdot10^{-1}$	5.00	0.9933	-
Dicloran	Uchuva	5-600	$5.44\cdot10^{-3} \pm 2.61\cdot10^{-4}$	$-6.41\cdot10^{-2} \pm 7.41\cdot10^{-2}$	$5.73\cdot10^{-2}$	0.82	0.9983	49
	Lulo	5-600	$5.95\cdot10^{-3} \pm 1.43\cdot10^{-4}$	$-1.51\cdot10^{-2} \pm 4.07\cdot10^{-2}$	$3.15\cdot10^{-2}$	3.77	0.9996	63
	Guanabana	5-600	$3.08\cdot10^{-3} \pm 2.58\cdot10^{-4}$	$-2.09\cdot10^{-2} \pm 7.33\cdot10^{-2}$	$5.67\cdot10^{-2}$	2.68	0.9947	-16
	Pitahaya	5-600	$5.12\cdot10^{-3} \pm 2.58\cdot10^{-4}$	$3.52\cdot10^{-2} \pm 7.33\cdot10^{-2}$	$5.66\cdot10^{-2}$	3.07	0.9981	40
	Standard calibration	5-600	$3.65\cdot10^{-3} \pm 2.50\cdot10^{-4}$	$-3.57\cdot10^{-2} \pm 7.10\cdot10^{-2}$	$5.49\cdot10^{-2}$	4.20	0.9965	-
Atrazine	Uchuva	5-600	$2.30\cdot10^{-3} \pm 4.69\cdot10^{-5}$	$2.28\cdot10^{-5} \pm 1.34\cdot10^{-2}$	$1.03\cdot10^{-2}$	4.37	0.9997	-11
	Lulo	5-600	$2.52\cdot10^{-3} \pm 3.24\cdot10^{-4}$	$3.47\cdot10^{-2} \pm 9.22\cdot10^{-2}$	$7.12\cdot10^{-2}$	1.70	0.9960	-3
	Guanabana	5-600	$2.39\cdot10^{-3} \pm 5.29\cdot10^{-5}$	$-1.08\cdot10^{-2} \pm 1.50\cdot10^{-2}$	$1.16\cdot10^{-2}$	2.71	0.9996	-8
	Pitahaya	5-600	$2.29\cdot10^{-3} \pm 3.12\cdot10^{-5}$	$9.39\cdot10^{-3} \pm 8.89\cdot10^{-3}$	$6.87\cdot10^{-3}$	2.17	0.9999	-12
	Standard calibration	5-600	$2.59\cdot10^{-3} \pm 2.96\cdot10^{-4}$	$-4.95\cdot10^{-2} \pm 8.43\cdot10^{-2}$	$6.51\cdot10^{-2}$	2.60	0.9902	-
Lindane	Uchuva	5-600	$6.35\cdot10^{-3} \pm 5.83\cdot10^{-4}$	$4.65\cdot10^{-1} \pm 1.66\cdot10^{-1}$	$1.28\cdot10^{-1}$	1.19	0.9937	-71
	Lulo	5-600	$6.67\cdot10^{-3} \pm 4.54\cdot10^{-4}$	$8.95\cdot10^{-1} \pm 1.29\cdot10^{-1}$	$9.99\cdot10^{-2}$	2.45	0.9965	-70
	Guanabana	5-600	$1.89\cdot10^{-3} \pm 1.19\cdot10^{-4}$	$7.52\cdot10^{-2} \pm 3.40\cdot10^{-2}$	$2.62\cdot10^{-2}$	3.71	0.9970	-91
	Pitahaya	5-600	$1.02\cdot10^{-2} \pm 4.24\cdot10^{-4}$	$5.68\cdot10^{-2} \pm 1.21\cdot10^{-1}$	$9.32\cdot10^{-2}$	4.64	0.9987	-54
	Standard calibration	5-600	$2.21\cdot10^{-2} \pm 1.47\cdot10^{-3}$	$-2.03\cdot10^{-1} \pm 4.18\cdot10^{-1}$	$3.23\cdot10^{-1}$	4.12	0.9967	-

Table S2.-(Continued).

Analyte	Sample	Studied linear range (µg/kg)	Regression equation (n=5)		$s_{y/x}$	LOQ (µg/kg)	R^2	ME (%)
			$b \pm s_b\cdot t_{(0.05;7)}$	$a \pm s_a\cdot t_{(0.05;7)}$				
Propyzamide	Uchuva	5-600	$4.98\cdot10^{-2} \pm 6.91\cdot10^{-4}$	$9.85\cdot10^{-2} \pm 1.97\cdot10^{-1}$	$1.52\cdot10^{-1}$	0.69	0.9999	-5
	Lulo	5-600	$5.33\cdot10^{-2} \pm 6.81\cdot10^{-4}$	$6.77\cdot10^{-2} \pm 1.94\cdot10^{-1}$	$1.50\cdot10^{-1}$	1.42	0.9999	2
	Guanabana	5-600	$4.98\cdot10^{-2} \pm 9.22\cdot10^{-4}$	$-1.01\cdot10^{-1} \pm 2.62\cdot10^{-1}$	$2.03\cdot10^{-1}$	0.73	0.9997	-5
	Pitahaya	5-600	$4.93\cdot10^{-2} \pm 4.42\cdot10^{-4}$	$1.82\cdot10^{-1} \pm 1.26\cdot10^{-1}$	$9.72\cdot10^{-2}$	0.49	0.9999	-6
	Standard calibration	5-600	$5.22\cdot10^{-2} \pm 4.79\cdot10^{-3}$	$-7.95\cdot10^{-1} \pm 1.36\cdot10$	$1.05\cdot10$	4.66	0.9937	-
Chlorpyrifos-methyl	Uchuva	5-600	$1.23\cdot10^{-2} \pm 3.93\cdot10^{-4}$	$-8.98\cdot10^{-3} \pm 1.12\cdot10^{-1}$	$8.65\cdot10^{-2}$	2.56	0.9992	-53
	Lulo	5-600	$1.33\cdot10^{-2} \pm 3.42\cdot10^{-4}$	$-3.95\cdot10^{-2} \pm 9.73\cdot10^{-2}$	$7.52\cdot10^{-2}$	5.00	0.9995	-49
	Guanabana	5-600	$3.87\cdot10^{-3} \pm 8.80\cdot10^{-5}$	$1.95\cdot10^{-2} \pm 2.50\cdot10^{-2}$	$1.94\cdot10^{-2}$	4.58	0.9996	-85
	Pitahaya	5-600	$1.81\cdot10^{-2} \pm 5.85\cdot10^{-4}$	$-3.03\cdot10^{-2} \pm 1.66\cdot10^{-1}$	$1.29\cdot10^{-1}$	2.36	0.9992	-30
	Standard calibration	5-600	$2.60\cdot10^{-2} \pm 1.18\cdot10^{-3}$	$-2.98\cdot10^{-1} \pm 3.34\cdot10^{-1}$	$2.58\cdot10^{-1}$	4.66	0.9985	-
Parathion-methyl	Uchuva	5-600	$3.15\cdot10^{-3} \pm 1.14\cdot10^{-4}$	$2.58\cdot10^{-2} \pm 3.25\cdot10^{-2}$	$2.51\cdot10^{-2}$	0.85	0.9990	-75
	Lulo	5-600	$4.46\cdot10^{-3} \pm 1.85\cdot10^{-4}$	$2.74\cdot10^{-3} \pm 5.26\cdot10^{-2}$	$4.07\cdot10^{-2}$	2.68	0.9987	-64
	Guanabana	5-600	$1.40\cdot10^{-3} \pm 7.41\cdot10^{-5}$	$2.03\cdot10^{-2} \pm 2.11\cdot10^{-2}$	$1.63\cdot10^{-2}$	1.56	0.9979	-89
	Pitahaya	5-600	$7.91\cdot10^{-3} \pm 5.99\cdot10^{-5}$	$-1.78\cdot10^{-2} \pm 1.70\cdot10^{-2}$	$1.32\cdot10^{-2}$	1.46	1.0000	-36
	Standard calibration	5-600	$1.24\cdot10^{-2} \pm 1.34\cdot10^{-3}$	$-3.33\cdot10^{-1} \pm 3.80\cdot10^{-1}$	$2.94\cdot10^{-1}$	4.79	0.9913	-
Alachlor	Uchuva	5-600	$1.60\cdot10^{-2} \pm 2.11\cdot10^{-4}$	$3.06\cdot10^{-2} \pm 5.99\cdot10^{-2}$	$4.63\cdot10^{-2}$	1.90	0.9999	-46
	Lulo	5-600	$1.66\cdot10^{-2} \pm 3.63\cdot10^{-4}$	$1.03\cdot10^{-2} \pm 1.03\cdot10^{-1}$	$7.98\cdot10^{-2}$	4.33	0.9996	-44
	Guanabana	5-600	$8.34\cdot10^{-3} \pm 1.61\cdot10^{-4}$	$1.43\cdot10^{-2} \pm 4.58\cdot10^{-2}$	$3.54\cdot10^{-2}$	3.73	0.9997	-72
	Pitahaya	5-600	$1.80\cdot10^{-2} \pm 1.77\cdot10^{-4}$	$5.04\cdot10^{-4} \pm 5.04\cdot10^{-2}$	$3.89\cdot10^{-2}$	1.19	0.9999	-39
	Standard calibration	5-600	$2.97\cdot10^{-2} \pm 2.32\cdot10^{-3}$	$-3.94\cdot10^{-1} \pm 6.59\cdot10^{-1}$	$5.10\cdot10^{-1}$	5.00	0.9954	-

Table S2.-(Continued).

Analyte	Sample	Studied linear range (µg/kg)	Regression equation (n=5)		$s_{y/x}$	LOQ (µg/kg)	R^2	ME (%)
			$b \pm s_b \cdot t_{(0.05;7)}$	$a \pm s_a \cdot t_{(0.05;7)}$				
Tolclofos-methyl	Uchuva	5-600	$1.89\cdot10^{-2} \pm 5.28\cdot10^{-4}$	$-2.18\cdot10^{-2} \pm 1.50\cdot10^{-1}$	$1.16\cdot10^{-1}$	1.76	0.9994	-57
	Lulo	5-600	$2.01\cdot10^{-2} \pm 2.54\cdot10^{-4}$	$-2.40\cdot10^{-3} \pm 7.22\cdot10^{-2}$	$5.58\cdot10^{-2}$	3.59	0.9999	-55
	Guanabana	5-600	$9.92\cdot10^{-3} \pm 2.48\cdot10^{-4}$	$6.58\cdot10^{-2} \pm 7.05\cdot10^{-2}$	$5.45\cdot10^{-2}$	2.82	0.9995	-78
	Pitahaya	5-600	$2.30\cdot10^{-2} \pm 1.13\cdot10^{-4}$	$3.76\cdot10^{-3} \pm 3.22\cdot10^{-2}$	$2.49\cdot10^{-2}$	0.99	1.0000	-48
	Standard calibration	5-600	$4.42\cdot10^{-2} \pm 1.86\cdot10^{-3}$	$-3.06\cdot10^{-1} \pm 5.28\cdot10^{-1}$	$4.08\cdot10^{-1}$	5.00	0.9987	-
Metalaxyl	Uchuva	5-600	$8.41\cdot10^{-3} \pm 2.18\cdot10^{-4}$	$3.15\cdot10^{-3} \pm 6.21\cdot10^{-2}$	$4.80\cdot10^{-2}$	3.55	0.9995	-43
	Lulo	5-600	$8.71\cdot10^{-3} \pm 2.74\cdot10^{-4}$	$3.83\cdot10^{-2} \pm 7.80\cdot10^{-2}$	$6.03\cdot10^{-2}$	4.70	0.9993	-41
	Guanabana	5-600	$8.36\cdot10^{-3} \pm 1.44\cdot10^{-4}$	$-1.89\cdot10^{-2} \pm 4.09\cdot10^{-2}$	$3.16\cdot10^{-2}$	4.28	0.9998	-44
	Pitahaya	5-600	$8.32\cdot10^{-3} \pm 1.16\cdot10^{-4}$	$2.99\cdot10^{-2} \pm 3.29\cdot10^{-2}$	$2.55\cdot10^{-2}$	2.49	0.9999	-44
	Standard calibration	5-600	$1.48\cdot10^{-2} \pm 1.66\cdot10^{-3}$	$-2.99\cdot10^{-1} \pm 4.73\cdot10^{-1}$	$3.66\cdot10^{-1}$	2.04	0.9905	-
Pirimiphos-methyl	Uchuva	5-600	$8.15\cdot10^{-3} \pm 1.13\cdot10^{-4}$	$-2.90\cdot10^{-2} \pm 3.22\cdot10^{-2}$	$2.49\cdot10^{-2}$	4.85	0.9999	-44
	Lulo	5-600	$8.62\cdot10^{-3} \pm 1.34\cdot10^{-4}$	$-3.50\cdot10^{-2} \pm 3.80\cdot10^{-2}$	$2.94\cdot10^{-2}$	5.00	0.9998	-41
	Guanabana	5-600	$5.05\cdot10^{-3} \pm 9.98\cdot10^{-5}$	$-2.77\cdot10^{-3} \pm 2.84\cdot10^{-2}$	$2.19\cdot10^{-2}$	4.73	0.9997	-65
	Pitahaya	5-600	$9.00\cdot10^{-3} \pm 1.77\cdot10^{-4}$	$-2.05\cdot10^{-2} \pm 5.04\cdot10^{-2}$	$3.90\cdot10^{-2}$	2.49	0.9997	-38
	Standard calibration	5-600	$1.45\cdot10^{-2} \pm 1.05\cdot10^{-3}$	$-2.36\cdot10^{-1} \pm 2.99\cdot10^{-1}$	$2.31\cdot10^{-1}$	4.12	0.9960	-
Fenitrothion	Uchuva	5-600	$4.62\cdot10^{-3} \pm 6.61\cdot10^{-5}$	$-1.68\cdot10^{-2} \pm 1.88\cdot10^{-2}$	$1.45\cdot10^{-2}$	4.84	0.9998	-55
	Lulo	5-600	$5.63\cdot10^{-3} \pm 2.11\cdot10^{-4}$	$-1.41\cdot10^{-2} \pm 6.00\cdot10^{-2}$	$4.64\cdot10^{-2}$	4.32	0.9989	-45
	Guanabana	5-600	$1.57\cdot10^{-3} \pm 8.20\cdot10^{-5}$	$-5.30\cdot10^{-3} \pm 2.33\cdot10^{-2}$	$1.80\cdot10^{-2}$	4.03	0.9979	-85
	Pitahaya	5-600	$9.26\cdot10^{-3} \pm 2.63\cdot10^{-4}$	$-3.85\cdot10^{-2} \pm 7.47\cdot10^{-2}$	$5.78\cdot10^{-2}$	3.11	0.9994	-10
	Standard calibration	5-600	$1.03\cdot10^{-2} \pm 1.09\cdot10^{-3}$	$-2.22\cdot10^{-1} \pm 3.09\cdot10^{-1}$	$2.39\cdot10^{-1}$	5.00	0.9916	-

Table S2.-(Continued).

Analyte	Sample	Studied linear range (µg/kg)	Regression equation (n=5)		$s_{y/x}$	LOQ (µg/kg)	R^2	ME (%)
			$b \pm s_b \cdot t_{(0.05;7)}$	$a \pm s_a \cdot t_{(0.05;7)}$				
Malathion	Uchuva	5-600	$1.28\cdot10^{-2} \pm 1.79\cdot10^{-4}$	$7.66\cdot10^{-3} \pm 5.09\cdot10^{-2}$	$3.94\cdot10^{-2}$	1.74	0.9999	-60
	Lulo	5-600	$1.36\cdot10^{-2} \pm 2.91\cdot10^{-4}$	$3.10\cdot10^{-2} \pm 8.29\cdot10^{-2}$	$6.41\cdot10^{-2}$	4.78	0.9997	-58
	Guanabana	5-600	$4.49\cdot10^{-3} \pm 1.65\cdot10^{-4}$	$8.27\cdot10^{-2} \pm 4.69\cdot10^{-2}$	$3.63\cdot10^{-2}$	4.76	0.9990	-86
	Pitahaya	5-600	$2.03\cdot10^{-2} \pm 2.53\cdot10^{-4}$	$1.29\cdot10^{-1} \pm 7.19\cdot10^{-2}$	$5.56\cdot10^{-2}$	1.04	0.9999	-37
	Standard calibration	5-600	$3.21\cdot10^{-2} \pm 2.72\cdot10^{-3}$	$-5.32\cdot10^{-1} \pm 7.73\cdot10^{-1}$	$5.97\cdot10^{-1}$	5.00	0.9946	-
Chlorpyrifos	Uchuva	5-600	$1.32\cdot10^{-2} \pm 1.76\cdot10^{-4}$	$2.27\cdot10^{-2} \pm 5.00\cdot10^{-2}$	$3.86\cdot10^{-2}$	2.50	0.9999	-42
	Lulo	5-600	$1.36\cdot10^{-2} \pm 1.24\cdot10^{-4}$	$1.89\cdot10^{-1} \pm 3.54\cdot10^{-2}$	$2.73\cdot10^{-2}$	4.56	0.9999	-40
	Guanabana	5-600	$6.85\cdot10^{-3} \pm 1.40\cdot10^{-4}$	$3.32\cdot10^{-2} \pm 3.98\cdot10^{-2}$	$3.07\cdot10^{-2}$	4.86	0.9997	-70
	Pitahaya	5-600	$1.45\cdot10^{-2} \pm 1.77\cdot10^{-4}$	$2.01\cdot10^{-2} \pm 5.04\cdot10^{-2}$	$3.89\cdot10^{-2}$	3.73	0.9999	-36
	Standard calibration	5-600	$2.25\cdot10^{-2} \pm 1.53\cdot10^{-3}$	$-3.72\cdot10^{-1} \pm 4.36\cdot10^{-1}$	$3.37\cdot10^{-1}$	4.13	0.9965	-
Fenthion	Uchuva	5-600	$2.12\cdot10^{-2} \pm 2.54\cdot10^{-4}$	$-4.29\cdot10^{-2} \pm 7.22\cdot10^{-2}$	$5.58\cdot10^{-2}$	1.87	0.9999	-49
	Lulo	5-600	$2.42\cdot10^{-2} \pm 3.82\cdot10^{-4}$	$-2.10\cdot10^{-2} \pm 1.09\cdot10^{-1}$	$8.41\cdot10^{-2}$	3.61	0.9998	-42
	Guanabana	5-600	$1.08\cdot10^{-2} \pm 2.64\cdot10^{-4}$	$1.34\cdot10^{-2} \pm 7.52\cdot10^{-2}$	$5.81\cdot10^{-2}$	3.28	0.9995	-74
	Pitahaya	5-600	$3.01\cdot10^{-2} \pm 1.05\cdot10^{-4}$	$-8.70\cdot10^{-3} \pm 2.97\cdot10^{-2}$	$2.30\cdot10^{-2}$	3.89	1.0000	-27
	Standard calibration	5-600	$4.15\cdot10^{-2} \pm 4.31\cdot10^{-3}$	$-8.98\cdot10^{-1} \pm 1.23\cdot10$	$9.47\cdot10^{-1}$	4.50	0.9919	-
Triadimefon	Uchuva	5-600	$1.69\cdot10^{-2} \pm 1.68\cdot10^{-4}$	$1.57\cdot10^{-1} \pm 4.78\cdot10^{-2}$	$3.69\cdot10^{-2}$	1.97	0.9999	-28
	Lulo	5-600	$1.75\cdot10^{-2} \pm 3.07\cdot10^{-4}$	$3.60\cdot10^{-1} \pm 8.74\cdot10^{-2}$	$6.76\cdot10^{-2}$	4.33	0.9998	-26
	Guanabana	5-600	$1.63\cdot10^{-2} \pm 2.89\cdot10^{-4}$	$2.18\cdot10^{-2} \pm 8.23\cdot10^{-2}$	$6.36\cdot10^{-2}$	2.39	0.9998	-31
	Pitahaya	5-600	$1.64\cdot10^{-2} \pm 2.83\cdot10^{-4}$	$1.38\cdot10^{-1} \pm 8.05\cdot10^{-2}$	$6.22\cdot10^{-2}$	2.52	0.9998	-30
	Standard calibration	5-600	$2.35\cdot10^{-2} \pm 1.71\cdot10^{-3}$	$-3.29\cdot10^{-1} \pm 4.87\cdot10^{-1}$	$3.76\cdot10^{-1}$	5.00	0.9960	-

Table S2.-(Continued).

Analyte	Sample	Studied linear range (µg/kg)	Regression equation (n=5)		$s_{y/x}$	LOQ (µg/kg)	R^2	ME (%)
			$b \pm s_b \cdot t_{(0.05;7)}$	$a \pm s_a \cdot t_{(0.05;7)}$				
Pirimiphos-ethyl	Uchuva	5-600	$3.95 \cdot 10^{-3} \pm 6.09 \cdot 10^{-5}$	$-1.89 \cdot 10^{-2} \pm 1.73 \cdot 10^{-2}$	$1.34 \cdot 10^{-2}$	5.00	0.9998	-41
	Lulo	5-600	$4.09 \cdot 10^{-3} \pm 1.35 \cdot 10^{-4}$	$-2.22 \cdot 10^{-2} \pm 3.84 \cdot 10^{-2}$	$2.97 \cdot 10^{-2}$	4.85	0.9992	-39
	Guanabana	5-600	$3.49 \cdot 10^{-3} \pm 1.02 \cdot 10^{-4}$	$-2.03 \cdot 10^{-2} \pm 2.91 \cdot 10^{-2}$	$2.25 \cdot 10^{-2}$	4.72	0.9993	-48
	Pitahaya	5-600	$4.00 \cdot 10^{-3} \pm 9.93 \cdot 10^{-5}$	$-1.22 \cdot 10^{-2} \pm 2.83 \cdot 10^{-2}$	$2.18 \cdot 10^{-2}$	4.99	0.9995	-40
	Standard calibration	5-600	$6.68 \cdot 10^{-3} \pm 3.60 \cdot 10^{-4}$	$-9.73 \cdot 10^{-2} \pm 1.02 \cdot 10^{-1}$	$7.92 \cdot 10^{-2}$	4.13	0.9978	-
Penconazole	Uchuva	5-600	$3.01 \cdot 10^{-2} \pm 2.39 \cdot 10^{-4}$	$6.19 \cdot 10^{-2} \pm 6.79 \cdot 10^{-2}$	$5.25 \cdot 10^{-2}$	0.79	1.0000	-26
	Lulo	5-600	$3.14 \cdot 10^{-2} \pm 5.06 \cdot 10^{-4}$	$4.01 \cdot 10^{-1} \pm 1.44 \cdot 10^{-1}$	$1.11 \cdot 10^{-1}$	1.74	0.9998	-23
	Guanabana	5-600	$2.95 \cdot 10^{-2} \pm 7.22 \cdot 10^{-4}$	$-8.17 \cdot 10^{-2} \pm 2.05 \cdot 10^{-1}$	$1.59 \cdot 10^{-1}$	1.21	0.9995	-27
	Pitahaya	5-600	$3.11 \cdot 10^{-2} \pm 2.21 \cdot 10^{-4}$	$-4.64 \cdot 10^{-2} \pm 6.29 \cdot 10^{-2}$	$4.86 \cdot 10^{-2}$	0.68	1.0000	-23
	Standard calibration	5-600	$4.05 \cdot 10^{-2} \pm 3.28 \cdot 10^{-3}$	$-3.53 \cdot 10^{-1} \pm 9.33 \cdot 10^{-1}$	$7.22 \cdot 10^{-1}$	5.00	0.9951	-
Triflumizole	Uchuva	5-600	$9.70 \cdot 10^{-3} \pm 1.07 \cdot 10^{-4}$	$-3.57 \cdot 10^{-2} \pm 3.03 \cdot 10^{-2}$	$2.34 \cdot 10^{-2}$	4.57	0.9999	-26
	Lulo	5-600	$1.00 \cdot 10^{-2} \pm 1.73 \cdot 10^{-4}$	$-3.43 \cdot 10^{-2} \pm 4.93 \cdot 10^{-2}$	$3.81 \cdot 10^{-2}$	4.54	0.9998	-24
	Guanabana	5-600	$8.60 \cdot 10^{-3} \pm 2.24 \cdot 10^{-4}$	$-4.16 \cdot 10^{-2} \pm 6.38 \cdot 10^{-2}$	$4.93 \cdot 10^{-2}$	5.00	0.9995	-35
	Pitahaya	5-600	$1.05 \cdot 10^{-2} \pm 1.15 \cdot 10^{-4}$	$-1.21 \cdot 10^{-2} \pm 3.28 \cdot 10^{-2}$	$2.53 \cdot 10^{-2}$	2.87	0.9999	-20
	Standard calibration	5-600	$1.32 \cdot 10^{-2} \pm 7.93 \cdot 10^{-4}$	$-2.01 \cdot 10^{-1} \pm 2.26 \cdot 10^{-1}$	$1.74 \cdot 10^{-1}$	3.40	0.9974	-
Methidathion	Uchuva	5-600	$9.23 \cdot 10^{-3} \pm 1.12 \cdot 10^{-4}$	$-2.54 \cdot 10^{-2} \pm 3.18 \cdot 10^{-2}$	$2.46 \cdot 10^{-2}$	3.50	0.9999	-72
	Lulo	5-600	$1.04 \cdot 10^{-2} \pm 1.98 \cdot 10^{-4}$	$-1.27 \cdot 10^{-2} \pm 5.64 \cdot 10^{-2}$	$4.36 \cdot 10^{-2}$	4.98	0.9997	-68
	Guanabana	5-600	$3.75 \cdot 10^{-3} \pm 3.02 \cdot 10^{-4}$	$2.07 \cdot 10^{-2} \pm 8.58 \cdot 10^{-2}$	$6.63 \cdot 10^{-2}$	4.97	0.9951	-89
	Pitahaya	5-600	$2.39 \cdot 10^{-2} \pm 3.70 \cdot 10^{-4}$	$-9.26 \cdot 10^{-2} \pm 1.05 \cdot 10^{-1}$	$8.14 \cdot 10^{-2}$	4.38	0.9998	-27
	Standard calibration	5-600	$3.29 \cdot 10^{-2} \pm 1.63 \cdot 10^{-3}$	$-4.41 \cdot 10^{-1} \pm 4.65 \cdot 10^{-1}$	$3.59 \cdot 10^{-1}$	4.96	0.9981	-

Table S2.-(Continued).

Analyte	Sample	Studied linear range (µg/kg)	Regression equation (n=5)		$s_{y/x}$	LOQ (µg/kg)	R^2	ME (%)
			$b \pm s_b \cdot t_{(0.05;7)}$	$a \pm s_a \cdot t_{(0.05;7)}$				
Fenamiphos	Uchuva	5-600	$6.20\cdot10^{-3} \pm 7.13\cdot10^{-5}$	$-2.26\cdot10^{-2} \pm 2.03\cdot10^{-2}$	$1.57\cdot10^{-2}$	5.00	0.9999	150
	Lulo	5-600	$6.52\cdot10^{-3} \pm 1.52\cdot10^{-4}$	$-3.49\cdot10^{-2} \pm 4.33\cdot10^{-2}$	$3.35\cdot10^{-2}$	5.00	0.9996	163
	Guanabana	5-600	$3.86\cdot10^{-3} \pm 8.09\cdot10^{-5}$	$-2.72\cdot10^{-2} \pm 2.30\cdot10^{-2}$	$1.78\cdot10^{-2}$	4.97	0.9997	56
	Pitahaya	5-600	$6.42\cdot10^{-3} \pm 1.04\cdot10^{-4}$	$-2.01\cdot10^{-2} \pm 2.95\cdot10^{-2}$	$2.28\cdot10^{-2}$	4.95	0.9998	159
	Standard calibration	5-600	$2.48\cdot10^{-3} \pm 2.32\cdot10^{-4}$	$-3.04\cdot10^{-2} \pm 6.60\cdot10^{-2}$	$5.10\cdot10^{-2}$	4.98	0.9934	-
Myclobutanil	Uchuva	5-600	$3.43\cdot10^{-2} \pm 5.61\cdot10^{-4}$	$4.31\cdot10^{-2} \pm 1.60\cdot10^{-1}$	$1.23\cdot10^{-1}$	1.48	0.9998	-37
	Lulo	5-600	$3.62\cdot10^{-2} \pm 8.32\cdot10^{-4}$	$-4.13\cdot10^{-4} \pm 2.37\cdot10^{-1}$	$1.83\cdot10^{-1}$	2.99	0.9996	-33
	Guanabana	5-600	$3.32\cdot10^{-2} \pm 6.94\cdot10^{-4}$	$-8.79\cdot10^{-2} \pm 1.97\cdot10^{-1}$	$1.53\cdot10^{-1}$	1.48	0.9997	-39
	Pitahaya	5-600	$3.41\cdot10^{-2} \pm 4.72\cdot10^{-4}$	$-1.43\cdot10^{-2} \pm 1.34\cdot10^{-1}$	$1.04\cdot10^{-1}$	0.99	0.9999	-37
	Standard calibration	5-600	$5.44\cdot10^{-2} \pm 6.05\cdot10^{-3}$	$-1.21\cdot10 \pm 1.72\cdot10$	$1.33\cdot10$	4.46	0.9907	-
Dieldrin	Uchuva	5-600	$4.21\cdot10^{-3} \pm 8.92\cdot10^{-5}$	$-5.20\cdot10^{-3} \pm 2.54\cdot10^{-2}$	$1.96\cdot10^{-2}$	5.00	0.9997	-54
	Lulo	5-600	$4.39\cdot10^{-3} \pm 6.33\cdot10^{-5}$	$-1.03\cdot10^{-2} \pm 1.80\cdot10^{-2}$	$1.39\cdot10^{-2}$	4.90	0.9998	-52
	Guanabana	5-600	$4.21\cdot10^{-3} \pm 7.06\cdot10^{-5}$	$-2.09\cdot10^{-2} \pm 2.01\cdot10^{-2}$	$1.55\cdot10^{-2}$	4.56	0.9998	-54
	Pitahaya	5-600	$4.42\cdot10^{-3} \pm 6.96\cdot10^{-5}$	$-9.59\cdot10^{-3} \pm 1.98\cdot10^{-2}$	$1.53\cdot10^{-2}$	5.00	0.9998	-52
	Standard calibration	5-600	$9.22\cdot10^{-3} \pm 6.34\cdot10^{-4}$	$-1.39\cdot10^{-1} \pm 1.80\cdot10^{-1}$	$1.39\cdot10^{-1}$	4.98	0.9964	-
Oxyfluorfen	Uchuva	5-600	$3.89\cdot10^{-3} \pm 8.60\cdot10^{-5}$	$-3.59\cdot10^{-2} \pm 2.44\cdot10^{-2}$	$1.89\cdot10^{-2}$	4.03	0.9996	-27
	Lulo	5-600	$4.28\cdot10^{-3} \pm 8.15\cdot10^{-5}$	$-2.98\cdot10^{-2} \pm 2.32\cdot10^{-2}$	$1.79\cdot10^{-2}$	4.86	0.9997	-20
	Guanabana	5-600	$2.25\cdot10^{-3} \pm 1.56\cdot10^{-4}$	$-2.88\cdot10^{-2} \pm 4.43\cdot10^{-2}$	$3.42\cdot10^{-2}$	4.93	0.9964	-58
	Pitahaya	5-600	$4.14\cdot10^{-3} \pm 6.37\cdot10^{-5}$	$-2.84\cdot10^{-2} \pm 1.81\cdot10^{-2}$	$1.40\cdot10^{-2}$	4.94	0.9998	-23
	Standard calibration	5-600	$5.35\cdot10^{-3} \pm 6.15\cdot10^{-4}$	$-8.28\cdot10^{-2} \pm 1.75\cdot10^{-1}$	$1.35\cdot10^{-1}$	4.98	0.9917	-

Table S2.-(Continued).

Analyte	Sample	Studied linear range (µg/kg)	Regression equation (n=5)		$s_{y/x}$	LOQ (µg/kg)	R^2	ME (%)
			$b \pm s_b \cdot t_{(0.05;7)}$	$a \pm s_a \cdot t_{(0.05;7)}$				
Buprofezin	Uchuva	5-600	$1.01\cdot10^{-2} \pm 5.68\cdot10^{-5}$	$2.52\cdot10^{-2} \pm 1.61\cdot10^{-2}$	$1.25\cdot10^{-2}$	3.15	1.0000	-59
	Lulo	5-600	$1.08\cdot10^{-2} \pm 1.97\cdot10^{-4}$	$2.89\cdot10^{-3} \pm 5.61\cdot10^{-2}$	$4.34\cdot10^{-2}$	5.00	0.9997	-56
	Guanabana	5-600	$9.95\cdot10^{-3} \pm 2.17\cdot10^{-4}$	$-1.76\cdot10^{-2} \pm 6.17\cdot10^{-2}$	$4.77\cdot10^{-2}$	4.92	0.9996	-59
	Pitahaya	5-600	$1.07\cdot10^{-2} \pm 1.54\cdot10^{-4}$	$1.94\cdot10^{-2} \pm 4.38\cdot10^{-2}$	$3.39\cdot10^{-2}$	3.95	0.9998	-56
	Standard calibration	5-600	$2.45\cdot10^{-2} \pm 1.67\cdot10^{-3}$	$-2.81\cdot10^{-1} \pm 4.76\cdot10^{-1}$	$3.68\cdot10^{-1}$	4.93	0.9965	-
Endrin	Uchuva	5-600	$2.94\cdot10^{-3} \pm 4.31\cdot10^{-5}$	$-2.01\cdot10^{-2} \pm 1.23\cdot10^{-2}$	$9.48\cdot10^{-3}$	4.95	0.9998	-49
	Lulo	5-600	$3.19\cdot10^{-3} \pm 5.31\cdot10^{-5}$	$-2.52\cdot10^{-2} \pm 1.51\cdot10^{-2}$	$1.17\cdot10^{-2}$	2.88	0.9998	-45
	Guanabana	5-600	$2.38\cdot10^{-3} \pm 1.05\cdot10^{-4}$	$-2.85\cdot10^{-2} \pm 2.99\cdot10^{-2}$	$2.31\cdot10^{-2}$	5.00	0.9985	-59
	Pitahaya	5-600	$2.89\cdot10^{-3} \pm 5.21\cdot10^{-5}$	$-1.51\cdot10^{-2} \pm 1.48\cdot10^{-2}$	$1.15\cdot10^{-2}$	4.64	0.9998	-50
	Standard calibration	5-600	$5.80\cdot10^{-3} \pm 3.44\cdot10^{-4}$	$-9.34\cdot10^{-2} \pm 9.79\cdot10^{-2}$	$7.56\cdot10^{-2}$	3.23	0.9973	-
Ethion	Uchuva	5-600	$2.37\cdot10^{-2} \pm 4.47\cdot10^{-4}$	$6.67\cdot10^{-3} \pm 1.27\cdot10^{-1}$	$9.82\cdot10^{-2}$	1.33	0.9997	-60
	Lulo	5-600	$2.69\cdot10^{-2} \pm 6.45\cdot10^{-4}$	$4.03\cdot10^{-2} \pm 1.83\cdot10^{-1}$	$1.42\cdot10^{-1}$	2.43	0.9996	-55
	Guanabana	5-600	$9.03\cdot10^{-3} \pm 1.03\cdot10^{-4}$	$1.79\cdot10^{-2} \pm 2.93\cdot10^{-2}$	$2.26\cdot10^{-2}$	3.36	0.9999	-85
	Pitahaya	5-600	$3.23\cdot10^{-2} \pm 2.27\cdot10^{-4}$	$-5.60\cdot10^{-3} \pm 6.46\cdot10^{-2}$	$4.99\cdot10^{-2}$	4.64	1.0000	-46
	Standard calibration	5-600	$5.96\cdot10^{-2} \pm 2.97\cdot10^{-3}$	$-7.01\cdot10^{-1} \pm 8.45\cdot10^{-1}$	$6.53\cdot10^{-1}$	4.87	0.9981	-
Propiconazole	Uchuva	5-600	$1.12\cdot10^{-2} \pm 1.29\cdot10^{-3}$	$6.35\cdot10^{-1} \pm 3.67\cdot10^{-1}$	$2.84\cdot10^{-1}$	0.55	0.9900	-55
	Lulo	5-600	$1.33\cdot10^{-2} \pm 6.96\cdot10^{-4}$	$1.09\cdot10 \pm 1.98\cdot10^{-1}$	$1.53\cdot10^{-1}$	0.72	0.9979	-47
	Guanabana	5-600	$1.14\cdot10^{-2} \pm 7.11\cdot10^{-4}$	$1.43\cdot10^{-1} \pm 2.02\cdot10^{-1}$	$1.56\cdot10^{-1}$	1.01	0.9970	-55
	Pitahaya	5-600	$1.10\cdot10^{-2} \pm 9.31\cdot10^{-4}$	$3.81\cdot10^{-1} \pm 2.65\cdot10^{-1}$	$2.05\cdot10^{-1}$	0.41	0.9946	-56
	Standard calibration	5-600	$2.51\cdot10^{-2} \pm 1.85\cdot10^{-3}$	$-2.34\cdot10^{-1} \pm 5.27\cdot10^{-1}$	$4.07\cdot10^{-1}$	2.04	0.9959	-

Table S2.-(Continued).

Analyte	Sample	Studied linear range (μg/kg)	Regression equation (n=5)		$s_{y/x}$	LOQ (μg/kg)	R^2	ME (%)
			$b \pm s_b \cdot t_{(0.05;7)}$	$a \pm s_a \cdot t_{(0.05;7)}$				
Tebuconazole	Uchuva	5-600	$1.97 \cdot 10^{-2} \pm 2.95 \cdot 10^{-4}$	$7.94 \cdot 10^{-2} \pm 8.40 \cdot 10^{-2}$	$6.49 \cdot 10^{-2}$	1.52	0.9998	-9
	Lulo	5-600	$2.18 \cdot 10^{-2} \pm 1.75 \cdot 10^{-3}$	$1.40 \cdot 10^{1} \pm 4.98 \cdot 10^{-1}$	$3.85 \cdot 10^{-1}$	0.30	0.9951	1
	Guanabana	5-600	$1.79 \cdot 10^{-2} \pm 3.60 \cdot 10^{-4}$	$-4.51 \cdot 10^{-2} \pm 1.03 \cdot 10^{-1}$	$7.93 \cdot 10^{-2}$	1.76	0.9997	-17
	Pitahaya	5-600	$1.97 \cdot 10^{-2} \pm 2.65 \cdot 10^{-4}$	$8.72 \cdot 10^{-1} \pm 7.54 \cdot 10^{-2}$	$5.83 \cdot 10^{-2}$	0.66	0.9999	-9
	Standard calibration	5-600	$2.16 \cdot 10^{-2} \pm 2.15 \cdot 10^{-3}$	$-3.74 \cdot 10^{-1} \pm 6.11 \cdot 10^{-1}$	$4.72 \cdot 10^{-1}$	2.42	0.9926	-
Iprodione	Uchuva	5-600	$3.99 \cdot 10^{-4} \pm 3.41 \cdot 10^{-5}$	$1.56 \cdot 10^{-2} \pm 9.70 \cdot 10^{-3}$	$7.50 \cdot 10^{-3}$	1.25	0.9945	-83
	Lulo	5-600	$4.14 \cdot 10^{-4} \pm 1.11 \cdot 10^{-5}$	$5.81 \cdot 10^{-2} \pm 3.16 \cdot 10^{-3}$	$2.44 \cdot 10^{-3}$	2.44	0.9995	-83
	Guanabana	5-600	$1.23 \cdot 10^{-5} \pm 3.12 \cdot 10^{-5}$	$2.27 \cdot 10^{-2} \pm 8.87 \cdot 10^{-3}$	$6.85 \cdot 10^{-3}$	1.39	0.1707	-99
	Pitahaya	5-600	$1.02 \cdot 10^{-3} \pm 4.61 \cdot 10^{-5}$	$1.01 \cdot 10^{-2} \pm 1.31 \cdot 10^{-2}$	$1.01 \cdot 10^{-2}$	0.83	0.9985	-57
	Standard calibration	5-600	$2.39 \cdot 10^{-3} \pm 2.45 \cdot 10^{-4}$	$-5.55 \cdot 10^{-2} \pm 6.98 \cdot 10^{-2}$	$5.40 \cdot 10^{-2}$	1.30	0.9921	-
EPN	Uchuva	5-600	$6.09 \cdot 10^{-3} \pm 4.10 \cdot 10^{-4}$	$1.29 \cdot 10^{-1} \pm 1.17 \cdot 10^{-1}$	$9.02 \cdot 10^{-2}$	5.00	0.9966	-74
	Lulo	5-600	$6.52 \cdot 10^{-3} \pm 2.22 \cdot 10^{-4}$	$1.39 \cdot 10^{-1} \pm 6.30 \cdot 10^{-2}$	$4.87 \cdot 10^{-2}$	4.89	0.9991	-72
	Guanabana	5-600	$1.76 \cdot 10^{-3} \pm 2.18 \cdot 10^{-4}$	$1.34 \cdot 10^{-1} \pm 6.20 \cdot 10^{-2}$	$4.79 \cdot 10^{-2}$	3.64	0.9905	-93
	Pitahaya	5-600	$1.18 \cdot 10^{-2} \pm 3.06 \cdot 10^{-4}$	$1.45 \cdot 10^{-1} \pm 8.70 \cdot 10^{-2}$	$6.72 \cdot 10^{-2}$	4.78	0.9995	-50
	Standard calibration	5-600	$2.37 \cdot 10^{-2} \pm 1.51 \cdot 10^{-3}$	$-3.17 \cdot 10^{-1} \pm 4.30 \cdot 10^{-1}$	$3.33 \cdot 10^{-1}$	4.10	0.9969	-
Pyriproxyfen	Uchuva	5-600	$2.21 \cdot 10^{-2} \pm 5.93 \cdot 10^{-4}$	$2.01 \cdot 10 \pm 1.69 \cdot 10^{-1}$	$1.30 \cdot 10^{-1}$	1.45	0.9995	-25
	Lulo	5-600	$2.62 \cdot 10^{-2} \pm 2.93 \cdot 10^{-4}$	$6.87 \cdot 10^{-1} \pm 8.32 \cdot 10^{-2}$	$6.43 \cdot 10^{-2}$	3.17	0.9999	-11
	Guanabana	5-600	$1.83 \cdot 10^{-2} \pm 4.53 \cdot 10^{-3}$	$3.01 \cdot 10 \pm 1.29 \cdot 10$	$9.95 \cdot 10^{-1}$	1.59	0.9957	-38
	Pitahaya	5-600	$2.49 \cdot 10^{-2} \pm 4.64 \cdot 10^{-4}$	$2.21 \cdot 10^{-1} \pm 1.32 \cdot 10^{-1}$	$1.02 \cdot 10^{-1}$	1.12	0.9997	-16
	Standard calibration	5-600	$2.95 \cdot 10^{-2} \pm 1.68 \cdot 10^{-3}$	$-3.11 \cdot 10^{-1} \pm 4.78 \cdot 10^{-1}$	$3.70 \cdot 10^{-1}$	1.74	0.9975	-

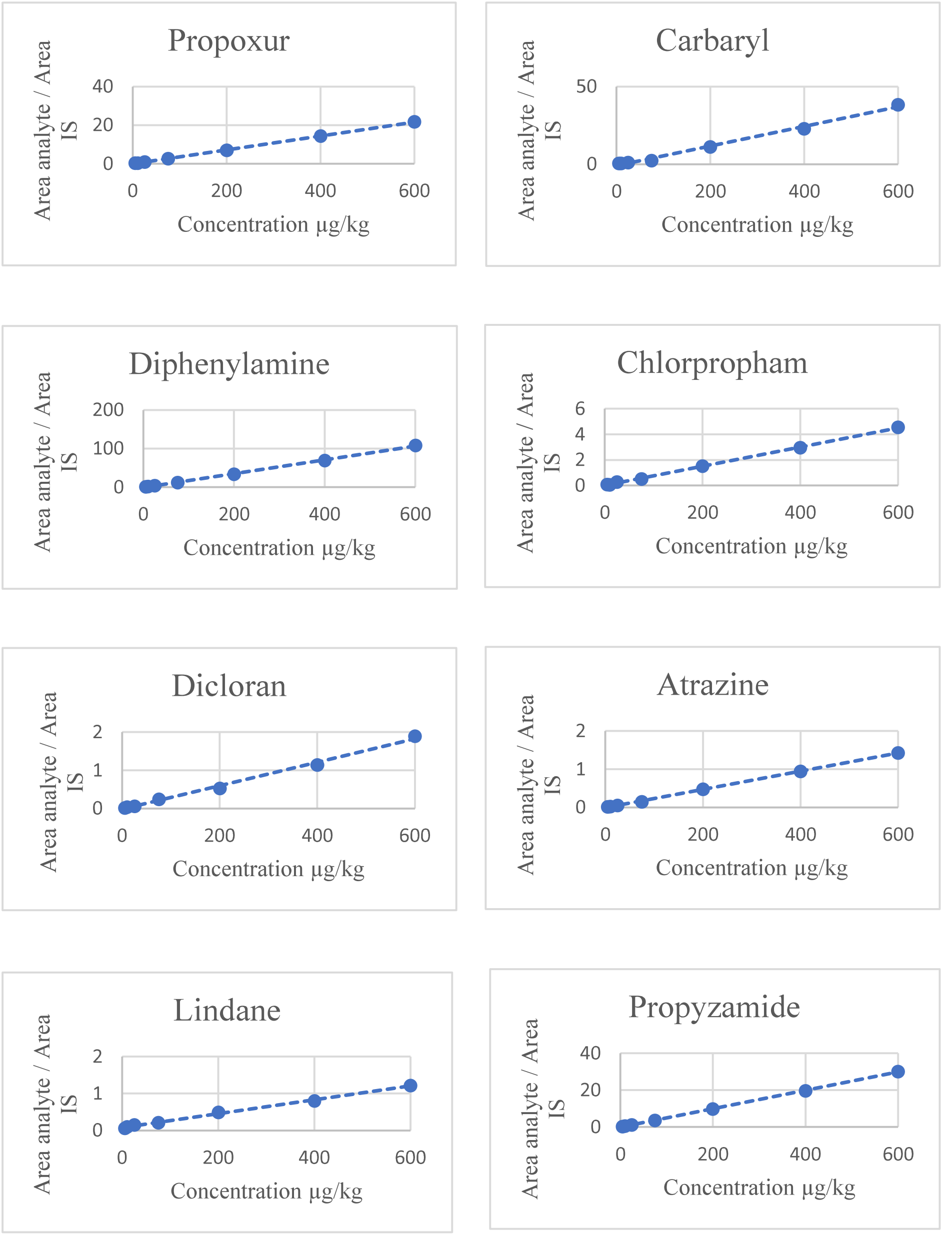
Table S2.-(Continued).

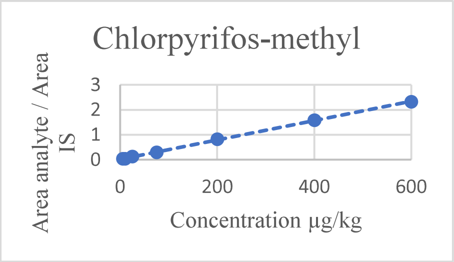
Analyte	Sample	Studied linear range (µg/kg)	Regression equation (n=5)		$S_{y/x}$	LOQ (µg/kg)	R^2	ME (%)
			$b \pm s_b \cdot t_{(0.05;7)}$	$a \pm s_a \cdot t_{(0.05;7)}$				
Fenvalerate	Uchuva	5-600	$3.09\cdot10^{-2} \pm 3.87\cdot10^{-4}$	$3.83\cdot10^{-2} \pm 1.10\cdot10^{-1}$	$8.51\cdot10^{-2}$	0.40	0.9999	41
	Lulo	5-600	$3.37\cdot10^{-2} \pm 1.12\cdot10^{-4}$	$2.55\cdot10^{-2} \pm 3.19\cdot10^{-2}$	$2.47\cdot10^{-2}$	0.77	1.0000	54
	Guanabana	5-600	$5.34\cdot10^{-3} \pm 2.55\cdot10^{-4}$	$-7.13\cdot10^{-3} \pm 7.24\cdot10^{-2}$	$5.60\cdot10^{-2}$	0.32	0.9983	-76
	Pitahaya	5-600	$3.18\cdot10^{-2} \pm 4.97\cdot10^{-4}$	$6.94\cdot10^{-2} \pm 1.41\cdot10^{-1}$	$1.09\cdot10^{-1}$	0.35	0.9998	45
	Standard calibration	5-600	$2.19\cdot10^{-2} \pm 2.23\cdot10^{-3}$	$-3.10\cdot10^{-1} \pm 6.36\cdot10^{-1}$	$4.91\cdot10^{-1}$	2.12	0.9922	-
Esfenvalerate	Uchuva	5-600	$2.42\cdot10^{-2} \pm 2.54\cdot10^{-4}$	$2.04\cdot10^{-2} \pm 7.22\cdot10^{-2}$	$5.58\cdot10^{-2}$	1.17	0.9999	85
	Lulo	5-600	$2.44\cdot10^{-2} \pm 3.82\cdot10^{-4}$	$-1.89\cdot10^{-2} \pm 1.09\cdot10^{-1}$	$8.41\cdot10^{-2}$	2.26	0.9998	87
	Guanabana	5-600	$5.34\cdot10^{-3} \pm 3.17\cdot10^{-4}$	$-6.16\cdot10^{-3} \pm 9.02\cdot10^{-2}$	$6.97\cdot10^{-2}$	4.99	0.9973	-59
	Pitahaya	5-600	$2.60\cdot10^{-2} \pm 6.93\cdot10^{-4}$	$6.64\cdot10^{-2} \pm 1.97\cdot10^{-1}$	$1.52\cdot10^{-1}$	4.87	0.9995	99
	Standard calibration	5-600	$1.31\cdot10^{-2} \pm 1.31\cdot10^{-3}$	$-2.14\cdot10^{-1} \pm 3.74\cdot10^{-1}$	$2.89\cdot10^{-1}$	4.93	0.9936	-

b: Slope; S_b: Standard deviation of the slope; a: intercept; S_a: Standard deviation of the intercept; R^2: determination coefficient; $S_{y/x}$: standard deviation of the estimate.

[a] For Standard calibration. data was converted to µg/kg for comparison purposes though the studied linear range. which was 3.7-444 µg/L. [b] Calculated following the equation used by Kwon *et al.* (Kwon, Lehotay, & Geis-Asteggiante, 2012).

Figure S1.- Matrix-matched calibration graphs for guanabana (calibration curves are given in Table 2S).

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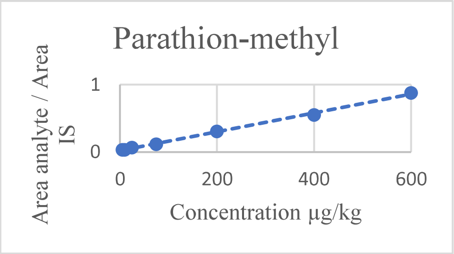
0
200
400
600
Concentration µg/kg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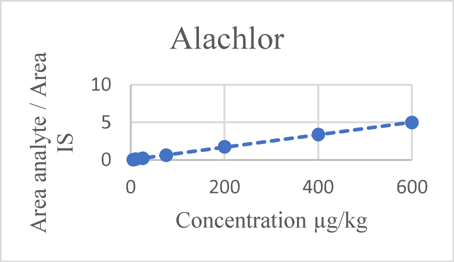
200
400
600
Concentration µg/kg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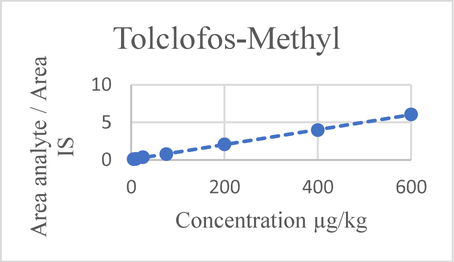
5
0
0
200
400
600
Concentration µg/kg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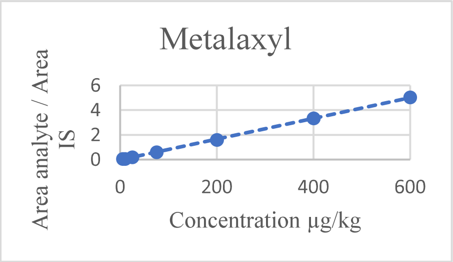
0
200
400
600
Concentration µg/kg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Area analyte / Area IS
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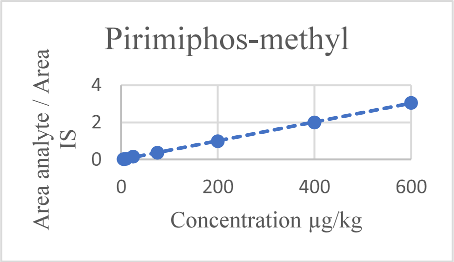
600
Concentration µg/kg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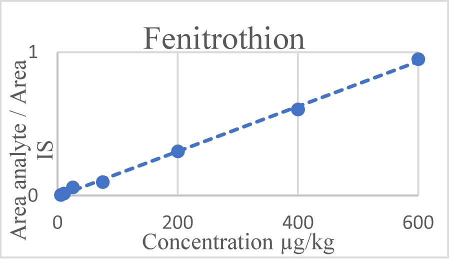
2
0
0
200
400
600
Concentration µg/kg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Area analyte / Area IS
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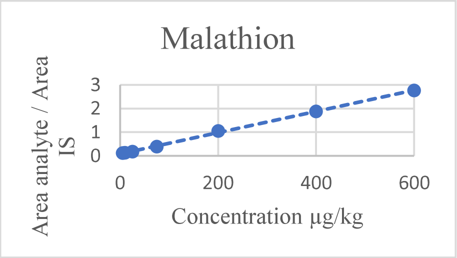
0
0
200
400
600
Concentration µg/kg


Malathion
Area analyte / Area IS
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1
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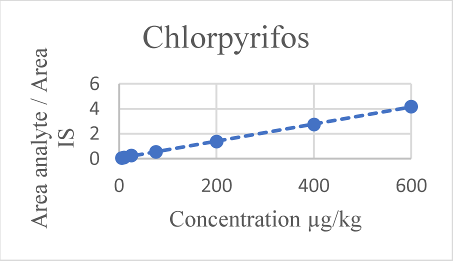
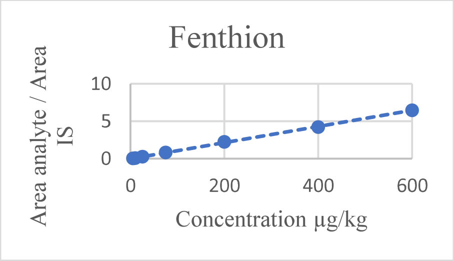
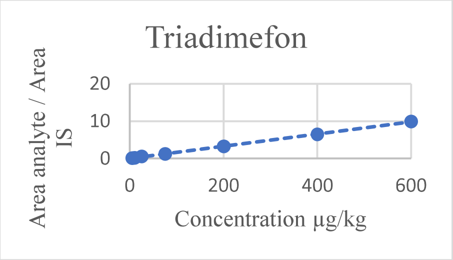
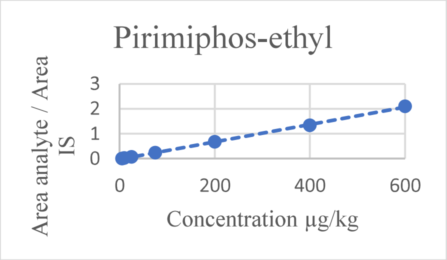
0
200
400
600
Concentration µg/kg

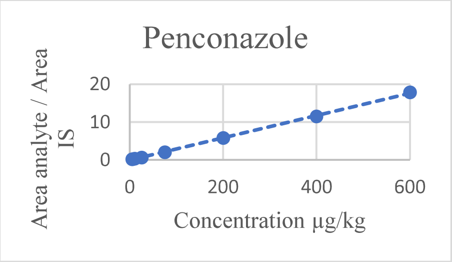
Results and discussion

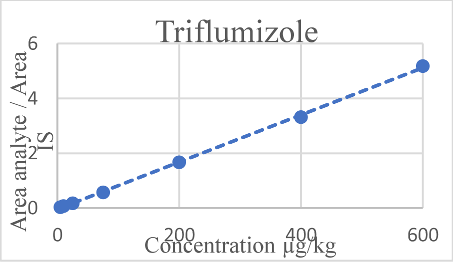


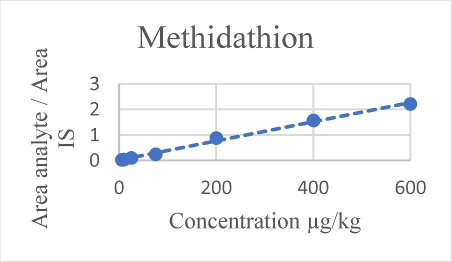


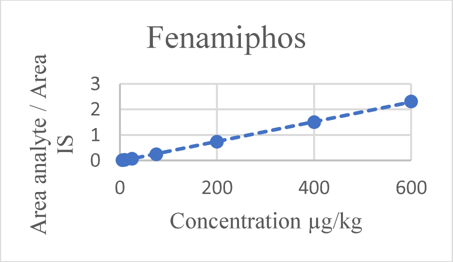




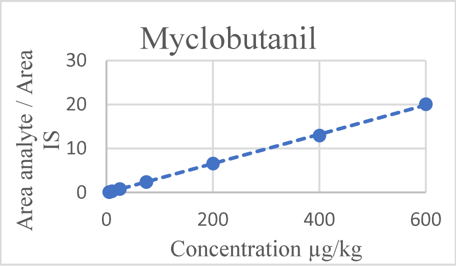


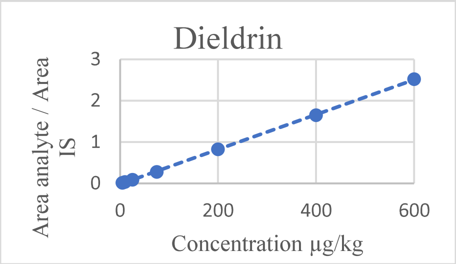


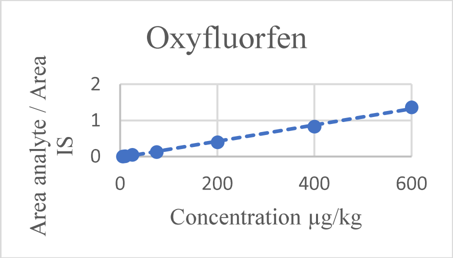


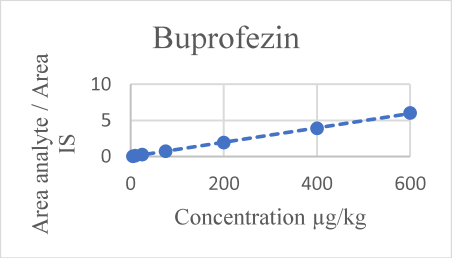


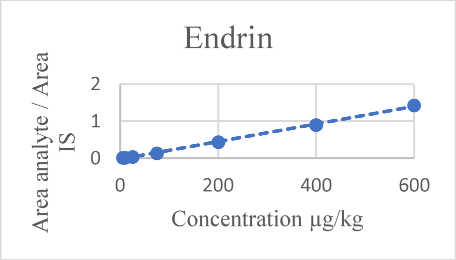
Results and discussion

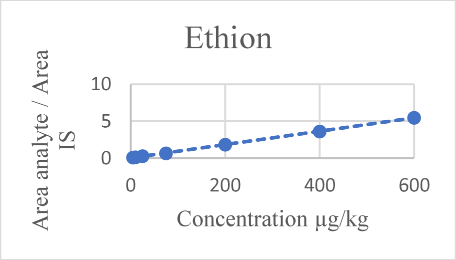


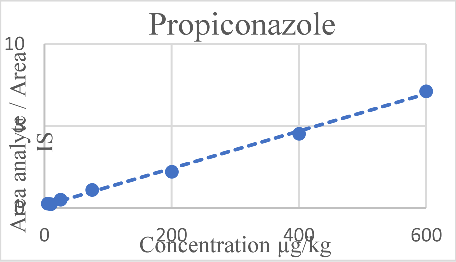


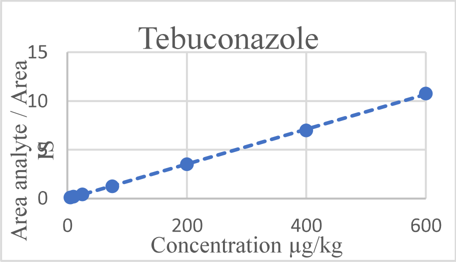


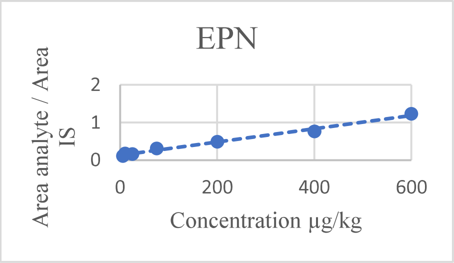








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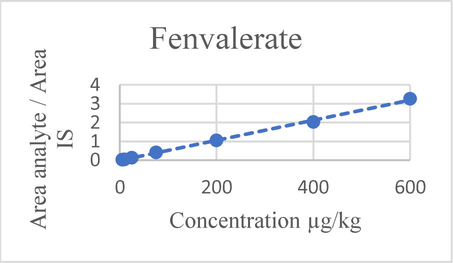
1
0
0
200
400
600
Concentration µg/kg


Fenvalerate
Area analyte / Area IS
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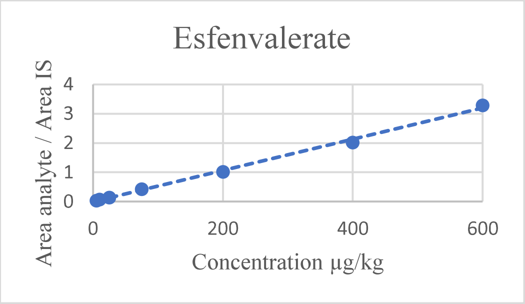
3
2
1
0
0
200
400
600
Concentration µg/kg


Esfenvalerate
Area analyte / Area IS
4
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2
1
0
0
200
400
600
Concentration µg/kg

IV.4.- Analysis of pesticides in cherimoya and gulupa minor tropical fruits using AOAC 2007.1 and ammonium formate QuEChERS versions: A comparative study.

*D.A. Varela Martínez, M.Á. González-Curbelo**, J. González-Sálamo, J. Hernández-Borges**

Microchemical Journal 2020, 15, 104950

In this work, a comparative study between the AOAC 2007.1 QuEChERS method and its modification replacing the HOAc/acetate buffer by ammonium formate was developed for the analysis of 48 representative pesticides in the minor tropical fruits cherimoya (*Annona cherimola*) and gulupa (*Passiflora pinnatistipula*). Since both fruits have intense colours (gulupa has a violet skin while cherimoya is green) and they provide highly coloured ACN extracts, the addition of GCB for pigments removal was also studied (up to 35 mg per mL of the ACN extract). In each experiment (which was developed in triplicate), the amount of co-extractive material of each method was determined. At the same time, recovery values of the selected pesticides were also determined at one concentration level.

When the ammonium formate method was applied, the amount of co-extractives was negligible when 15 mg of GCB were added to cherimoya extracts and when 25 mg of GCB were added to gulupa extracts. On the contrary, the addition of GCB up to 35 mg using the AOAC 2007.01 method was not able to completely eliminate the co-extractives as the previous method did. Concerning recovery values, they were found practically consistent with small variations between them. As a result, and since the ammonium formate method provided cleaner extracts with lower amounts of co-extractives, such method was considered but using 15 mg of GCB for cherimoya and 25 mg of GCB for gulupa per mL of extract of the first partitioning step. Besides, the use of ammonium formate is highly advantageous for instrument performance and durability as already reported in the literature.

Once the most suitable extraction conditions were selected, the method was validated for both samples in terms of matrix-matched calibration, matrix effects and trueness. Recovery values in the 70-120 % range with relative standard deviation values below 20 % (spiked levels of 10, 100, and 400 μg/kg) were obtained for most pesticides while matrix-matched calibration curves showed determination coefficients (R^2) above 0.9901. Matrix effects were also studied, finding soft matrix effects for most pesticides in both matrices. The analysis of 10 samples of each type revealed the presence of propoxur in two gulupa samples and propyzamide in one cherimoya sample, but below the lowest calibration level of the method (set at 5 μg/kg). This works provides the first reported data concerning the analysis of pesticides in cherimoya.

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Analysis of pesticides in cherimoya and gulupa minor tropical fruits using AOAC 2007.1 and ammonium formate QuEChERS versions: A comparative study

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ABSTRACT

In this work, 48 representative pesticides of different chemical families were analysed in cherimoya (*Annona cherimola*) and gulupa (*Passiflora pinnatistipula*), two minor tropical fruits cultivated in Colombia. For this purpose, a comparative study between the AOAC 2007.1 QuEChERS method and its modification replacing the acetic acid/acetate buffer by ammonium formate was developed. Besides, the addition of graphitized carbon black (GCB) was also studied during the dispersive solid-phase extraction clean up to eliminate pigments. Gas chromatography tandem mass spectrometry analysis was performed. Triphenyl phosphate as quality control of the injection and atrazine-d_5 as surrogate internal standard were used. Among both methods, the ammonium formate version with GCB addition provided the cleanest extracts (lowest amounts of co-extractive material) as well as consistent recovery values in the 70–120% range with relative standard deviation values below 20% for a higher number of analytes (spiked levels of 10, 100, and 400 µg/kg). Matrix-matched calibration was carried out obtaining determination coefficients above 0.9901. Matrix effects were also studied, finding soft matrix effects for most pesticides in both matrices. The analysis of 10 samples of each type revealed the presence of propoxur in two gulupa samples and propyzamide in one cherimoya sample, but below the lowest calibration level of the method (set at 5 µg/kg).

1. Introduction

Nowadays, the QuEChERS method has highly consolidated among most official and non-official laboratories in the world for pesticide residue analysis. Its simplicity, high sample throughput, rapidity and ruggedness fulfil the ideal characteristics of any analytical method. However, QuEChERS is much more than a *quick, easy, cheap, effective, rugged* and *safe* method, adjectives for what it stands for. It is indeed a "mega method" as it has been recently designated by Dr. Steven J. Lehotay [1], one of its creators, since it can be successfully applied to a wide variety of analytes and matrices. Furthermore, it is frequently included as part of "Green Analytical Chemistry" procedures, which also increases its interest and application [2].

Although it may seem that QuEChERS may not go any further as a sample preparation method, there are still issues that are clearly situated on its horizon [3]. On the one hand, QuEChERS is trying to face its automation [4], which is an important challenge. On the other, it is being extended to other matrices and analytes, new sorbents are also being introduced, and its miniaturization, which is not an easy task, is also awakening much interest [3].

In 2015, based on the previous work of Nanita and Padivitage [5] who compared the application of different salts for pesticide extraction from food and biological samples prior to flow injection tandem mass spectrometry (MS/MS) analysis, González-Curbelo et al. [6,7] showed that the modification of the QuEChERS method using an ammonium formate buffer minimized the disadvantages of the use of magnesium and sodium salts in MS analysis (i.e. deposition as solids on the surfaces of the MS source or in the gas chromatograph lines). In their work, 43 different pesticides were studied in representative food matrices (apple, lettuce, lemon, and wheat) finding that such modification performed

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favourably compared to the AOAC 2007.1 official method and other volatile salts (ammonium chloride and ammonium acetate). From that moment, different research articles (though still reduced) have shown the suitability of the addition of ammonium formate (without the need of buffering) for the extraction of certain groups of pesticides from different fruits and vegetables [8-10] which is highly advantageous for instrument performance and durability.

Despite the fact that pesticides are probably one of the groups of compounds mostly analysed nowadays worldwide, especially in food commodities, there are still certain gaps regarding the application of analytical methods, among other issues. In particular, the analysis of pesticides in minor tropical fruits has not been sufficiently tackled since their market is relatively small. In this sense, it is also very frequent not to have a list of authorized pesticides in the countries in which these fruits are produced, since pesticides have not been specifically studied or applied to them. Consequently, maximum residue limits (MRLs) are neither regularly established.

Two minor tropical fruits of interest are cherimoya (*Annona cherimola*) and gulupa (*Passiflora pinnatistipula*). Concerning the analysis of pesticides in both matrices, up to now, only gulupa has been previously studied in two works [11,12]. In their first work, Botero-Coy et al. [11] carried out the analysis of around 30 pesticides in seven tropical fruits from Colombia, which included gulupa. The extraction procedure consisted on a solid-liquid extraction with acetonitrile (ACN) in an Ultra-Turrax® high-speed blender, without any clean up step. After filtration and dilution with water, the sample was directly injected in an ultra-high-performance liquid chromatography-MS/MS system using a small amount of formic acid and ammonium acetate as additives in the mobile phase in order to reduce the formation of sodium adducts and favour the ionization. This methodology allowed obtaining recovery values in the range 70–120% with relative standard deviation (RSD) values lower than 20% for most of the analytes, with some exceptions. Regarding gulupa samples, residues of pyrimethanil were found (concentrations < 0.05 mg/kg). In the second work, the same research group [12] used the CEN Standard Method EN 15,662 version of the QuEChERS method and a high-performance liquid chromatography (HPLC)-MS/MS system for the determination of 20 pesticides and metabolites in twelve tropical fruits exported from Colombia to EU, including once more gulupa. The methodology allowed to obtain recovery percentages in the range 70–120% for most of the selected analytes. Carbendazim and dimethoate were found at concentrations above the limit of quantification of the method in gulupa samples analysed in this study (2.6 and 7.2 μg/kg for carbendazim and 2.0 μg/kg for dimethoate).

The aim of this work is to compare the performance of the AOAC 2007.1 QuEChERS version with that in which ammonium formate is applied, for the analysis of the two minor tropical fruits cherimoya and gulupa, among which, as previously commented, only gulupa has been analysed by the QuEChERS method [12]. Such study would reveal the suitability of the application of the second method as an alternative to the first one. For this purpose, 48 representative pesticides of different nature (i.e. organophosphorus pesticides, triazines, triazoles, carbamates, organochlorine pesticides, etc.) were studied and different samples of each type were also analysed. To the best of our knowledge, this is the first published article in which pesticides have been analysed in cherimoya and the first time that ammonium formate is evaluated for the extraction of pesticides from both matrices, which clearly has several advantages over previous versions of the method, especially in terms of instrumental long-term performance.

2. Materials and methods

2.1. Chemicals

Analytical standards of the pesticides studied, the internal standard (IS) (atrazine-d$_5$) and the quality control (QC) of the injection (triphenyl phosphate, TPP) were from Sigma-Aldrich (St. Louis, MO, USA) and had a purity $\geq$ 95.9%. The analyte protectants used in this work (3-ethoxy-1,2-propanediol (ethylglycerol), L-gulonic acid-γ-lactone (gulonolactone), D-sorbitol and shikimic acid) were also obtained from Sigma-Aldrich (purity $\geq$ 95.0%).

Individual stock solutions of each pesticide at approximately 1000 mg/L were prepared in toluene while atrazine-d$_5$ and TPP solutions were prepared at 750 mg/L and 1050 mg/L, respectively. All the solutions were stored in the darkness at −20 °C until their use. Mixtures of the pesticides, the IS and QC were prepared in ACN with 0.05% (v/v) of formic acid to yield 10, 100 and 400 μg/kg sample equivalents for the pesticides and 200 μg/kg for the ISs. Calibration solutions of the pesticides and IS were prepared in the same way to yield 5, 10, 25, 50, 100, 200, 400 and 600 μg/kg, and 200 μg/kg, respectively. Concerning analyte protectants, a mixture containing 100 g/L of ethylglycerol, 10 g/L of gulonolactone, 10 g/L of D-sorbitol and 5 g/L of shikimic acid was prepared in 4/1 (v/v) ACN/water with 0.5% (v/v) of formic acid and was also added just before the injection.

Gas chromatography (GC)–MS-grade ACN, GC-electron capture detector/flame ionization detector-(ECD/FID)-grade methanol, ethyl acetate, toluene and glacial acetic acid were from Merck (Darmstadt, Germany). Anhydrous MgSO$_4$, sodium acetate and ammonium formate were purchased from Sigma-Aldrich while primary secondary amine (PSA), graphitized carbon black (GCB) and octadecylsilane (C$_{18}$) were obtained from Supelco (Bellefonte, PA, USA).

2.2. GC-QqQ-MS/MS separation and detection conditions

A Shimadzu gas chromatograph coupled to a triple quadrupole (QqQ) mass spectrometer GCMS-TQ8040 equipped with an electron ionisation interface and an AOC 20i/s autosampler was used for analytes determination. Analyses were performed in the multiple reaction monitoring (MRM) mode. For instrument control, the GCMS Real Time Analysis software was used while data processing was carried out using the GCMS Post-run Analysis software. Separation was developed using an SH-Rxi-5Sil MS GC column (30 m, 0.25 mm i.d., 0.25 μm film thickness) from Shimadzu. Helium was used as carrier gas at 1.2 mL/min. The gradient program used was the following: 50 °C were maintained for 1 min, then the temperature was increased to 180 °C at 25 °C/min, afterwards, it was increased to 230 °C at 5 °C/min and then to 290 °C at 25 °C/min and maintained at that temperature for 6 min. The total analysis time was 24.6 min. Injection (1 μL) was performed at 250 °C in the splitless mode though the split was opened after 1 min. Between injections, the 10 μL syringe was washed with methanol, ethyl acetate and ACN (a single rinse with each solvent was developed in each case).

2.3. Samples

Cherimoya and gulupa samples were bought at local food stores. Before the application of the QuEChERS method, 1 kg of each fruit were cut into small pieces, comminuted in a 2-L chopper (Oster, Mexico) and stored in a freezer at −18 °C. For the application of both versions of the QuEChERS method, 10 g of each thawed and homogenized fruit were weighted into a 50-mL centrifuge tube. Then, analytes and atrazine-d$_5$ solutions were added, except for the matrix-matched calibration, in which analytes and the IS, as well as TPP, were added after the QuEChERS procedure. For recovery purposes, spikes were made to yield 10, 100 and 400 μg/kg for the pesticides, and 200 μg/kg for the IS, in the sample.

2.4. QuEChERS versions applied

The AOAC 2007.01 method consisted in the addition of 10 mL of ACN containing 1% (v/v) of acetic acid to 10 g of the homogenized samples and an energetic agitation by hand for 30 s. Then, 6 g of anhydrous MgSO$_4$ and 1.5 g of sodium acetate were added, and the

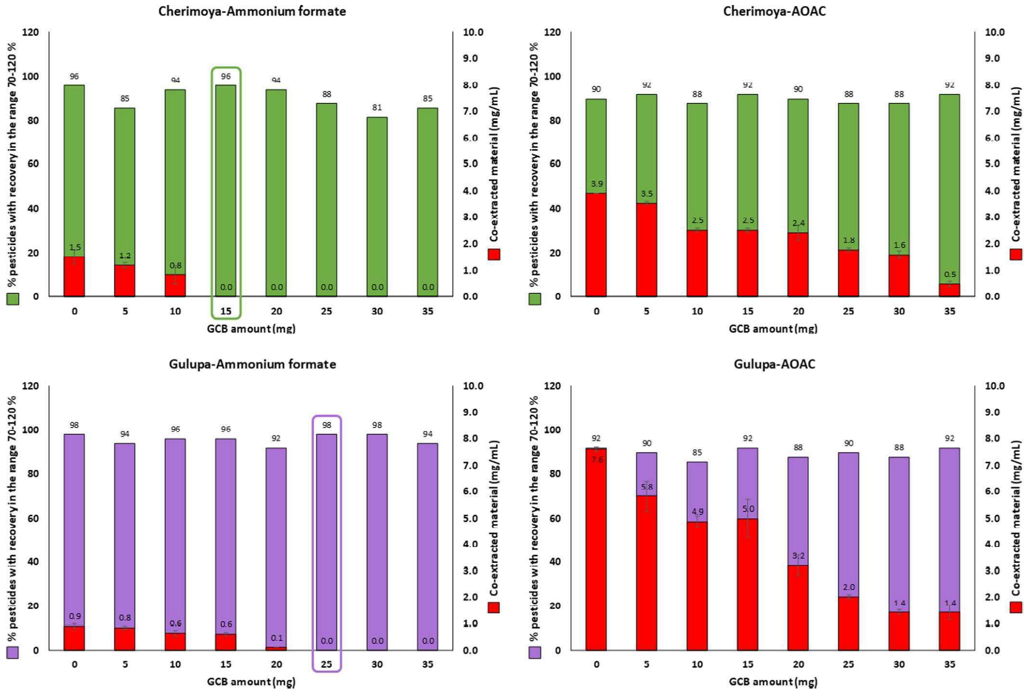

Fig. 1. Comparison of the performance of AOAC 2007.01 and ammonium formate versions of the QuEChERS methods in terms of the amount of co-extracted material (including its standard deviation, $n = 3$) and percentage of pesticides with recovery values in the 70–120% range.

sample was agitated in a tube roller (Scilogex Mx-t6-pro) at 70 rpm for 5 min and centrifuged for 5 min at 4400 rpm. One mL of the supernatant was transferred to a 2-mL tube containing 150 mg of anhydrous $MgSO_4$, 50 mg of PSA and 50 mg of C_{18} (different amounts of GCB were added -see Results and discussion section-). The tube was immediately closed, shaken in a vortex for 10 s and agitated in a tube roller (Scilogex Mx-t6-pro) at 70 rpm for 5 min. Afterwards, centrifugation was carried out for 5 min at 4400 rpm.

The ammonium formate version of the method consisted in the addition of 10 mL of ACN, manual agitation for 30 s, addition of 5 g of ammonium formate plus agitation in a tube roller (Scilogex Mx-t6-pro) at 70 rpm for 5 min. One mL of the supernatant phase was transferred to a 2-mL centrifuge tube that contained 150 mg of anhydrous $MgSO_4$, 50 mg of PSA, 50 mg of C_{18} and 15 mg of GCB for cherimoya samples and 25 mg for gulupa (optimum GCB amounts). The tube was immediately closed, vigorously shaken in a vortex for 10 s and agitated in a tube roller (Scilogex Mx-t6-pro) at 70 rpm for 5 min. Afterwards, centrifugation was carried out for 5 min at 4400 rpm.

For both methods, 200 µL of the final supernatant were introduced in 2-mL vials and 20 µL of the analyte protectants mixture in 4/1 (v/v) ACN/water and 50 µL of the TPP solution in ACN were added.

3. Results and discussion

3.1. GC-QqQ-MS/MS analysis

The 48 pesticides selected in this work, which are representative pesticides of different families, plus the procedural IS (atrazine-d_5) and the QC (TPP), were separated by GC–MS/MS using the thermal gradient already applied by our group [13-15]. A mixture of four analyte protectants (i.e. ethylglycerol, gulonolactone, D-sorbitol and shikimic acid) which was checked in our previous work [15] was applied in all cases to compensate matrix effects (MEs). Regarding detection conditions, the QqQ was operated in MRM mode with three transitions for each analyte, one for quantification and two for confirmation. Table 1S of the Supplementary Material compiles the retention times, the quantifier and qualifier transitions, as well as the collision energies. Concerning quantification, in all cases it was checked that the MS ion ratio between two product fragments satisfy a range of ± 30% of maximum tolerance as criteria diagnostic of their presence [16].

3.2. AOAC 2007.01 and ammonium formate versions comparison

As previously commented, the use of the ammonium formate version of the QuEChERS method provides clear advantages, especially from an instrumental point of view [6,7]. Despite this fact, up to now, a relatively reduced number of works have applied such change [6-9], probably as a result of the already well-established versions of the method. Even though, the changes required to adapt such method are not significant.

In the case of gulupa and cherimoya samples, both of them have intense colours and, therefore, they provide highly coloured ACN extracts. In particular, gulupa has a violet skin and, as a result, it has a strong violet colour after its homogenization. On the contrary, cherimoya has a strong green colour. When high coloured samples are analysed, especially those that contain important amounts of anthocyanins, chlorophyll or carotenoids, the addition of GCB is often a good approach for their elimination. However, the addition of GCB should be careful considered, since it is able to irreversibly retain planar pesticides [17].

In order to compare the performance of both methods for the extraction of gulupa and cherimoya, they were applied for their extraction. However, and as previously commented, GCB was also added in the dispersive solid-phase extraction clean up step to study its effect on pigment/co-extractives removal (increasing amounts of GCB up to 35 mg per mL of extract were tested, see Experimental Section for details). In each experiment (which was developed in triplicate), the amount of co-extractive material of each method was determined. For this purpose, the extracts from a sufficient number of extractions for each amount of GCB were collected so that 1 mL of extract could be taken both before and after the clean up step. Then, it was evaporated to dryness using a water bath at 40 °C under a stream of nitrogen and the result was obtained by simple weight difference. This is an easy and effective way of studying the capacity of the method to eliminate matrix components [14]. At the same time, recovery values of the selected pesticides, calculated by comparing the peak area/IS peak area ratios obtained from real samples, were also determined at 100 µg/kg, taken the 70–120% range with RSD values ≤ 20% as an optimum performance [16].

Fig. 1 shows the variation of the amount of the co-extracted material as well as the percentage of pesticides that meet such recovery criterion. As can be seen in the Figure, when the ammonium formate method was applied, the amount of co-extractives was negligible when 15 mg of GCB were added to cherimoya extracts (the amount of co-extractives was 2.17 mg/mL of extract without clean up step), and when 25 mg of GCB were added to gulupa extracts (the amount of co-extractives was 1.50 mg/mL of extract without clean up step). On the contrary, the addition of GCB up to 35 mg using the AOAC 2007.01 method was not able to completely eliminate the co-extractives as the previous method did (the amount of co-extractives was 9.30 mg/mL for cherimoya extract and 11.87 mg/mL for gulupa extract, both without the clean up step). Concerning recovery values, they were found practically consistent with small variations between them. As a result, and since the ammonium formate method provided cleaner extracts with lower amounts of co-extractives, such method was considered but using 15 mg of GCB for cherimoya and 25 mg of GCB for gulupa per mL of extract of the first partitioning step.

3.3. Method validation

Once the most suitable extraction conditions were selected, the method was validated in terms of matrix-matched calibration, MEs and trueness. Firstly, extractions were carried out with non-spiked samples that were first checked to ensure the absence of the studied pesticides. In the final step, the analytes were added at eight different concentration levels in both cherimoya and gulupa samples to obtain the matrix-matched standards. All standards were injected in triplicate. Table 1 shows the matrix-matched calibration data for all pesticides and matrices including the linear range, the full calibration curve with the standard deviation of the slope and intercept, the error of the estimate ($s_{y/x}$) and the determination coefficient (R^2). As can be seen in the table, the studied linear range was 5–600 µg/kg for all pesticides and matrices being the R^2 above 0.9901 in all cases. Table 1 also shows the calibration curve in pure solvent, which was also injected at the same concentration levels (also in triplicate). Calibration curves in pure solvent were obtained in order to evaluate the presence of MEs. For this purpose, ME was calculated using the following equation: ME (%) = (slope of matrix-matched calibration curve − slope of pure solvent-based calibration curve)/(slope of pure solvent-based calibration curve) × 100 [18]. ME percentages are also compiled in Table 1. Positive ME values mean that a signal enhancement takes place, while negative values correspond to a signal suppression. In general, it is widely accepted that a soft ME takes place when the percentage ranges between −20% and 20% and a medium ME when it ranges between −20% and −50% or between 20% and 50%. Values higher than 50% or lower than −50% correspond to a strong/significant ME. As can be seen in Table 1, in general, soft ME was found, that is 66 out of 96 pesticide-matrix combinations, which represents a 68.8%. A medium ME was found for 20.8% (20 out of 96) of all the pesticide-matrix combinations possible while a strong ME was obtained for only few pesticides: iprodione, fenvalerate, esfenvalerate and deltamethrin in both matrices, propoxur in cherimoya and fenamiphos in gulupa. Such results clearly suggest the need of developing matrix-matched calibration for both samples.

Concerning the trueness of the method, recovery values were calculated by comparing the peak area/IS peak area ratios obtained from real samples spiked with the selected analytes at three concentration levels (i.e. 10, 100 and 400 µg/kg) before the application of the QuEChERS method with that of matrix-matched standards (spiking at the end of the procedure) at the same concentration levels. Five extractions were carried out in each case. Results are shown in Table 2, in which it can clearly be seen that acceptable recovery values, between 70 and 120% with RSD values ≤ 20%, were obtained for the great majority of the pesticides [16]. However, in all cases in which recovery values were outside the 70 and 120% range, RSD% values were also consistent (≤ 20%). Moreover, if mean recovery percentages are considered (the mean recovery values of the 3 spiking levels), it can be seen that all values were in the range 30–140%, also with RSD values ≤ 20% (except for fenamiphos in cherimoya and triflumizole, oxyfluorfen and DDD in gulupa) which is also an acceptable criterion according to SANTE guidelines [16].

It should also be remarked that the lowest calibration level (LCL) of this method was set at 5 µg/kg, which is lower than the standard and most frequent MRLs established at 10 µg/kg [19]. Concerning MRLs in Colombia, the country adopts those MRL values established by the Codex Alimentarius [20]. However, no specific values have been set for any pesticide in gulupa and cherimoya samples, though it is possible that they may appear in the future. Even though, this method is able to detect them at 5 µg/kg which is below such general MRL of 10 µg/kg.

3.4. Real sample analysis

Finally, in order to demonstrate the applicability of the method, 10 samples of each type were bought at local stores of Bogota in August 2019 and analysed in duplicate (see Table 2S of the Supplementary Material). among the studied pesticides, only propoxur was found in two gulupa samples and only propyzamide was found in one cherimoya sample. However, in all cases they were found at concentrations below the LCL (5 µg/kg).

Concerning the published articles in which the analysis of pesticides in similar samples from all over the world has been carried out, as previously commented, only gulupa has been studied in two works [11,12]. In both cases, HPLC-MS/MS was analysed and only pyrimethanil [11] and carbendazim and dimethoate [12] were found in some of the samples. However, none of these pesticides are in common with our work. As also previously indicated, this is the first data concerning the analysis of pesticides in cherimoya samples and one of the very few regarding the analysis of pesticides in gulupa samples.

4. Conclusions

The application of the AOAC 2007.01 and ammonium formate versions of the QuEChERS method to the extraction of 48 representative pesticides from gulupa and cherimoya samples, revealed that the latter one provides the lowest amount of co-extractive material maintaining acceptable recovery values. The addition of GCB was found of particular importance to minimize co-extractives. Such results, together with the acceptable validation data (matrix-matched calibration, MEs and trueness) of the method, clearly suggest that the ammonium formate version can be successfully applied to the extraction of such group of

Table 1
Solvent and matrix-matched calibration data of the selected pesticides and matrix effect percentages[a].

Analyte	Sample	Studied linear range (μg/kg)	Regression equation (n = 8)		$s_{y/x}$	R^2	ME (%)[b]
			$b \pm s_b{\cdot}t_{(0.05;6)}$	$a \pm s_a{\cdot}t_{(0.05;6)}$			
Propoxur	Cherimoya	5–600	$1.89\cdot10^{-2} \pm 1.07\cdot10^{-3}$	$1.46\cdot10^{-1} \pm 3.07\cdot10^{-1}$	$2.21\cdot10^{-1}$	0.9956	−52
	Gulupa	5–600	$1.15\cdot10^{-2} \pm 5.65\cdot10^{-4}$	$1.27\cdot10^{-1} \pm 1.62\cdot10^{-1}$	$1.16\cdot10^{-1}$	0.9950	−36
	Solvent calibration	5–600	$2.37\cdot10^{-2} \pm 1.96\cdot10^{-3}$	$2.20\cdot10^{-2} \pm 5.60\cdot10^{-1}$	$4.03\cdot10^{-1}$	0.9939	–
Carbofuran	Cherimoya	5–600	$5.38\cdot10^{-3} \pm 1.66\cdot10^{-4}$	$-5.9\cdot10^{-3} \pm 4.75\cdot10^{-2}$	$3.42\cdot10$	0.9990	−28
	Gulupa	5–600	$3.92\cdot10^{-3} \pm 1.65\cdot10^{-4}$	$-1.10\cdot10^{-2} \pm 4.72\cdot10^{-2}$	$3.40\cdot10^{-2}$	0.9972	−11
	Solvent calibration	5–600	$5.08\cdot10^{-3} \pm 2.11\cdot10^{-4}$	$-1.31\cdot10^{-2} \pm 6.04\cdot10^{-2}$	$4.35\cdot10^{-2}$	0.9975	–
Diphenylamine	Cherimoya	5–600	$1.04\cdot10^{-1} \pm 7.53\cdot10^{-3}$	$-6.41\cdot10^{-1} \pm 2.15\cdot10$	$1.55\cdot10$	0.9985	5
	Gulupa	5–600	$1.04\cdot10^{-1} \pm 4.31\cdot10^{-3}$	$-2.49\cdot10^{-1} \pm 1.23\cdot10$	$8.88\cdot10^{-1}$	0.9965	5
	Solvent calibration	5–600	$9.34\cdot10^{-2} \pm 5.31\cdot10^{-3}$	$-4.89\cdot10^{-1} \pm 1.52\cdot10$	$1.09\cdot10$	0.9983	–
Chlorpropham	Cherimoya	5–600	$6.34\cdot10^{-3} \pm 3.19\cdot10^{-4}$	$-2.49\cdot10^{-2} \pm 9.12\cdot10^{-2}$	$6.57\cdot10^{-2}$	0.9986	4
	Gulupa	5–600	$6.36\cdot10^{-3} \pm 2.47\cdot10^{-4}$	$-1.71\cdot10^{-3} \pm 7.08\cdot10^{-2}$	$5.10\cdot10^{-2}$	0.9970	3
	Solvent calibration	5–600	$5.99\cdot10^{-3} \pm 1.88\cdot10^{-4}$	$-5.07\cdot10^{-3} \pm 5.37\cdot10^{-2}$	$3.87\cdot10^{-2}$	0.9983	–
Dicloran	Cherimoya	5–600	$4.76\cdot10^{-3} \pm 2.30\cdot10^{-4}$	$-4.67\cdot10^{-2} \pm 6.57\cdot10^{-2}$	$4.73\cdot10^{-2}$	0.9977	−10
	Gulupa	5–600	$5.13\cdot10^{-3} \pm 2.28\cdot10^{-4}$	$-3.92\cdot10^{-2} \pm 6.54\cdot10^{-2}$	$4.71\cdot10^{-2}$	0.9968	−26
	Solvent calibration	5–600	$4.61\cdot10^{-3} \pm 3.96\cdot10^{-4}$	$-7.01\cdot10^{-2} \pm 1.13\cdot10^{-1}$	$8.16\cdot10^{-2}$	0.9928	–
Atrazine	Cherimoya	5–600	$5.00\cdot10^{-3} \pm 2.16\cdot10^{-4}$	$-1.78\cdot10^{-2} \pm 6.19\cdot10^{-2}$	$4.45\cdot10^{-2}$	0.9983	−6
	Gulupa	5–600	$5.17\cdot10^{-3} \pm 1.82\cdot10^{-4}$	$-2.41\cdot10^{-2} \pm 5.20\cdot10^{-2}$	$3.75\cdot10^{-2}$	0.9975	−7
	Solvent calibration	5–600	$5.29\cdot10^{-3} \pm 1.67\cdot10^{-4}$	$-1.80\cdot10^{-2} \pm 4.78\cdot10^{-2}$	$3.44\cdot10^{-2}$	0.9980	–
Lindane	Cherimoya	5–600	$1.62\cdot10^{-2} \pm 1.06\cdot10^{-3}$	$-4.61\cdot10^{-2} \pm 3.04\cdot10^{-1}$	$2.19\cdot10^{-1}$	0.9928	5
	Gulupa	5–600	$1.57\cdot10^{-2} \pm 6.37\cdot10^{-4}$	$-3.87\cdot10^{-2} \pm 1.82\cdot10^{-1}$	$1.31\cdot10^{-1}$	0.9973	−27
	Solvent calibration	5–600	$1.52\cdot10^{-2} \pm 4.26\cdot10^{-3}$	$-1.91\cdot10^{-2} \pm 1.22\cdot10^{-1}$	$8.78\cdot10^{-2}$	0.9985	–
Propyzamide	Cherimoya	5–600	$3.06\cdot10^{-3} \pm 2.7\cdot10^{-4}$	$-3.04\cdot10^{-2} \pm 7.98\cdot10^{-2}$	$5.74\cdot10^{-2}$	0.9940	−7
	Gulupa	5–600	$3.04\cdot10^{-3} \pm 1.76\cdot10^{-4}$	$-4.71\cdot10^{-3} \pm 5.02\cdot10^{-2}$	$3.62\cdot10^{-2}$	0.9934	−9
	Solvent calibration	5–600	$3.19\cdot10^{-3} \pm 1.20\cdot10^{-4}$	$-1.03\cdot10^{-2} \pm 3.44\cdot10^{-2}$	$2.48\cdot10^{-2}$	0.9973	–
β-HCH	Cherimoya	5–600	$2.50\cdot10^{-2} \pm 1.24\cdot10^{-3}$	$-6.68\cdot10^{-2} \pm 3.53\cdot10^{-1}$	$2.55\cdot10^{-1}$	0.9986	−2
	Gulupa	5–600	$2.60\cdot10^{-2} \pm 1.04\cdot10^{-4}$	$-7.39\cdot10^{-2} \pm 2.99\cdot10^{-1}$	$2.15\cdot10^{-1}$	0.9973	−31
	Solvent calibration	5–600	$2.62\cdot10^{-2} \pm 8.40\cdot10^{-4}$	$-2.99\cdot10^{-2} \pm 2.40\cdot10^{-1}$	$1.73\cdot10^{-1}$	0.9983	–
α-HCH	Cherimoya	5–600	$3.38\cdot10^{-2} \pm 1.67\cdot10^{-3}$	$-9.59\cdot10^{-2} \pm 4.79\cdot10^{-1}$	$3.45\cdot10^{-1}$	0.9984	−2
	Gulupa	5–600	$3.49\cdot10^{-2} \pm 1.46\cdot10^{-3}$	$1.13\cdot10^{-1} \pm 4.19\cdot10^{-1}$	$3.02\cdot10^{-1}$	0.9970	−31
	Solvent calibration	5–600	$3.53\cdot10^{-2} \pm 1.13\cdot10^{-3}$	$-4.49\cdot10^{-1} \pm 3.23\cdot10^{-1}$	$2.33\cdot10^{-1}$	0.9982	–
Chlorpyrifos-methyl	Cherimoya	5–600	$1.77\cdot10^{-2} \pm 1.65\cdot10^{-3}$	$-3.25\cdot10^{-2} \pm 4.72\cdot10^{-1}$	$3.40\cdot10^{-1}$	0.9999	2
	Gulupa	5–600	$1.90\cdot10^{-2} \pm 8.15\cdot10^{-4}$	$-4.32\cdot10^{-2} \pm 2.33\cdot10^{-1}$	$1.68\cdot10^{-1}$	0.9964	−7
	Solvent calibration	5–600	$1.64\cdot10^{-2} \pm 5.89\cdot10^{-4}$	$-4.47\cdot10^{-2} \pm 1.69\cdot10^{-1}$	$1.21\cdot10^{-1}$	0.9975	–
Parathion-methyl	Cherimoya	5–600	$6.87\cdot10^{-3} \pm 3.88\cdot10^{-4}$	$-5.77\cdot10^{-2} \pm 1.11\cdot10^{-1}$	$7.99\cdot10^{-2}$	0.9935	−4
	Gulupa	5–600	$9.61\cdot10^{-3} \pm 6.44\cdot10^{-4}$	$-9.45\cdot10^{-2} \pm 1.84\cdot10^{-1}$	$1.33\cdot10^{-1}$	0.9949	−23
	Solvent calibration	5–600	$7.10\cdot10^{-3} \pm 6.35\cdot10^{-4}$	$-8.70\cdot10^{-2} \pm 1.82\cdot10^{-1}$	$1.31\cdot10^{-1}$	0.9953	–
Alachlor	Cherimoya	5–600	$1.64\cdot10^{-2} \pm 5.97\cdot10^{-4}$	$-1.11\cdot10^{-2} \pm 1.71\cdot10^{-1}$	$1.23\cdot10^{-1}$	0.9985	−9
	Gulupa	5–600	$1.62\cdot10^{-2} \pm 6.24\cdot10^{-4}$	$-4.02\cdot10^{-2} \pm 1.79\cdot10^{-1}$	$1.29\cdot10^{-1}$	0.9970	−12
	Solvent calibration	5–600	$1.77\cdot10^{-2} \pm 5.51\cdot10^{-4}$	$-1.00\cdot10^{-2} \pm 1.58\cdot10^{-1}$	$1.14\cdot10^{-1}$	0.9982	–
Tolclofos-methyl	Cherimoya	5–600	$2.08\cdot10^{-2} \pm 8.77\cdot10^{-4}$	$-4.14\cdot10^{-2} \pm 2.51\cdot10^{-1}$	$1.81\cdot10^{-1}$	0.9983	−7
	Gulupa	5–600	$2.14\cdot10^{-2} \pm 8.67\cdot10^{-4}$	$-4.14\cdot10^{-2} \pm 2.48\cdot10^{-1}$	$1.79\cdot10^{-1}$	0.9968	−8
	Solvent calibration	5–600	$2.16\cdot10^{-2} \pm 7.99\cdot10^{-4}$	$-4.14\cdot10^{-2} \pm 2.29\cdot10^{-1}$	$1.65\cdot10^{-1}$	0.9977	–
Metalaxyl	Cherimoya	5–600	$6.41\cdot10^{-3} \pm 2.65\cdot10^{-4}$	$-1.72\cdot10^{-2} \pm 7.58\cdot10^{-2}$	$5.46\cdot10^{-2}$	0.9981	−7
	Gulupa	5–600	$6.13\cdot10^{-3} \pm 2.42\cdot10^{-4}$	$-2.07\cdot10^{-2} \pm 6.93\cdot10^{-2}$	$4.99\cdot10^{-2}$	0.9969	−11
	Solvent calibration	5–600	$6.77\cdot10^{-3} \pm 2.75\cdot10^{-4}$	$-1.68\cdot10^{-2} \pm 7.86\cdot10^{-2}$	$5.66\cdot10^{-2}$	0.9970	–
Pirimiphos-methyl	Cherimoya	5–600	$8.40\cdot10^{-3} \pm 2.77\cdot10^{-4}$	$-2.10\cdot10^{-2} \pm 7.92\cdot10^{-2}$	$5.71\cdot10^{-2}$	0.9983	−9
	Gulupa	5–600	$8.68\cdot10^{-3} \pm 3.58\cdot10^{-4}$	$-2.72\cdot10^{-2} \pm 1.03\cdot10^{-1}$	$7.39\cdot10^{-2}$	0.9966	−6
	Solvent calibration	5–600	$8.64\cdot10^{-3} \pm 3.45\cdot10^{-4}$	$-3.93\cdot10^{-2} \pm 9.87\cdot10^{-2}$	$7.11\cdot10^{-2}$	0.9980	–
Fenitrothion	Cherimoya	5–600	$7.73\cdot10^{-3} \pm 4.73\cdot10^{-4}$	$-6.40\cdot10^{-2} \pm 1.35\cdot10^{-1}$	$9.57\cdot10^{-2}$	0.9983	−5
	Gulupa	5–600	$1.05\cdot10^{-2} \pm 6.29\cdot10^{-4}$	$-9.68\cdot10^{-2} \pm 1.80\cdot10^{-1}$	$1.30\cdot10^{-1}$	0.9943	−17
	Solvent calibration	5–600	$8.23\cdot10^{-3} \pm 7.37\cdot10^{-4}$	$-1.02\cdot10^{-1} \pm 2.11\cdot10^{-1}$	$1.52\cdot10^{-1}$	0.9950	–
Malathion	Cherimoya	5–600	$1.87\cdot10^{-2} \pm 5.75\cdot10^{-4}$	$-2.28\cdot10^{-2} \pm 1.65\cdot10^{-1}$	$1.19\cdot10^{-1}$	0.9985	−5
	Gulupa	5–600	$2.30\cdot10^{-2} \pm 1.06\cdot10^{-3}$	$-3.77\cdot10^{-2} \pm 3.03\cdot10^{-1}$	$2.18\cdot10^{-1}$	0.9957	2
	Solvent calibration	5–600	$1.83\cdot10^{-2} \pm 1.18\cdot10^{-3}$	$-1.67.10^{-2} \pm 3.38\cdot10^{-1}$	$2.43\cdot10^{-1}$	0.9947	–
Chlorpyrifos	Cherimoya	5–600	$1.27\cdot10^{-2} \pm 4.73\cdot10^{-4}$	$-2.91\cdot10^{-2} \pm 1.35\cdot10^{-1}$	$9.75\cdot10^{-2}$	0.9987	−2
	Gulupa	5–600	$1.27\cdot10^{-2} \pm 4.86\cdot10^{-4}$	$-2.68\cdot10^{-2} \pm 1.39\cdot10^{-1}$	$1.00\cdot10^{-1}$	0.9970	−5
	Solvent calibration	5–600	$1.24\cdot10^{-2} \pm 4.56\cdot10^{-4}$	$-3.63\cdot10^{-2} \pm 1.31\cdot10^{-1}$	$9.40\cdot10^{-2}$	0.9977	–
Fenthion	Cherimoya	5–600	$1.92\cdot10^{-2} \pm 6.67\cdot10^{-4}$	$-5.03\cdot10^{-2} \pm 1.91\cdot10^{-1}$	$1.38\cdot10^{-1}$	0.9984	−8
	Gulupa	5–600	$2.09\cdot10^{-2} \pm 8.84\cdot10^{-4}$	$-7.14\cdot10^{-2} \pm 2.53\cdot10^{-1}$	$1.82\cdot10^{-1}$	0.9964	−7
	Solvent calibration	5–600	$2.02\cdot10^{-2} \pm 8.29\cdot10^{-4}$	$-7.36\cdot10^{-2} \pm 2.37\cdot10^{-1}$	$1.71\cdot10^{-1}$	0.9977	–
Triadimefon	Cherimoya	5–600	$1.39\cdot10^{-2} \pm 5.27\cdot10^{-4}$	$-2.34\cdot10^{-2} \pm 1.51\cdot10^{-2}$	$1.09\cdot10^{-1}$	0.9984	−9
	Gulupa	5–600	$1.34\cdot10^{-2} \pm 5.52\cdot10^{-4}$	$-4.88\cdot10^{-2} \pm 1.58\cdot10^{-1}$	$1.14\cdot10^{-1}$	0.9965	−13
	Solvent calibration	5–600	$1.49\cdot10^{-2} \pm 6.43\cdot10^{-4}$	$-3.86\cdot10^{-2} \pm 1.84\cdot10^{-1}$	$1.32\cdot10^{-1}$	0.9971	–
Aldrin	Cherimoya	5–600	$5.93\cdot10^{-3} \pm 2.66\cdot10^{-4}$	$-1.71\cdot10^{-2} \pm 7.62\cdot10^{-2}$	$5.49\cdot10^{-2}$	0.9988	−9
	Gulupa	5–600	$5.62\cdot10^{-3} \pm 1.79\cdot10^{-4}$	$8.20\cdot10^{-3} \pm 5.13\cdot10^{-2}$	$3.70\cdot10^{-2}$	0.9979	−12
	Solvent calibration	5–600	$2.59\cdot10^{-3} \pm 7.63\cdot10^{-4}$	$-8.59\cdot10^{-2} \pm 2.18\cdot10^{-2}$	$1.57\cdot10^{-2}$	0.9983	–
Pirimiphos-ethyl	Cherimoya	5–600	$2.15\cdot10^{-3} \pm 3.22\cdot10^{-4}$	$-2.47\cdot10^{-2} \pm 9.22\cdot10^{-2}$	$6.64\cdot10^{-2}$	0.9959	−34
	Gulupa	5–600	$1.39\cdot10^{-3} \pm 1.39\cdot10^{-4}$	$8.53\cdot10^{-4} \pm 3.98\cdot10^{-2}$	$2.68\cdot10^{-2}$	0.9925	−36
	Solvent calibration	5–600	$6.38\cdot10^{-3} \pm 1.58\cdot10^{-4}$	$-6.63\cdot10^{-3} \pm 4.51\cdot10^{-2}$	$3.25\cdot10^{-2}$	0.9988	–
Heptachlor	Cherimoya	5–600	$2.26\cdot10^{-3} \pm 6.61\cdot10^{-5}$	$-9.28\cdot10^{-3} \pm 1.89\cdot10^{-2}$	$1.36\cdot10^{-2}$	0.9988	−14
	Gulupa	5–600	$2.16.10^{-3} \pm 7.70\cdot10^{-5}$	$-1.09\cdot10^{-2} \pm 2.20\cdot10^{-2}$	$1.59\cdot10^{-2}$	0.9974	−22
	Solvent calibration	5–600	$2.96\cdot10^{-3} \pm 9.65\cdot10^{-5}$	$-9.53\cdot10^{-3} \pm 2.76\cdot10^{-2}$	$1.99\cdot10^{-2}$	0.9990	–
Penconazole	Cherimoya	5–600	$1.61\cdot10^{-2} \pm 7.73\cdot10^{-4}$	$-5.86\cdot10^{-2} \pm 2.21\cdot10^{-1}$	$1.59\cdot10^{-1}$	0.9980	−1
	Gulupa	5–600	$1.48\cdot10^{-2} \pm 6.87\cdot10^{-4}$	$-1.25\cdot10^{-2} \pm 1.97\cdot10^{-1}$	$1.42\cdot10^{-1}$	0.9962	−5
	Solvent calibration	5–600	$1.55\cdot10^{-2} \pm 4.84\cdot10^{-4}$	$-2.29\cdot10^{-2} \pm 1.39\cdot10^{-1}$	$9.97\cdot10^{-2}$	0.9980	–

(*continued on next page*)

Table 1 (*continued*)

Analyte	Sample	Studied linear range (µg/kg)	Regression equation (n = 8)		$s_{y/x}$	R^2	ME (%)[b]
			$b \pm s_b \cdot t_{(0.05;6)}$	$a \pm s_a \cdot t_{(0.05;6)}$			
Triflumizole	Cherimoya	5–600	$7.61 \cdot 10^{-4} \pm 1.00 \cdot 10^{-3}$	$1.00 \cdot 10^{-4} \pm 1.10 \cdot 10^{-2}$	$1.00 \cdot 10^{-3}$	0.9979	−20
	Gulupa	5–600	$6.59 \cdot 10^{-3} \pm 3.38 \cdot 10^{-4}$	$1.90 \cdot 10^{-4} \pm 1.35 \cdot 10^{-3}$	$2.00 \cdot 10^{-3}$	0.9901	−21
	Solvent calibration	5–600	$8.49 \cdot 10^{-4} \pm 1.25 \cdot 10^{-4}$	$2.35 \cdot 10^{-4} \pm 4.25 \cdot 10^{-3}$	$2.00 \cdot 10^{-3}$	0.9905	–
Methidathion	Cherimoya	5–600	$2.64 \cdot 10^{-2} \pm 8.81 \cdot 10^{-4}$	$-6.21 \cdot 10^{-2} \pm 2.52 \cdot 10^{-1}$	$1.82 \cdot 10^{-1}$	0.9983	−34
	Gulupa	5–600	$3.58 \cdot 10^{-2} \pm 1.85 \cdot 10^{-4}$	$-2.04 \cdot 10^{-1} \pm 5.29 \cdot 10^{-1}$	$3.81 \cdot 10^{-1}$	0.9952	−16
	Solvent calibration	5–600	$2.57 \cdot 10^{-2} \pm 2.25 \cdot 10^{-3}$	$-2.82 \cdot 10^{-1} \pm 6.43 \cdot 10^{-1}$	$4.63 \cdot 10^{-1}$	0.9949	–
Heptachlor *cis*	Cherimoya	5–600	$2.04 \cdot 10^{-3} \pm 7.90 \cdot 10^{-5}$	$-8.20 \cdot 10^{-3} \pm 2.26 \cdot 10^{-2}$	$1.63 \cdot 10^{-2}$	0.9983	−17
	Gulupa	5–600	$1.89 \cdot 10^{-3} \pm 6.71 \cdot 10^{-5}$	$-6.63 \cdot 10^{-3} \pm 1.92 \cdot 10^{-2}$	$1.38 \cdot 10^{-2}$	0.9975	−24
	Solvent calibration	5–600	$1.75 \cdot 10^{-3} \pm 4.81 \cdot 10^{-5}$	$-4.42 \cdot 10^{-3} \pm 1.38 \cdot 10^{-2}$	$9.90 \cdot 10^{-3}$	0.9985	–
Heptachlor *trans*	Cherimoya	5–600	$1.54 \cdot 10^{-3} \pm 4.14 \cdot 10^{-5}$	$-8.47 \cdot 10^{-3} \pm 1.18 \cdot 10^{-2}$	$8.52 \cdot 10^{-3}$	0.9989	−13
	Gulupa	5–600	$1.45 \cdot 10^{-3} \pm 5.21 \cdot 10^{-5}$	$-7.13 \cdot 10^{-3} \pm 1.49 \cdot 10^{-2}$	$1.07 \cdot 10^{-2}$	0.9973	−23
	Solvent calibration	5–600	$2.29 \cdot 10^{-3} \pm 1.60 \cdot 10^{-4}$	$-4.19 \cdot 10^{-2} \pm 4.59 \cdot 10^{-2}$	$3.31 \cdot 10^{-2}$	0.9907	–
Fenamiphos	Cherimoya	5–600	$4.20 \cdot 10^{-3} \pm 1.62 \cdot 10^{-4}$	$-3.21 \cdot 10^{-2} \pm 4.63 \cdot 10^{-2}$	$3.33 \cdot 10^{-2}$	0.9979	13
	Gulupa	5–600	$5.03 \cdot 10^{-3} \pm 2.75 \cdot 10^{-4}$	$-3.52 \cdot 10^{-2} \pm 7.88 \cdot 10^{-2}$	$5.67 \cdot 10^{-2}$	0.9939	96
	Solvent calibration	5–600	$1.58 \cdot 10^{-3} \pm 2.14 \cdot 10^{-4}$	$-3.28 \cdot 10^{-2} \pm 8.45 \cdot 10^{-2}$	$3.91 \cdot 10^{-2}$	0.9909	–
Endosulfan A	Cherimoya	5–600	$5.30 \cdot 10^{-3} \pm 1.71 \cdot 10^{-4}$	$-9.45 \cdot 10^{-3} \pm 4.89 \cdot 10^{-2}$	$3.52 \cdot 10^{-2}$	0.9987	−15
	Gulupa	5–600	$5.02 \cdot 10^{-3} \pm 1.81 \cdot 10^{-4}$	$-7.20 \cdot 10^{-3} \pm 5.18 \cdot 10^{-2}$	$3.73 \cdot 10^{-2}$	0.9974	−22
	Solvent calibration	5–600	$6.12 \cdot 10^{-3} \pm 1.70 \cdot 10^{-4}$	$-9.03 \cdot 10^{-2} \pm 4.86 \cdot 10^{-2}$	$3.50 \cdot 10^{-2}$	0.9987	–
Myclobutanil	Cherimoya	5–600	$4.92 \cdot 10^{-2} \pm 1.74 \cdot 10^{-3}$	$-9.39 \cdot 10^{-2} \pm 4.98 \cdot 10^{-1}$	$3.58 \cdot 10^{-1}$	0.9986	−2
	Gulupa	5–600	$4.90 \cdot 10^{-2} \pm 2.05 \cdot 10^{-3}$	$-1.22 \cdot 10^{-1} \pm 5.87 \cdot 10^{-1}$	$4.23 \cdot 10^{-1}$	0.9965	−2
	Solvent calibration	5–600	$4.88 \cdot 10^{-2} \pm 3.67 \cdot 10^{-3}$	$-4.39 \cdot 10^{-1} \pm 1.05 \cdot 10$	$7.56 \cdot 10^{-1}$	0.9933	–
Dieldrin	Cherimoya	5–600	$2.80 \cdot 10^{-3} \pm 6.79 \cdot 10^{-5}$	$-7.47 \cdot 10^{-3} \pm 1.94 \cdot 10^{-2}$	$1.40 \cdot 10^{-2}$	0.9989	−12
	Gulupa	5–600	$2.63 \cdot 10^{-3} \pm 1.14 \cdot 10^{-4}$	$5.51 \cdot 10^{-3} \pm 3.27 \cdot 10^{-2}$	$2.35 \cdot 10^{-2}$	0.9967	−19
	Solvent calibration	5–600	$3.11 \cdot 10^{-3} \pm 9.01 \cdot 10^{-4}$	$-7.28 \cdot 10^{-2} \pm 2.58 \cdot 10^{-2}$	$1.86 \cdot 10^{-2}$	0.9983	–
Oxyfluorfen	Cherimoya	5–600	$2.45 \cdot 10^{-3} \pm 1.15 \cdot 10^{-4}$	$-1.71 \cdot 10^{-2} \pm 3.29 \cdot 10^{-2}$	$2.37 \cdot 10^{-2}$	0.9976	2
	Gulupa	5–600	$2.58 \cdot 10^{-3} \pm 1.32 \cdot 10^{-4}$	$-1.58 \cdot 10^{-2} \pm 3.78 \cdot 10^{-2}$	$2.72 \cdot 10^{-2}$	0.9946	−18
	Solvent calibration	5–600	$2.37 \cdot 10^{-3} \pm 2.04 \cdot 10^{-4}$	$-3.20 \cdot 10^{-2} \pm 5.82 \cdot 10^{-2}$	$4.19 \cdot 10^{-2}$	0.9953	–
Buprofezin	Cherimoya	5–600	$7.69 \cdot 10^{-3} \pm 2.17 \cdot 10^{-4}$	$-1.12 \cdot 10^{-2} \pm 6.20 \cdot 10^{-2}$	$4.47 \cdot 10^{-2}$	0.9989	−11
	Gulupa	5–600	$7.43 \cdot 10^{-3} \pm 3.27 \cdot 10^{-4}$	$-1.94 \cdot 10^{-2} \pm 9.35 \cdot 10^{-2}$	$6.73 \cdot 10^{-2}$	0.9961	−14
	Solvent calibration	5–600	$8.42 \cdot 10^{-3} \pm 3.51 \cdot 10^{-4}$	$-3.39 \cdot 10^{-2} \pm 1.00 \cdot 10^{-1}$	$7.23 \cdot 10^{-2}$	0.9979	–
Endrin	Cherimoya	5–600	$1.86 \cdot 10^{-3} \pm 6.00 \cdot 10^{-5}$	$-8.48 \cdot 10^{-3} \pm 1.72 \cdot 10^{-2}$	$1.24 \cdot 10^{-2}$	0.9984	−14
	Gulupa	5–600	$1.75 \cdot 10^{-3} \pm 7.21 \cdot 10^{-5}$	$-8.82 \cdot 10^{-3} \pm 2.06 \cdot 10^{-2}$	$1.49 \cdot 10^{-2}$	0.9965	−22
	Solvent calibration	5–600	$2.11 \cdot 10^{-3} \pm 6.02 \cdot 10^{-5}$	$-8.25 \cdot 10^{-3} \pm 1.72 \cdot 10^{-2}$	$1.24 \cdot 10^{-2}$	0.9983	–
Ethion	Cherimoya	5–600	$5.31 \cdot 10^{-3} \pm 1.88 \cdot 10^{-4}$	$-1.10 \cdot 10^{-2} \pm 5.38 \cdot 10^{-2}$	$3.87 \cdot 10^{-2}$	0.9978	−5
	Gulupa	5–600	$5.27 \cdot 10^{-3} \pm 2.44 \cdot 10^{-4}$	$-1.27 \cdot 10^{-2} \pm 6.97 \cdot 10^{-2}$	$5.02 \cdot 10^{-2}$	0.9962	−7
	Solvent calibration	5–600	$5.54 \cdot 10^{-3} \pm 3.77 \cdot 10^{-4}$	$-4.65 \cdot 10^{-2} \pm 1.08 \cdot 10^{-2}$	$7.77 \cdot 10^{-2}$	0.9959	–
DDE	Cherimoya	5–600	$3.41 \cdot 10^{-2} \pm 1.17 \cdot 10^{-3}$	$-1.51^{2} \pm 3.36 \cdot 10^{-1}$	$2.42 \cdot 10^{-1}$	0.9985	−14
	Gulupa	5–600	$3.11 \cdot 10^{-2} \pm 1.20 \cdot 10^{-3}$	$-1.68 \cdot 10^{-2} \pm 3.44 \cdot 10^{-1}$	$2.48 \cdot 10^{-1}$	0.9971	−21
	Solvent calibration	5–600	$3.86 \cdot 10^{-2} \pm 1.18 \cdot 10^{-3}$	$1.59 \cdot 10^{-2} \pm 3.37 \cdot 10^{-1}$	$2.43 \cdot 10^{-1}$	0.9981	–
DDD	Cherimoya	5–600	$3.35 \cdot 10^{-4} \pm 6.74 \cdot 10^{-6}$	$-1.59 \cdot 10^{-3} \pm 1.93 \cdot 10^{-3}$	$1.39 \cdot 10^{-3}$	0.9997	−30
	Gulupa	5–600	$3.17 \cdot 10^{-4} \pm 1.70 \cdot 10^{-5}$	$-2.74 \cdot 10^{-3} \pm 4.86 \cdot 10^{-3}$	$3.50 \cdot 10^{-3}$	0.9943	−32
	Solvent calibration	5–600	$4.70 \cdot 10^{-4} \pm 2.88 \cdot 10^{-5}$	$-2.94 \cdot 10^{-3} \pm 8.23 \cdot 10^{-3}$	$5.93 \cdot 10^{-3}$	0.9930	–
Propiconazole	Cherimoya	5–600	$6.96 \cdot 10^{-3} \pm 2.81 \cdot 10^{-4}$	$-3.51^{-2} \pm 8.04 \cdot 10^{-2}$	$5.97 \cdot 10^{-2}$	0.9981	−6
	Gulupa	5–600	$6.10 \cdot 10^{-3} \pm 2.75 \cdot 10^{-4}$	$1.26 \cdot 10^{-2} \pm 7.86 \cdot 10^{-2}$	$5.66 \cdot 10^{-2}$	0.9964	−12
	Solvent calibration	5–600	$6.76 \cdot 10^{-3} \pm 2.41 \cdot 10^{-4}$	$-1.46 \cdot 10^{-2} \pm 6.90 \cdot 10^{-2}$	$4.97 \cdot 10^{-2}$	0.9977	–
Tebuconazole	Cherimoya	5–600	$1.29 \cdot 10^{-2} \pm 4.5310^{-4}$	$-1.14 \cdot 10^{-2} \pm 1.30 \cdot 10^{-1}$	$9.33 \cdot 10^{-2}$	0.9987	−5
	Gulupa	5–600	$1.18 \cdot 10^{-2} \pm 5.52 \cdot 10^{-4}$	$-1.35 \cdot 10^{-2} \pm 1.58 \cdot 10^{-1}$	$1.14 \cdot 10^{-1}$	0.9956	1
	Solvent calibration	5–600	$1.15 \cdot 10^{-2} \pm 5.79 \cdot 10^{-4}$	$-4.96 \cdot 10^{-2} \pm 1.66 \cdot 10^{-1}$	$1.19 \cdot 10^{-1}$	0.9972	–
Iprodione	Cherimoya	5–600	$3.81 \cdot 10^{-4} \pm 2.68 \cdot 10^{-5}$	$-5.1 \cdot 10^{-4} \pm 7.66 \cdot 10^{-3}$	$5.51 \cdot 10^{-3}$	0.9963	−273
	Gulupa	5–600	$5.28 \cdot 10^{-4} \pm 2.17 \cdot 10^{-5}$	$-3.19 \cdot 10^{-23} \pm 6.22 \cdot 10^{-3}$	$4.48 \cdot 10^{-3}$	0.9975	115
	Solvent calibration	5–600	$1.27 \cdot 10^{-4} \pm 1.45 \cdot 10^{-5}$	$-6.54 \cdot 10^{-4} \pm 3.02 \cdot 10^{-3}$	$2.04 \cdot 10^{-3}$	0.9907	–
EPN	Cherimoya	5–600	$7.41 \cdot 10^{-3} \pm 5.32 \cdot 10^{-4}$	$-3.27 \cdot 10^{-2} \pm 1.52 \cdot 10^{-1}$	$1.10 \cdot 10^{-1}$	0.9954	16
	Gulupa	5–600	$8.78 \cdot 10^{-3} \pm 5.76 \cdot 10^{-4}$	$-7.81 \cdot 10^{-2} \pm 1.65 \cdot 10^{-1}$	$1.19 \cdot 10^{-1}$	0.9935	−40
	Solvent calibration	5–600	$6.03 \cdot 10^{-3} \pm 6.02 \cdot 10^{-4}$	$-8.97 \cdot 10^{-2} \pm 1.72 \cdot 10^{-1}$	$1.24 \cdot 10^{-1}$	0.9936	–
Pyriproxyfen	Cherimoya	5–600	$1.62 \cdot 10^{-2} \pm 3.11 \cdot 10^{-3}$	$2.26 \cdot 10 \pm 9.11 \cdot 10^{-1}$	$6.56 \cdot 10^{-1}$	0.9919	3
	Gulupa	5–600	$1.53 \cdot 10^{-2} \pm 7.33 \cdot 10^{-4}$	$-2.20 \cdot 10^{-2} \pm 2.10 \cdot 10^{-1}$	$1.51 \cdot 10^{-1}$	0.9954	−2
	Solvent calibration	5–600	$1.51 \cdot 10^{-2} \pm 6.86 \cdot 10^{-4}$	$-2.00 \cdot 10^{-2} \pm 1.96 \cdot 10^{-1}$	$1.41 \cdot 10^{-1}$	0.9971	–
DDT	Cherimoya	5–600	$4.61 \cdot 10^{-2} \pm 2.22 \cdot 10^{-3}$	$-1.38 \cdot 10^{-1} \pm 6.34 \cdot 10^{-1}$	$4.57 \cdot 10^{-1}$	0.9983	−9
	Gulupa	5–600	$4.63 \cdot 10^{-2} \pm 1.82 \cdot 10^{-3}$	$-6.98 \cdot 10^{-2} \pm 5.21 \cdot 10^{-1}$	$3.75 \cdot 10^{-1}$	0.9968	−7
	Solvent calibration	5–600	$4.77 \cdot 10^{-2} \pm 2.01 \cdot 10^{-3}$	$-1.98 \cdot 10^{-1} \pm 5.74 \cdot 10^{-1}$	$4.13 \cdot 10^{-1}$	0.9977	–
Fenvalerate	Cherimoya	5–600	$2.30 \cdot 10^{-2} \pm 9.20 \cdot 10^{-4}$	$-5.92 \cdot 10^{-2} \pm 2.63 \cdot 10^{-1}$	$1.90 \cdot 10^{-1}$	0.9983	98
	Gulupa	5–600	$2.23 \cdot 10^{-2} \pm 1.07 \cdot 10^{-3}$	$-7.42 \cdot 10^{-2} \pm 3.06 \cdot 10^{-1}$	$2.21 \cdot 10^{-1}$	0.9954	113
	Solvent calibration	5–600	$9.50 \cdot 10^{-3} \pm 9.99 \cdot 10^{-4}$	$-1.08 \cdot 10^{-2} \pm 2.86 \cdot 10^{-1}$	$2.06 \cdot 10^{-1}$	0.9903	–
Esfenvalerate	Cherimoya	5–600	$2.24 \cdot 10^{-2} \pm 1.13 \cdot 10^{-3}$	$-6.17 \cdot 10^{-2} \pm 3.24 \cdot 10^{-1}$	$2.33 \cdot 10^{-1}$	0.9953	135
	Gulupa	5–600	$2.42 \cdot 10^{-2} \pm 1.19 \cdot 10^{-3}$	$-8.31 \cdot 10^{-2} \pm 3.40 \cdot 10^{-1}$	$2.45 \cdot 10^{-1}$	0.9951	113
	Solvent calibration	5–600	$7.54 \cdot 10^{-4} \pm 8.85 \cdot 10^{-4}$	$-4.25 \cdot 10^{-2} \pm 3.54 \cdot 10^{-1}$	$2.04 \cdot 10^{-1}$	0.9912	–
Deltamethrin	Cherimoya	5–600	$1.34 \cdot 10^{-3} \pm 5.77 \cdot 10^{-5}$	$-1.06 \cdot 10^{-2} \pm 1.65 \cdot 10^{-2}$	$1.19 \cdot 10^{-2}$	0.9976	100
	Gulupa	5–600	$1.16 \cdot 10^{-3} \pm 6.25 \cdot 10^{-5}$	$-9.26 \cdot 10^{-2} \pm 1.78 \cdot 10^{-2}$	$1.29 \cdot 10^{-2}$	0.9943	163
	Solvent calibration	5–600	$4.30 \cdot 10^{-4} \pm 8.06 \cdot 10^{-5}$	$-1.06 \cdot 10^{-2} \pm 2.31 \cdot 10^{-2}$	$1.66 \cdot 10^{-2}$	0.9955	–

b: slope.10; S_b: standard deviation of the slope; a: intercept; S_a: standard deviation of the intercept; R^2: determination coefficient; $s_{y/x}$: standard deviation of the estimate.

[a] For solvent calibration, data was converted to µg/kg for comparison purposes though the studied linear range which was 3.7–444 µg/L.

[b] Calculated following the equation used by Kwon et al. [18].

Table 2
Average recovery values (RSD %) of the selected pesticides in cherimoya and gulupa samples ($n = 5$ at each spiking level and $n = 15$ for the mean recovery of the three levels). Bold text indicates recovery outside the 70–120% range and RSD > 20%.

Pesticide	Cherimoya				Gulupa			
	10 μg/kg	100 μg/kg	400 μg/kg	Mean recovery and RSD%	10 μg/kg	100 μg/kg	400 μg/kg	Mean recovery and RSD%
Propoxur	87 (18)	78 (15)	58 (2)	74 (19)	112 (15)	77 (11)	98 (15)	106 (15)
Carbofuran	74 (13)	90 (3)	77 (7)	80 (12)	114 (5)	82 (6)	96 (9)	99 (18)
Diphenylamine	101 (5)	103 (5)	118 (9)	107 (9)	100 (9)	95 (2)	112 (12)	102 (11)
Chlorpropham	108 (6)	100 (4)	113 (6)	107 (7)	72 (9)	92 (3)	103 (11)	88 (18)
Dicloran	94 (8)	83 (4)	96 (9)	89 (13)	100 (11)	80 (5)	**62** (14)	81 (19)
Atrazine	106 (7)	96 (2)	111 (2)	104 (7)	97 (15)	96 (4)	92 (12)	95 (11)
Lindane	104 (8)	102 (4)	106 (5)	104 (6)	113 (8)	96 (3)	109 (11)	106 (10)
Propyzamide	95 (10)	104 (3)	103 (4)	101 (7)	82 (14)	105 (8)	94 (14)	91 (12)
β-HCH	74 (3)	100 (3)	108 (10)	94 (17)	109 (7)	95 (3)	103 (10)	102 (9)
A-HCH	76 (2)	101 (4)	109 (8)	95 (16)	112 (6)	95 (2)	104 (10)	104 (9)
Chlorpyrifos-methyl	97 (4)	95 (4)	108 (6)	100 (7)	79 (10)	95 (4)	75 (13)	83 (14)
Parathion-methyl	118 (3)	104 (4)	116 (2)	117 (13)	85 (9)	102 (5)	87 (12)	91 (12)
Alachlor	102 (6)	100 (3)	113 (4)	105 (7)	107 (5)	100 (3)	114 (11)	107 (9)
Tolclofos-methyl	93 (4)	97 (3)	116 (4)	102 (10)	89 (7)	99 (3)	96 (11)	95 (8)
Metalaxyl	70 (6)	101 (3)	107 (8)	93 (19)	102 (9)	98 (3)	102 (11)	102 (11)
Pirimiphos-methyl	102 (5)	95 (2)	111 (3)	103 (7)	70 (3)	91 (4)	94 (11)	84 (16)
Fenitrothion	113 (6)	103 (3)	**124** (1)	117 (16)	86 (9)	101 (6)	88 (12)	92 (11)
Malathion	109 (3)	107 (3)	**120** (6)	118 (13)	113 (5)	104 (4)	112 (13)	102 (15)
Chlorpyrifos	79 (5)	91 (5)	109 (4)	93 (14)	72 (7)	91 (4)	71 (12)	78 (14)
Fenthion	107 (3)	97 (3)	120 (8)	108 (10)	85 (7)	100 (3)	94 (11)	93 (10)
Triadimefon	101 (5)	98 (3)	111 (3)	103 (7)	100 (4)	97 (4)	114 (11)	104 (10)
Aldrin	**60** (11)	82 (6)	100 (2)	80 (20)	114 (8)	86 (4)	113 (9)	105 (15)
Pirimiphos-ethyl	72 (12)	102 (8)	99 (15)	89 (20)	75 (3)	91 (6)	**124** (13)	96 (15)
Heptachlor	78 (12)	98 (2)	110 (3)	95 (15)	109 (13)	102 (4)	**121** (10)	111 (12)
Penconazole	110 (6)	93 (2)	111 (15)	105 (12)	85 (10)	90 (4)	108 (13)	94 (14)
Triflumizole	101 (10)	92 (7)	99 (10)	100 (13)	**158** (12)	77 (20)	**120** (13)	128 (**25**)
Methidathion	110 (2)	109 (4)	118 (9)	115 (19)	93 (3)	99 (5)	99 (12)	97 (8)
Heptachlor *cis*	70 (11)	94 (2)	110 (3)	91 (19)	**121** (16)	97 (4)	**126** (10)	118 (17)
Heptachlor *trans*	88 (10)	92 (3)	114 (11)	98 (15)	120 (12)	102 (4)	**125** (10)	117 (12)
Fenamiphos	100 (13)	**65** (7)	119 (2)	95 (**30**)	**65** (10)	75 (18)	81 (14)	73 (19)
Endosulfan A	72 (1)	93 (3)	104 (5)	88 (12)	118 (5)	95 (3)	**121** (11)	112 (13)
Myclobutanil	97 (2)	101 (3)	112 (4)	103 (7)	105 (3)	93 (4)	108 (11)	102 (9)
Dieldrin	84 (6)	91 (4)	106 (3)	93 (11)	110 (11)	99 (3)	**121** (11)	110 (12)
Oxyfluorfen	98 (6)	93 (3)	88 (4)	95 (10)	81 (14)	104 (5)	**40** (20)	75 (**25**)
Buprofezin	84 (6)	88 (6)	106 (4)	93 (12)	86 (5)	86 (4)	107 (10)	93 (13)
Endrin	105 (14)	89 (7)	106 (1)	102 (14)	97 (13)	98 (2)	**124** (10)	107 (15)
Ethion	77 (9)	97 (4)	108 (1)	94 (15)	86 (5)	94 (3)	105 (11)	95 (11)
DDE	70 (2)	83 (4)	98 (1)	83 (15)	120 (5)	88 (3)	114 (10)	109 (17)
DDD	98 (4)	89 (8)	100 (6)	96 (8)	**145** (11)	93 (6)	**133** (11)	**131** (**24**)
Propiconazole	112 (15)	86 (11)	103 (1)	104 (19)	95 (12)	91 (3)	110 (13)	100 (14)
Tebuconazole	80 (3)	93 (3)	105 (7)	93 (12)	91 (5)	88 (4)	89 (12)	89 (8)
Iprodione	119 (6)	112 (4)	100 (7)	100 (18)	118 (7)	106 (3)	110 (18)	75 (15)
EPN	71 (12)	98 (5)	109 (20)	93 (20)	85 (8)	95 (5)	**62** (14)	81 (14)
Pyriproxyfen	120 (4)	120 (16)	112 (10)	119 (18)	84 (3)	102 (3)	94 (11)	93 (10)
DDT	86 (4)	97 (4)	117 (5)	100 (14)	114 (13)	102 (4)	116 (12)	112 (12)
Fenvalerate	70 (5)	99 (4)	117 (9)	96 (19)	108 (7)	102 (3)	106 (12)	105 (8)
Esfenvalerate	77 (5)	100 (3)	122 (3)	100 (19)	103 (7)	108 (3)	107 (13)	106 (8)
Deltamethrin	71 (10)	107 (7)	**124** (5)	102 (18)	100 (14)	87 (4)	96 (12)	96 (15)

pesticides from both types of samples. The first application of such method to the extraction of 10 samples of this type (first data reported concerning cherimoya analysis) revealed the presence of two pesticides, propoxur and propyzamide, in some of the studied samples but below the LCL set at 5 μg/kg. Whenever possible, the application of the ammonium formate version should be suitably studied and applied since it is clearly advantageous from different points of view.

CRediT authorship contribution statement

Diana Angélica Varela-Martínez: Validation, Formal analysis, Investigation, Resources, Data curation, Funding acquisition. **Miguel Ángel González-Curbelo:** Conceptualization, Methodology, Formal analysis, Resources, Data curation, Writing - original draft, Writing - review & editing, Supervision, Project administration, Funding acquisition. **Javier González-Sálamo:** Formal analysis, Data curation, Writing - original draft, Writing - review & editing, Visualization. **Javier Hernández-Borges:** Conceptualization, Methodology, Writing - original draft, Writing - review & editing, Supervision.

Declaration of competing interest

Authors declare no conflict of interest.

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Supplementary materials

Supplementary material associated with this article can be found, in the online version, at doi:10.1016/j.microc.2020.104950.

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SUPPLEMENTARY MATERIAL

Analysis of pesticides in Cherimoya and Gulupa minor tropical fruits using AOAC 2007.1 and ammonium formate QuEChERS versions: A comparative study

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Table S1.- Retention times. quantifier and qualifier transitions in GC-QqQ-MS/MS analyses of the selected pesticides.

Analyte	Retention time (min)	Quantifier transition (m/z)	Colision energy (V)	Qualifier transition (m/z)	Colision energy (V)	Qualifier transition (m/z)	Colision energy (V)
Propoxur	5.60	110.00→64.00	20	152.00→110.00	10	110.00→82.00	15
Carbofuran	6.44	164.00→149.00	10	149.00→103.00	15	-	15
Diphenylamine	8.91	168.00→167.00	10	169.00→168.00	5	169.00→167.00	5
Chlorpropham	9.11	213.00→171.00	5	213.00→127.00	15	127.00→90.00	15
Dicloran	9.95	206.00→176.00	10	124.00→97.00	10	176.00→124.00	10
Atrazine-d_5	10.05	205.00→127.00	10	220.00→178.00	5	205.00→178.00	5
Atrazine	10.08	215.00→173.00	5	215.00→200.00	10	200.00→173.00	10
Lindane	10.39	183.00→181.00	5	219.00→181.00	10	181.00→109.00	25
Propyzamide	10.08	175.00→173.00	15	175.00→173.00	5	173.00→109.00	10
β-HCH	10.39	183.00→147.00	15	183.00→145.00	20	183.00→111.00	35
Α-HCH	10.39	181.00→145.00	15	219.00→181.00	5	181.00→74.00	35
Chlorpyrifos-methyl	11.72	288.00→286.00	5	286.00→93.00	25	286.00→125.00	25
Parathion-methyl	11.87	263.00→109.00	15	109.00→79.00	10	263.00→125.00	10
Alachlor	11.90	188.00→160.00	10	160.00→132.00	15	188.00→146.00	10
Tolclofos-methyl	11.91	265.00→250.00	15	267.00→265.00	5	265.00→125.00	5
Metalaxyl	12.07	206.00→132.00	20	160.00→146.00	10	206.00→160.00	15
Pirimiphos-methyl	12.43	290.00→233.00	10	305.00→290.00	10	290.00→276.00	10
Fenitrothion	12.53	277.00→260.00	5	277.00→109.00	20	125.00→109.00	15
Malathion	12.73	127.00→99.00	5	173.00→127.00	5	125.00→93.00	5
Chlorpyrifos	12.98	314.00→258.00	15	199.00→171.00	15	197.00→97.00	15
Fenthion	13.08	278.00→109.00	20	278.00→169.00	20	278.00→245.00	10
Triadimefon	13.29	208.00→181.00	10	208.00→128.00	15	128.00→85.00	10

Table S1.- (Continued).

Analyte	Retention time (min)	Quantifier transition (m/z)	Colision energy (V)	Qualifier transition (m/z)	Colision energy (V)	Qualifier transition (m/z)	Colision energy (V)
Aldrin	13.17	263.00→193.00	25	263.00→193.00	30	263.00→228.00	25
Pirimiphos-ethyl	13.57	333.00→168.00	25	333.00→318.00	10	318.00→180.00	10
Heptachlor	14.38	274.00→239.00	15	274.00→141.00	30	100.00→65.00	5
Penconazole	14.13	161.00→159.00	5	248.00→159.00	25	248.00→161.00	5
Triflumizole	14.25	278.00→206.00	5	278.00→206.00	20	278.00→179.00	5
Methidathion	14.86	145.00→85.00	10	145.00→58.00	15	145.00→93.00	10
Heptachlor *cis*	14.39	253.00→219.00	35	253.00→219.00	15	253.00→205.00	20
Heptachlor *trans*	14.39	183.00→147.00	25	353.00→220.00	35	183.00→147.00	20
Fenamiphos	15.52	303.00→288.00	10	303.00→154.00	20	303.00→217.00	10
Endosulfan A	15.39	241.00→206.00	20	241.00→204.00	15	206.00→170.00	25
Myclobutanil	16.15	179.00→125.00	15	179.00→150.00	10	179.00→82.00	10
Dieldrin	16.24	263.00→191.00	30	263.00→193.00	30	263.00→81.00	35
Oxyfluorfen	16.21	252.00→223.00	15	252.00→223.00	15	300.00→252.00	15
Buprofezin	16.27	172.00→57.00	20	175.00→172.00	5	105.00→83.00	10
Endrin	16.24	263.00→228.00	5	263.00→81.00	35	263.00→228.00	20
Ethion	16.15	153.00→125.00	10	153.00→125.00	5	231.00→153.00	5
DDE	16.05	246.00→176.00	25	210.00→176.00	35	246.00→210.00	35
DDD	15.38	235.00→200.00	5	235.00→200.00	30	165.00→147.00	15
Propiconazole	17.86	175.00→173.00	5	259.00→69.00	10	259.00→173.00	10
Tebuconazole	18.13	250.00→125.00	20	250.00→70.00	10	125.00→70.00	10
Tryphenyl phosphate	18.19	326.00→325.00	5	326.00→169.00	25	326.00→215.00	25
Iprodione	18.52	314.00→56.00	25	314.00→187.00	5	314.00→245.00	5

Table S1.- (Continued).

Analyte	Retention time (min)	Quantifier transition (m/z)	Colision energy (V)	Qualifier transition (m/z)	Colision energy (V)	Qualifier transition (m/z)	Colision energy (V)
EPN	18.66	185.00→157.00	5	169.00→157.00	5	157.00→141.00	10
Pyriproxyfen	19.31	136.00→78.00	20	136.00→96.00	15	136.00→78.00	15
DDT	17.16	235.00→165.00	15	200.00→165.00	5	235.00→163.00	20
Fenvalerate	22.21	167.00→125.00	10	181.00→152.00	25	225.00→125.00	40
Esfenvalerate	22.51	167.00→125.00	10	225.00→167.00	20	225.00→181.00	20
Deltamethrin	23.05	253.00→172.00	10	253.00→174.00	10	253.00→181.00	10

Table 2S.- Pesticides content of several minor tropical fruit samples bought in Bogotá and analysed by the proposed QuEChERS-GC-QqQ-MS/MS method.

Fruits	Sample	Date of collection	Pesticides detected	Concentration (µg/kg)
Gulupa	1	Aug-2019	-	-
	2	Aug-2019	Propoxur	< LCL
	3	Aug-2019	-	-
	4	Aug-2019	-	-
	5	Aug-2019	-	-
	6	Aug-2019	-	-
	7	Aug-2019	Propoxur	< LCL
	8	Aug-2019	-	-
	9	Aug-2019	-	-
	10	Aug-2019	-	-
Cherimoya	1	Aug-2019	-	-
	2	Aug-2019	-	-
	3	Aug-2019	-	-
	4	Aug-2019	-	-
	5	Aug-2019	-	-
	6	Aug-2019	Propizamide	< LCL
	7	Aug-2019	-	-
	8	Aug-2019	-	-
	9	Aug-2019	-	-
	10	Aug-2019	-	-

(-) Pesticides were not detected.

CHAPTER V

GENERAL CONCLUSIONS

V.- GENERAL CONCLUSIONS

From all the results obtained in the present PhD Thesis, the following general conclusions can be drawn:

-The analytical methodologies developed in this PhD Thesis, which are based on the application of different modified versions of the QuEChERS method, together with GC-MS/MS as determination technique, could be applied with success for the analysis of a wide range of multiclass pesticide residues in fresh and dried agri-food products from Colombia, especially, in minor tropical fruits.

-The AOAC 2007.01 and ammonium formate QuEChERS versions provided better performance in terms of lower co-extractive materials, matrix effects, extraction efficiency and precision than the original and the CEN 15662 methods. In particular, the application of the ammonium formate version is clearly advantageous from different points of view (it does not contaminate the detection system and it increases analytes ionization) and should be properly studied and applied, whenever possible.

-The studied clean-up sorbents were found to be highly effective for their application on the selected minor tropical fruits, since they were able to minimize the amount of co-extractive materials, particularly pigments, maintaining acceptable recovery values and enhancing precision.

-The results of the validation of the developed multiresidue methodologies through calibration, recovery, and repeatability studies, revealed that they could be perfectly applied to the analysis of most of the selected groups of pesticides and matrices. The existence of matrix effects was evidenced for the majority of the pesticide/matrix combinations studied, which was clearly reduced using atrazine-d_5 as surrogate IS, matrix-matched calibration, and the use of a proper mixture of analyte protectants.

-The evaluation of matrix effects is extremely important when MS detection is applied and when complex samples like food are analysed. Minor tropical fruits are not oblivious to this issue, in particular, when different versions of the QuEChERS method are applied.

-The development of an adequate instrumental GC-MS/MS method, together with the different QuEChERS versions employed, allowed reaching LOQs in accordance with the agreed limit set at 10 µg/kg for monitoring purposes in food applications.

-The application of the developed methodologies to the analysis of 77 real samples (i.e. rose apple/pomarrosa (6), starfruit/carambola (5), yoyomo (6), papayuela (5), dried strawberry (3), dried blackberry (3), dried passion fruit (3), dried pineapple (3), dried grapes (3), dried uchuva (5), dried lulo (5), dried guanabana (5), dried pitahaya (5), gulupa (10) and cherimoya (10)), revealed the presence of pesticide residues in some of them, but mostly below the LCLs of the method (5 µg/kg). This data clearly indicates that, concerning the pesticides selected, their consumption is safe, though there are still other pesticides that could be analysed, in particular, non-volatile ones, for which LC-MS/MS is required.

-Particular attention should be paid to the application of pesticide multiresidue analytical methods to other minor tropical fruits, since there is still a good number of them for which no analytical methods have been applied as a result of their low commercial value, low amounts of exports or reduced consumption.

GLOSSARY

GLOSSARY

ACN	Acetonitrile
AcOH	Acetic acid
APCI	Atmospheric pressure chemical ionization
C_{18}	Octadecylsilane
CAS	Chemical Abstract Service
CE	Capillary electrophoresis
CEC	Capillary electrochromatography
CE-MS	Capillary electrophoresis mass spectrometry
CE-MS/MS	Capillary electrophoresis tandem mass spectrometry
CEN	European Committee for Standardization
CIPS	Cold induced aqueous acetonitrile phase separation
CIT	Citrinin
CLC	Capillary liquid chromatography
CZE	Capillary zone electrophoresis
DAD	Diode array detector
DANE	National Administrative Department of Statistics
DDD	Dichlorodiphenyldichloroethane
DDE	Dichlorodiphenyldichloroethylene
DLLME	Dispersive liquid-liquid microextraction
dSPE	Dispersive solid-phase extraction
ECD	Electron capture detector
ECs	Emerging contaminants
ECC	Emergent contaminants of concern
ED	Electrochemical detector
EPA	Environmental Protection Agency

Glossary

ESI	Electrospray ionisation
FAO	Food and Agriculture Organization
FD	Fluorescence detector
FID	Flame ionisation detector
FLD	Fluorescence detector
FPD	Flame photometric detector
FR	Flame retardants
GC	Gas chromatography
GCB	Graphitised carbon black
GCxGC	Two-dimensional gas chromatography
GC-MS	Gas chromatography mass spectrometry
GC-MS/MS	Gas chromatography tandem mass spectrometry
HCB	Hexachlorobenzene
HCH	Hexachlorocyclohexane
HILIC	Hydrophobic interaction liquid chromatography
HLB	Hydrophilic lipophilic balance
HOAc	Acetic acid
HPLC	High-performance liquid chromatography
IS	Internal standard
IC	Ion chromatography
IT	Ion trap
ITSP	Instrument top sample preparation
LC	Liquid chromatography
LCXLC	Two-dimensional liquid chromatography
LC-MS	Liquid chromatography-mass spectrometry
LC-MS/MS	Liquid chromatography tandem mass spectrometry
LCL	Lowest calibration level

Glossary

LOD	Limit of detection
LOQ	Limit of quantification
LDS	Quinoid niclosamide
LP	Low pressure
NPD	Nitrogen phosphorus detector
m-dSPE	Magnetic-dispersive solid-phase extraction
MD	Multidimensional
MD-GC	Multidimensional gas chromatography
MD-LC	Multidimensional liquid chromatography
MECN	Acetonitrile
MEKC	Micellar electrokinetic chromatography
MeOH	Methanol
MM	Molecular mass
MRL	Maximum residue limit
MRM	Multiple reaction monitoring
MS	Mass spectrometry
MS/MS	Tandem mass spectrometry
MSPD	Matrix solid-phase dispersion
MWCNTs	Multiwalled carbon nanotubes
NaOAC	Sodium acetate
NIST	National Institute for Standards and Technology
OCPs	Organochlorine pesticides
ONPs	Organonitrogen pesticides
OPPs	Organophosphate pesticides
OTA	Ochratoxin A
PAHs	Polycyclic aromatic hydrocarbons
PBDE	Polybrominated diphenyl ethers

Glossary

PBT	Persistent bioaccumulative and toxic chemicals
PCBs	Polychlorinated biphenyls
PCDD/Fs	Polychlorinated dibenzodioxins and dibenzofurans
PFAS	Perfluoroalkyl substances
PP	Polypropylene
PPCPs	Personal care products
PSA	Primary secondary amine
PTFE	Polytetrafluoroethylene
PTV	Programmable temperature vaporizer
Q	Single quadrupole
QqQ	Triple quadrupole
Q-TOF	Quadrupole-time-of-flight
QuEChERS	Quick, Easy, Cheap, Effective, Rugged and Safe
QuPPE	Quick polar pesticides method
R^2	Determination coefficient
rpm	Revolutions per minute
RP	Reversed-phase
RPLC	Reversed-phase liquid chromatography
RSD	Relative standard deviation
SAM	Standard addition method
SFC	Supercritical fluid chromatography
SIM	Selected ion monitoring
SLE	Solid-liquid extraction
SPE	Solid-phase extraction
SPME	Solid phase microextraction
TOF	Time-of-flight
UHPLC	Ultra-high-performance liquid chromatography

Glossary

UV	Ultraviolet
Vis	Visible
WHO	World Health Organization

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