Published in final edited form as:
Environ Monit Assess. 2017 June ; 189(6): 303. doi:10.1007/s10661-017-6009-0.

Presence of pesticide residues on produce cultivated in Suriname

F. Abdoel Wahid,
Department of Global Environmental Health Sciences, Tulane University School of Public Health and Tropical Medicine, 1440 Canal Street, Suite 2100, New Orleans, LA 70112, USA

J. Wickliffe,
Department of Global Environmental Health Sciences, Tulane University School of Public Health and Tropical Medicine, 1440 Canal Street, Suite 2100, New Orleans, LA 70112, USA

M. Wilson,
Department of Global Environmental Health Sciences, Tulane University School of Public Health and Tropical Medicine, 1440 Canal Street, Suite 2100, New Orleans, LA 70112, USA

A. Van Sauers,
Ministry of Agriculture, Livestock, and Fisheries, Paramaribo, Suriname

N. Bond,
Agricultural & Environmental Services Laboratory, University of Georgia, 2300 College Station Road, Athens, GA 30605, USA

W. Hawkins,
Department of Global Environmental Health Sciences, Tulane University School of Public Health and Tropical Medicine, 1440 Canal Street, Suite 2100, New Orleans, LA 70112, USA

D. Mans, and
Faculty of Medical Sciences, Anton de Kom University of Suriname, Kernkampweg 5, Paramaribo, Suriname

M. Lichtveld
Department of Global Environmental Health Sciences, Tulane University School of Public Health and Tropical Medicine, 1440 Canal Street, Suite 2100, New Orleans, LA 70112, USA

Abstract

Agricultural pesticides are widely used in Suriname, an upper middle-income Caribbean country located in South America. Suriname imported 1.8 million kg of agricultural pesticides in 2015. So far, however, national monitoring of pesticides in crops is absent. Reports from the Netherlands on imported Surinamese produce from 2010 to 2015 consistently showed that samples exceeded plant-specific pesticide maximum residue limits (MRLs) of the European Union (EU). Consumption of produce containing unsafe levels of pesticide residues can cause neurological

---

Correspondence to: F. Abdoel Wahid.

Compliance with ethical standards
Conflict of interest The authors declare that they have no conflict of interest.

disorders, and particularly, pregnant women and children may be vulnerable. This pilot study assessed the presence of pesticide residues in commonly consumed produce items cultivated in Suriname. Thirty-two insecticides (organophosphates, organochlorines, carbamates, and pyrethroids) and 12 fungicides were evaluated for their levels in nine types of produce. Pesticide residue levels exceeding MRLs in this study regarded cypermethrin (0.32 μg/g) in tomatoes (USA MRL 0.20 μg/g), lambda-cyhalothrin (1.08 μg/g) in Chinese cabbage (USA MRL 0.40 μg/g), endosulfan (0.07 μg/g) in tannia (EU MRL 0.05 μg/g), and lindane (0.02 and 0.03 μg/g, respectively) in tannia (EU MRL 0.01 μg/g). While only a few pesticide residues were detected in this small pilot study, these residues included two widely banned pesticides (endosulfan and lindane). There is a need to address environmental policy gaps. A more comprehensive sampling and analysis of produce from Suriname is warranted to better understand the scope of the problem. Preliminary assessments, using intake rate, hazard quotient, and level of concern showed that it is unlikely that daily consumption of tannia leads to adverse health effects.

Keywords

Pesticides; Agricultural crops; Pesticide residues; Environmental monitoring; Food safety; Health policy

Introduction

The agricultural application of pesticides not only increases crop yield but can also result in the presence of pesticide residues in produce items, potentially hampering food safety (Carvalho 2006). Some pesticides are considered persistent organic pollutants (POPs), as they remain in the environment for many years where they bio-accumulate and travel long distances by wind and water (US EPA 2009; Weber et al. 2010). The global environmental consequences of POPs are recognized and internationally regulated by the Stockholm Convention (Stockholm Convention 2015).

Agriculture is an important and rising sector in the Republic of Suriname, an upper middle income Caribbean country located in South America. It contributes for about 9% to Suriname's gross domestic product, employs 17% of the population, and supplies, among others, rice, the country's most important staple food, (Derlagen et al. 2013; Ministry of Agriculture, Animal Husbandry and Fisheries 2013). In 2013, 444,625 t of crops were produced, an increase of 34.6% compared to 2008 (Ministry of Agriculture, Animal Husbandry and Fisheries 2015b). Among the most cultivated produce items are tannia *Xanthosoma brasiliense* (Desf.) Engl. (Arecaceae), the most cultivated leafy vegetable; head cabbage *Brassica oleracea* L. (Brassicaceae) and the Chinese cultivar *Brassica rapa chinensis* L. (the most cultivated *Brassica* vegetables); habanero pepper *Capsicum chinense* Jacq. (Solanaceae); and yard-long beans *Vigna unguiculata* (L.) Walp. (Fabaceae) (Ministry of Agriculture, Animal Husbandry and Fisheries 2015a). While agriculture is an increasingly important sector in Suriname, national pesticide policies and laws are not keeping up. The Pesticide Ordinance—enacted in 1972 and amended in 2005—regulates the use of pesticides to some extent, but control and enforcement mechanisms are not incorporated (De Nationale Assemblee van de Republiek Suriname n.d.). The amount of imported pesticides has been increasing from 1993. The average amount of pesticides imported (1993–2013) was 1,080,901 kg per year, and primarily consisted of herbicides (34.5%), fungicides (19.2%), and insecticides (16.4%) (Ministry of Agriculture, Animal Husbandry and Fisheries 2014). Recent figures show a peak import in 2015 of 1.8 million kg of agricultural pesticides (Ministry of Agriculture, Animal Husbandry and Fisheries 2016). So far, there is no capacity to conduct laboratory analysis of pesticide residues in crops (Ministry of Agriculture, Animal Husbandry and Fisheries 2013). Existing legislation and policy documents also do not include national monitoring of pesticide residues in crops or establishment/adoption of maximum residue limits (MRLs) (De Nationale Assemblee van de Republiek Suriname n.d.). MRLs are maximum concentrations of pesticide residues that are permitted in agricultural commodities and are based on Good Agricultural Practices (GAP) (FAO and WHO 2009). MRLs meet health safety standards, and there is a “reasonable certainty of no harm” when consuming produce items that comply with the respective MRLs (FAO n.d.; US EPA 2016a). As part of an occupational health risk assessment, a limited pesticide residue analysis of Surinamese crops conducted in 2010 in the district of Commewijne showed the presence of the fungicide chlorothalonil and the neonicotinoid insecticide imidacloprid in four selected produce items (yard-long beans, African eggplant, aubergine, and pepper) (Mahabali and Spanoghe 2015). Thirty percent of the 20 samples contained residue values that exceeded MRLs from the European Union (EU). The residues regarded imidacloprid in mostly yard-long beans. Screening data from the Dutch Food and Consumer Product Safety Authority (NVWA) on imported Surinamese produce from 2010 to 2015 consistently showed that samples exceeded plant-specific pesticide MRLs of the EU (NVWA 2012, 2013, 2014b, 2015). More detailed data over 2011–2013 from the NVWA on imported crops from Suriname showed that 60.6% of the 99 samples tested were positive for at least one pesticide below the MRL and that 21.2% of them had residues exceeding the EU MRLs (NVWA 2014a). Samples taken by the NVWA included eggplant, okra, pepper, and produce items belonging to the categories “beans with pods,” “other cucurbits with edible peel, “ and “other spinach and similar leaves. “ The pesticides that were detected included the neonicotinoids, imidacloprid, and acetamiprid, the fungicides chlorothalonil and carbendazim, as well as the pyrethroids cypermethrin and lambda-cyhalothrin. Residues with values exceeding the EU MRLs were mainly chlorothalonil, lambda-cyhalothrin, and acetamiprid. The highest proportion of samples exceeding the EU MRL concerned the group “other spinach and similar leaves” (the most cultivated leafy vegetable in Suriname *X. brasiliense* belongs to this category).

To date, no research has been conducted in Suriname to examine the association of pesticide exposure and adverse health effects. However, chronic low-level pesticide exposures, including those associated with food intake, have been associated with neurological effects such as depression and neurodegenerative disease in adults (Beard et al. 2014; London et al. 2012). Pesticide exposures have been linked to fetal growth decrements and preterm birth, and there is mounting evidence that exposure to pesticides during pre- and post-natal development is associated with neurodevelopmental deficits in young children (Burns et al. 2013; Harley et al. 2011). Evaluating exposure pathways is critical in assessing possible public health consequences (CDC 2005). The application of agricultural pesticides in Suriname potentially meets the criteria for a completed exposure pathway including applied pesticides (source), air/soil/water (environmental media), crops containing pesticide residues (exposure point), food consumption (exposure route), and pregnant women (susceptible population). Taking into account the quantities of imported pesticides in Suriname, the results from the study conducted in Commewijne, and the Dutch pesticide residue screening data, it is important to assess crop items produced in Suriname for possible presence of pesticide residues. This paper reports on the initial data obtained on pesticide residues in selected Surinamese produce and determines levels of concern as well as intake rates of produce at which adverse health effects may occur after chronic exposure. The environmental data are integral to a more comprehensive exposure characterization strategy as a component of a 5-year linked research and research training environmental epidemiological cohort study in Suriname (NIH-funded—U01 TW010087-01; U2R TW010104-01), focused on examining the association between neurotoxicant exposure (specifically pesticides and metals, including Hg) to birth outcomes and child neurodevelopmental trajectories in 1000 mother/child dyads.

Materials and methods

Study area

This study was conducted in the districts of Paramaribo and Wanica of Suriname. The country has a surface area of about 165,000 km^2 (64,000 mile^2) and a population of 541,638 (ABS 2013) people. These districts are the most densely populated areas and account for two thirds of the country's total population (ABS 2013). Suriname's climate is tropical with annually two rainy seasons (the short rainy and the long rainy season) and two dry seasons (the short dry and the long dry season). There is an abundance of rainfall, with an average annual precipitation of 2210 mm in Paramaribo (NIMOS 2013).

Study design

The assessment of the presence of pesticide residues was conducted in two phases and included spatial and seasonal sampling. Phase I entailed an initial pesticide analysis of selected produce items and was conducted in Paramaribo during the short rainy season of 2014. In phase II, selected produce items were tested against an expanded pesticide panel in Paramaribo and Wanica during the long dry season of the same year. The spatial sampling entailed the collection of produce items from fresh markets located in two districts in Suriname (Paramaribo and Wanica).

Selection of produce items

Based on World Health Organization (WHO) and EU classifications of produce items, crops were categorized in this study as leafy vegetables, *Brassica* vegetables, legume vegetables, fruiting vegetables, cereal grains, root/tuber vegetables, and fruits (EU 2016; WHO 2016). The selection of produce items was based on production rates, since no national consumption data were available (Ministry of Agriculture, Animal Husbandry and Fisheries 2015b). The production rates in tons (1000 kg) are presented in Tables 1 and 2.

The production rates of different vegetables cultivated in Suriname over the year 2011 are shown in Table 2.

The sampling of the produce items was conducted according to a protocol that was based on the standard operating procedures for sampling of the US Department of Agriculture (USDA), the Food and Agriculture Organization (FAO), and the Canadian Food Inspection Agency (CFIA) (Canadian Food Inspection Agency 2012; FAO 1999; USDA 2016). The primary goal of the protocol was to maintain the integrity of the products and to prevent cross-contamination of the different samples. Sampling of the produce items was conducted at selected fresh markets in Suriname. For each produce item, one stall was selected by a trained field researcher for collection of a sample. The stalls that were close to hand were sampled (convenience sampling). The produce itself was grab sampled; all the material needed was collected at one point in time. Samples were taken from various locations (top, middle, and bottom) of the lot. According to the sampling protocol, the sample quantity of each produce item consisted of least 2 kg of edible portion of that item or the amount that fitted in a 1-gallon bag. Logistical barriers related to transporting biota samples to the USA for residue analysis limited the number of samples (Suriname does not have the capacity to conduct the laboratory analysis of pesticide residues) per selected produce item.

In phase I, seven types of produce were collected from the largest fresh market in Paramaribo, the Centrale Markt, during the rainy season (Table 3). One sample per selected produce item was collected at this market.

In phase II, a second round of sampling was conducted in the dry season. In this round of sampling, the focus was placed on only vegetable items (Table 4).

The crop items were sampled at the two largest markets in phase II, the Centrale Markt in the district of Paramaribo and Covezomag in the district of Wanica. One sample per selected produce item was collected at each of these markets. The leafy vegetable in highest production, tannia (called tayerblad in Suriname), was also sampled at three additional markets in the district of Paramaribo, viz. Saoena Markt, Kwatta Markt, and Markt Zuid. One sample of tannia was collected at each of these three markets.

Pesticide panel

The selection of pesticides for residue testing of the crop items was based on import data of pesticides and was extended by the existing pesticide-screening panel used by the Agricultural and Environmental Services Laboratory of The University of Georgia (UGA) in Athens, Georgia. The total amounts of the top 10 most imported pesticides from 2009 to 2103 are shown in Table 5.

In phase I, the samples were tested for the 44 pesticides belonging to the panel of this laboratory. In phase II, two insecticides and one fungicide were added to this pesticide panel. This addition was based on pesticides used in Suriname that were not part of the standard screening panel of this laboratory. The pesticide panel is displayed in Table 6.

Laboratory analysis

The samples collected from phases I and II were extracted and chemically analyzed using US Environmental Protection Agency (USEPA) and USDA approved methods by the Agricultural and Environmental Services Laboratory of the UGA.

Sample receipt and storage

All samples were shipped from Paramaribo to the laboratory of the UGA via Micro Macro International Analytical Laboratory (Animal and Plant Health Inspection Service plant import permit no. PDEP-13-00057) and arrived within 5 days and were transferred to the AESL analytic laboratory at a suitable temperature (<6 °C, all cases). There was no indication of contamination during shipment noted and none of the samples showed visible signs of degradation. The samples were logged in and stored at −20 ± 4 °C until analysis.

Sample extraction

Samples of chopped tannia, head cabbage, Chinese cabbage, yard-long beans, habanero pepper, sweet potatoes, banana, and tomatoes were individually analyzed in triplicate by blending the chopped sample with 20 g Na_2SO_4 and 100 mL ethyl acetate. The extract was filtered through a glass fiber filter, and the filter cake together with the glass fiber filter were extracted a second time. The combined filtrates were concentrated to near dryness using a rotary evaporator under reduced pressure, and the residue was made up in ethyl acetate for gel permeation chromatography (GPC) cleanup. These procedures were conducted according to the Methods 302 and 303 of the *US FDA Pesticide Analytical Manual Vol. 1 3rd Edition 1994* (US FDA 1999). The samples of rice were individually and in triplicate Soxhlet-extracted with 200 mL ethyl acetate plus 20 g Na_2SO_4 for 4 to 6 h. The extract was concentrated to near dryness using a rotary evaporator under reduced pressure, and the residue was made up in GPC solvent (25% toluene/75% ethyl acetate) for cleanup (US FDA 1999).

Gel permeation sample cleanup

Samples were cleaned up by GPC using Bio-Beads S-X3 resin (200–400 mesh) and 25% toluene/75% ethyl acetate as mobile phase. The eluting mobile phase was selected since it produced better separation of pesticides and natural products in the leafy and *Brassica* vegetables than the chlorinated solvents. The GPC extract was again concentrated to near dryness using a rotary evaporator under reduced pressure, and the residue was made up in 5 mL ethyl acetate for gas liquid chromatography (GLC) analysis according to EPA’s Method 8081B (US EPA 2016b).

Gas liquid Chromatography analysis

Chlorinated and pyrethroid insecticides were analyzed using the Agilent 7890A GLC system equipped with an auto sampler, a Ni_{63} detector, a Thermo Scientific TG-1701MS column (30 m × 0.25 mm × 0.25 μm) with a temperature program of 1 min initial hold at 135 °C followed by a temperature ramp from 135 °C to 275 °C at 5 °C/min and a final hold of 10 min. A second column confirmation was achieved using the same GLC with the Agilent DB-35 column (30 m × 0.25 mm × 0.25 μm), a Ni_{63} detector, and using a similar temperature program. Authentic mixed or individual standards containing all reported pesticides and a reagent blank were analyzed daily with each group of samples (US EPA 2016b) The organophosphate screen was conducted using the Agilent 7890 B GLC system equipped with an NP detector, a DB-35 capillary column (30 m × 0.25 mm × 0.25 μm) with a temperature program of 1 min initial hold at 135 °C followed by a temperature ramp from

135 to 275 °C at 5 °C/min and a final hold of 10 min. Authentic mixed or individual standards containing all reported pesticides as well as a reagent blank were analyzed daily with each group of samples (US EPA 2016b).

Confirmation by gas chromatography-mass spectrometry

Pesticides tentatively identified as positive in the initial screen we confirmed by gas chromatography-mass spectrometry (GC-MS) using the HP 5890 Series II GLC with the HP6970 MSD equipped with an Agilent DB-5MS column (30 m × 0.25 mm × 0.25 μm) with the following operating parameters: inlet temperature 250 °C, splitless, 1 mL volume, detector 300 °C, and 50–500 m^2 scan. The oven temperature program was 50 °C initial hold, 50–100 °C at 25 °C/min, 100–300 °C at 5 °C/min, and a final hold at 300 °C for 5 min.

Data analysis

Data analysis was done using the Agilent Open LAB data system (Program Revision A. 01.01 Nov. 2012). Initial positive identification was based on comparable retention times (±0.5%) to known authentic standards that run daily on the same instrument. If the retention times matched on two columns, then the residue scan was considered positive, and further confirmation was attempted by gas liquid chromatography-mass spectrometry (GLC-MS). All chromatograms were reviewed and spot-checked for accuracy. The average recoveries were 84.3% for the organophosphates, 92.5% for the chlorinated pesticides, and 104.8% for the synthetic pyrethroids. All recoveries were >70% with the exception of phosdrin which was 67.9%. Fortification standards were one or a combination of the following compounds: lindane, dieldrin, mirex, endosulfan II, bifenthrin, permethrin, cypermethrin, pydrin, lambda cyhalothrin, dimethoate, phosdrin, terbufos, and bravo. These compounds served as surrogates for the other compounds in their class. Values were reported on an as received basis and not corrected for percent recovery.

For GC-MS confirmation, the extract was concentrated to 1 mL and 1.0 μL was injected. If the fragmentation pattern matched, it was considered confirmed. Some residue levels were so low that they were not confirmed but reported as unconfirmed. All reported quantification was conducted on the GLC screens and not the GLC-MS scan.

All solvents used for pesticide extraction were pesticide-grade and obtained from JT Baker, Center Valley, PA. The Bio-Beads S-X3 (200–300 mesh) was purchased from Bio-Rad Laboratories, Richmond, CA. All pesticide standards were obtained from Accu Standard Inc., Haven, CT, as 100 ppm in suitable solvent and used within 1 month of receipt. Based on previous experience, mixed standards were prepared by dilution of the commercial standards.

Statistical analysis

The laboratory analysis of the produce samples was conducted in triplicate (three repetitions per produce sample). Laboratory results of individual repetitions included non-detects (NDs), essentially values that were below the limit of detection (LOD). The NDs did not necessarily have the value of zero, but could range from zero to the LOD. Therefore, for this study, the values of the NDs were not assumed to be zero but were chosen to be half of the value of the LOD (Hornung and Reed 1990; US EPA 1991). For each of the samples that were positive for a pesticide, the mean of the triplicates of that sample was calculated. It was evaluated whether the means of the triplicates were above or below the available MRLs. Comparisons were made with EU MRLs, USA MRLs, and WHO MRLs (EU 2016; Global MRL Database 2016; WHO 2016).

Determination of critical intake rates and level of concern

The following formula in deterministic non-cancer risk assessment was used for calculating intake rates and level of concern (US EPA 2017):

ADD	$(C \times IR)/BW$
ADD	Average daily dose
C	Concentration of the agent (mass/volume)
IR	Intake rate (mass/time)
BW	Body weight

The daily intake rates of tannia were calculated using the EU MRLs and the highest detected pesticide residue levels of endosulfan and lindane in this study. The intake rates were calculated using the USEPA's reference doses (RfDs) for endosulfan and lindane and a conservative adult body weight of 60 kg (IRIS US EPA 1987, 1994). The critical effects used in determining the RfD for endosulfan were reduced body weight gain in males and females, increased incidence of marked progressive glomerulonephrosis, and blood vessel aneurysms in males. For lindane, the critical effect in determining the RfD was the liver and kidney toxicities.

Hazard quotients (non-cancer risk assessments, LADD/RfD) were calculated using the USEPA's RfDs, a conservative adult body weight of 60 kg, the highest levels detected for endosulfan and lindane, and the total vegetable intake rate for the 95th percentile (as described in the USEPA exposure factors handbook for consumers over the ages 11 years and past 50 years) (US EPA 2017).

The chemical level of concern (LoC) was calculated using USEPA RfD for endosulfan and lindane, the conservative body weight of 60 kg, and the aforementioned total vegetable intake rate.

Results

Phase I pesticide residue analysis

Seven samples were collected at the Centrale Markt. One sample per selected produce item (tannia, head cabbage, yard-long beans, habanero pepper, rice, sweet potato, and bananas) was collected. Of the seven samples, one sample—that of tannia—tested positive for a pesticide residue. The tannia sample contained residues of the largely banned organochlorine insecticide endosulfan. The mean value of the triplicate was 0.07 ± 0.01 μg/g which slightly exceeds the EU MRL of 0.05 μg/g. There are no USA and WHO MRLs available for pesticide residues in tannia.

Phase II pesticide residue analysis

Fifteen samples were collected at the selected markets. Six samples were taken at the Centrale Markt and Covezomag, respectively. One sample per selected produce item (tannia, head cabbage, Chinese cabbage, yard-long beans, tomatoes, and sweet potato) was collected per market. In addition, single samples of tannia were collected at the Saoena Markt, Kwatta Markt, and Markt Zuid. Of the 15 samples, four samples (26.7%) contained detectable levels of at least one pesticide. These four samples regarded two samples of tannia and one sample of Chinese cabbage and tomatoes each. The detected pesticides were two organochlorines (endosulfan and lindane) and two pyrethroids (cypermethrin and lambda cyhalothrin). The mean values of the triplicates were 0.04 ± 0.03 μg/g endosulfan in tannia from Centrale Markt (EU MRL 0.05 μg/g), 0.02 ± 0.01 μg/g lindane in tannia from Centrale Markt (EU MRL 0.01 μg/g), 0.03 ± 0.02 μg/g lindane in tannia from Covezomag, 0.32 ± 0.20 μg/g cypermethrin in tomatoes from Centrale Markt (EU MRL 0.5 μg/g, USA and WHO MRL 0.20 μg/g), and 1.08 ± 0.71 μg/g lambda-cyhalothrin in Chinese cabbage from Covezomag (EU MRL 1.00 μg/g, USA MRL 0.40 μg/g). Table 7 shows these mean values of the pesticide residues including the available plant-specific MRLs of the USDA, the EU, and the WHO. All the produce samples with detectable pesticide levels had residues of at least one pesticide that exceeded at least one MRL.

At the Centrale Markt, two of the six samples (33.3%) had detectable levels of one or more pesticides. The samples were tannia and tomato. The tannia sample contained residues of endosulfan and lindane, as well as the tomato sample residues of cypermethrin. At Covezomag, two of the six samples (33.3%) had detectable levels of one pesticide. At this market, the samples were tannia and Chinese cabbage. The tannia sample contained residues of lindane, and the Chinese cabbage sample had residues of lambda cyhalothrin. Tannia samples collected at the Saoena Markt, Kwatta Markt, and Markt Zuid did not have detectable levels of pesticide residues.

Intake rates and level of concern

Daily intake rates of tannia above which adverse health effects may occur were determined (Table 8). The intake rates were calculated for tannia containing pesticide residue levels of endosulfan and lindane equaling the EU MRLs (0.05 and 0.01 mg/kg, respectively) and the highest detected pesticide residue levels of these two pesticides in this study (0.07 mg/kg for endosulfan and 0.03 mg/kg for lindane). The USEPA RfDs used for the calculations were 6.10^{-3} mg/kg per day for endosulfan and 3.10^{-4} mg/kg per day for lindane (IRIS US EPA 1987; IRIS US EPA 1994). The health risk of consuming tannia at the highest detected levels was determined using the hazard quotient (HQ) with an intake rate of 0.4 kg/day, adapted from the *USEPA Exposure Factors Handbook* (US EPA 2017). The HQ and the LoC are shown in Table 8.

The LoC for endosulfan in tannia is 14.3 times higher than the highest detected residue level for this pesticide in this study. For lindane in tannia, the LoC is 1.7 times higher than the highest detected lindane residue level in this study.

Discussion

The current study intends to assess the presence of pesticide residues of crop items produced in Suriname. Residues of endosulfan in tannia (0.07 and 0.04 μg/g, respectively), lindane in tannia (0.02 and 0.03 μg/g, respectively), cypermethrin in tomatoes (0.32 μg/g), and lambda-cyhalothrin in Chinese cabbage (1.08 μg/g) were detected. Pesticide residues that exceeded MRLs were endosulfan in tannia, lindane in tannia, cypermethrin in tomatoes, and lambda cyhalothrin in Chinese cabbage. Only endosulfan was detected in phase I and endosulfan, lindane, cypermethrin, and lambda cyhalothrin in phase II. While this pilot assessment is a first step in the stepwise process of ultimately examining any health risks that may result from the consumption of produce containing unsafe levels of pesticide residues, a much more comprehensive sampling and analysis of produce from Suriname needs to be conducted.

In this small pilot study, only a few pesticide residues were detected and quantified in selected produce items and only some of the pesticide residues exceeded widely used MRLs. Among the detected pesticide residues were endosulfan and lindane, two largely banned pesticides. Endosulfan and lindane are prohibited in Suriname and are listed under the Stockholm Convention to eliminate and/or control their use (Stockholm Convention 2015). Both pesticides are POPs which can be transported over long distances. The management of POPs is therefore not just of national concern, but of global concern. The import of both endosulfan and lindane is prohibited in Suriname. Lindane has not been imported since 1993 for agricultural purposes; however, it was imported for medical purposes (treatment of head lice) until 2006. Endosulfan has not been imported since 2003 (Van Sauers 2015). The presence of these pesticides in crops may be explained by their persistence in the environment and/or by the transport from remote places. Given the lack of monitoring and enforcement, other possible sources may be illegal entry of these chemicals into the country, the use of an old stock from farmers, or the import of permitted pesticides that are adulterated with prohibited pesticides. The latter possibility relates to the inability of the country to chemically identify pesticides. National screening of residues in crops or of the chemical constituents of imported pesticides is absent.

In both rounds of the pesticide residue analysis (phases I and II), pesticides were detected and identified. These pesticides were either organochlorines or pyrethroids. In phase II (dry season), endosulfan and other residues were detected. Seasonal variation may account for these differences, but a much more comprehensive sampling across seasons is needed to confirm this. It is possible that higher concentrations as well as different pesticide residues in products may be expected in the dry season, possibly because of less wash-off and/or increased application because of differences in pest levels.

The export of produce items that exceeds MRLs as set by the importing country can lead to fining and ultimately a loss of economic benefits. The value of an MRL is based on Good Agricultural Practices (GAP) (FAO 2008) and meets safety standards. While the economic ramifications of exceeding MRLs are clear, the public health implications cannot be inferred from relating pesticide residue levels with only MRLs.

The high daily intake rate of tannia required for the development of possible adverse health effects, even when the highest pesticide residue levels were used, does not make it likely that daily consumption of tannia poses a health risk. Indeed, the HQs of less than 1 showed that a health risk is not likely when consuming tannia daily with an assumed intake rate of 0.4 kg/day. These findings are also supported by the LoCs that are much higher than the highest detected residue levels of endosulfan and lindane in tannia.

Data regarding the use of pesticides in agriculture in Suriname are absent. Provided that farmers only have access to pesticides that are imported, the import data are a reasonable proxy for what is used for production. Therefore, the selection of pesticides for residue testing in this study was based on import data and on the composition of the pesticide panel of the analyzing laboratory. It is possible that the types of pesticides used for agricultural purposes are different from those that are imported, implying that certain pesticide residues in crops may have been overlooked because they were not part of the laboratory analysis. However, the pesticide panel of the UGA laboratory is broad, which was also illustrated by the identification of pesticides now banned for use in agriculture (i.e., endosulfan and lindane). Two of the most widely used herbicides, paraquat and glyphosate, were not of part of the UGA pesticide panel. Herbicides are used to kill weeds and are usually applied before cultivation of vegetables. They are not intentionally applied to crops, but may end up on them through spray misapplication or drift. However, it is not likely that these two herbicides are of much concern, because any produce exposed to such herbicides will either perish or look inedible. Also, not part of the UGA pesticide panel was the insecticide imidacloprid. Imidacloprid is among the most frequently imported insecticides in Suriname and its residues have been detected in prior screenings from the NVWA and the study conducted in district Commewijne by Mahabali and Spanoghe. The absence of imidacloprid in the pesticide panel may have led to an underestimation of the presence of pesticides in Surinamese produce. A more reliable picture of actual pesticide use in the different regions of Suriname could have been portrayed by using sales figures from shops selling pesticides. Unfortunately, these sale figures were not available. Important to note is that pesticides can be purchased at any local store and not just agricultural shops. The selection of produce items for pesticide residue testing was not based on actual consumption data but on production data (Ministry of Agriculture, Animal Husbandry and Fisheries 2015b). Nonetheless, crops in Suriname are cultivated not only for local use but also for export. There fore, ultimately assessing exposure among the consuming population by using production data may not precisely reflect the actual exposure in the Surinamese population. The sampling of the produce items was conducted at fresh produce markets. These fresh produce markets have numerous stalls. For each produce item, one stall was selected. This was not conducted at random but rather in a grab sampling scheme. The pesticide residue testing in this study did not take into account the effects of cleaning and processing the vegetables, since the samples were analyzed in the same state as they were purchased from the markets. Washing vegetables with water or soaking them in salt solutions, as well as processing those (e.g., peeling, blanching) may diminish the pesticide residue levels in such produce items (Bajwa and Sandhu 2014; Keikotlhaile et al. 2010). The total number of samples precludes generalizing the pesticide residue results for Suriname. For the same reason, any comparison of the pesticide residue levels (with MRLs or between seasons) is of limited value. Inaddition, comparing pesticide residue levels with MRLs depends on which MRLs have been adopted.

Conclusions

Agriculture is of economic importance to Suriname. However, there are gaps in policy and enforcement regarding the management of pesticides. There is no policy in place for the screening of produce items for pesticide residues, nor are there nationally set MRLs of pesticide concentrations in these items. The pesticide residue analysis indicated that even in a small pilot sample of selected produce, pesticide residues were detected and in a few cases the levels of those residues exceeded widely accepted MRLs. This includes organochlorine pesticides that have long been banned in Suriname for agricultural use. However, preliminary assessments showed that it is not likely that daily dietary exposure may lead to adverse health effects. As has been discussed, MRLs relate to GAP. Since both the screening data from the NVWA and the data from this study show that some produce items have pesticide residues higher than the MRLs, a detailed investigation of agricultural practices is warranted. Maintaining and expanding agriculture needs to go hand in hand with ensuring food safety, and therefore, the management of agricultural pesticides needs to be improved. There is a need for a pesticide monitoring plan and program for produce from Suriname. This pilot study clearly indicates a much more comprehensive sampling, and analysis of produce from Suriname is warranted. This entails that selecting produce items for residue analysis based on future dietary surveys, collecting more samples per selected produce item per market per season, further expand the pesticide panel with pesticides frequently imported and previously detected (such as imidacloprid), using regional sales figures of pesticides to select the pesticide panel and collecting samples, not only from fresh markets but also from the agricultural areas. In addition, a larger sample size would allow for examining statistically significant differences between detected pesticide residue levels and MRLs, as well as pesticide residue levels between fresh markets and between seasons. A more comprehensive sampling and analysis will allow producers, consumers, and leaders in agriculture and public health to better understand the scope of the problem. This would inform policy and resource needs and would be necessary to protect public health and the agricultural export economy of Suriname.

Acknowledgments

This research was funded by the Fogarty International Center of the National Institutes of Health under Award Numbers R24TW009570 and R24TW009561. We thank Micro Macro International Analytical Laboratory for assisting in the overseas transport of the samples, Dr. P. Bush for his leadership in the laboratory analysis, Ms. Carrie Williams from the Agricultural and Environmental Services Laboratory of The University of Georgia for the laboratory analysis, and Dr. A. Shankar for her advice on the statistical analysis.

References

ABS. Resultaten achtste volksen woningtelling in Suriname (volume 1) demografische en sociale karakteristieken en migratie. Paramaribo, Suriname: Algemeen Bureau voor de Statistiek—Suriname; 2013.

Bajwa U, Sandhu KS. Effect of handling and processing on pesticide residues in food—a review. Journal of Food Science and Technology. 2014; 51(2):201–220. DOI: 10.1007/s13197-011-0499-5 [PubMed: 24493878]

Beard JD, Umbach DM, Hoppin JA, Richards M, Alavanja MC, Blair A, Kamel F. Pesticide exposure and depression among male private pesticide applicators in the agricultural health study. Environmental Health Perspectives. 2014; 122(9):984–991. DOI: 10.1289/ehp.1307450 [PubMed: 24906048]

Burns CJ, et al. Pesticide exposure and neurodevelopmental outcomes: review of the epidemiologic and animal studies. Journal of Toxicology and Environmental Health Part B, Critical Reviews. 2013; 16(3–4):127–283. DOI: 10.1080/10937404.2013.783383

Canadian Food Inspection Agency. Procedures for sampling fresh fruit and vegetables. 2012. Retrieved from http://www.inspection.gc.ca/food/fresh-fruits-and-vegetables/food-safety/sampling-fresh-fruit-and-vegetables/eng/1353610539095/1353610619804

Carvalho FP. Agriculture, pesticides, food security and food safety. Environmental Science & Policy. 2006; 9(7–8):685–692. DOI: 10.1016/j.envsci.2006.08.002

CDC. ATSDR—PHA guidance manual—chapter 6: exposure evaluation: evaluating exposure pathways. 2005. Retrieved from http://www.atsdr.cdc.gov/hac/PHAManual/ch6.html#6.2

De Nationale Assemblee van de Republiek Suriname. Bestrijdingsmiddelenwet. n.d. Retrieved from http://www.dna.sr/wetgeving/surinaamse-wetten/geldende-teksten-tm-2005/bestrijdingsmiddelenwet/

Derlagen, C., et al. Agricultural sector support in Suriname. Rome: IDB/FAO; 2013.

EU. EU pesticides database. 2016. Retrieved from http://ec.europa.eu/food/plant/pesticides/eu-pesticides-database/public/?event=product.selection&language=EN

FAO. Recommended methods of sampling for the determination of pesticide residues for compliance with MRLs. Rome, Italy: FAO; 1999.

FAO. Good agricultural practices. 2008. Retrieved from http://www.fao.org/prods/gap/

FAO. Codex maximum residue limits for pesticides. n.d. Retrieved from http://www.fao.org/waicent/faostat/Pest-Residue/pest-e.htm

Sheffer, M., editor. FAO, & WHO. Principles and methods for the risk assessment of chemicals in food. Geneva, Switzerland: WHO; 2009.

Global MRL Database. Global MRL database. 2016. Retrieved from https://www.globalmrl.com/db#query

Harley KG, Huen K, Aguilar Schall R, Holland NT, Bradman A, Barr DB, Eskenazi B. Association of organophosphate pesticide exposure and par-aoxonase with birth outcome in Mexican-American women. PloS One. 2011; 6(8):e23923.doi: 10.1371/journal.pone.0023923 [PubMed: 21904599]

Hornung RW, Reed LD. Estimation of average concentration in the presence of nondetectable values. Applied Occupational and Environmental Hygiene. 1990; 5(1):46–51. DOI: 10.1080/1047322X.1990.10389587

IRIS US EPA. Gamma-hexachlorocyclohexane (gamma-HCH); CASRN 58-89-9. Washington DC, United States of America: U.S. Environmental Protection Agency; 1987.

IRIS US EPA. Endosulfan; CASRN 115-29-7. Washington DC: United States of America: U.S Environmental Protection Agency; 1994.

Keikotlhaile BM, et al. Effects of food processing on pesticide residues in fruits and vegetables: a meta-analysis approach. Food and Chemical Toxicology. 2010; 48(1):1–6. DOI: 10.1016/j.fct.2009.10.031 [PubMed: 19879312]

London L, Beseler C, Bouchard MF, Bellinger DC, Colosio C, Grandjean P, Stallones L. Neurobehavioral and neurodevelopmental effects of pesticide exposures. Neurotoxicology. 2012; 33(4):887–896. DOI: 10.1016/j.neuro.2012.01.004 [PubMed: 22269431]

Mahabali S, Spanoghe P. Risk assessment of pesticide usage by farmers in Commewijne, Suriname, South America: a pilot study for the Alkmaar and Tamanredjo regions. Environmental Monitoring and Assessment. 2015; 187(3):153.doi: 10.1007/s10661-015-4363-3 [PubMed: 25726027]

Ministry of Agriculture, Animal Husbandry and Fisheries. The national agricultural innovation of the republic of Suriname. Paramaribo, Suriname: Ministry of Agriculture, Animal Husbandry and Fisheries; 2013.

Ministry of Agriculture, Animal Husbandry and Fisheries. Bestrijdingsmiddelen import 1993–2013. 2014. Unpublished manuscript

Ministry of Agriculture, Animal Husbandry and Fisheries. Beplante arealen, productie en export van groenten. 2015a. Unpublished manuscript

Ministry of Agriculture, Animal Husbandry and Fisheries. Productie van landbouwgewassen. 2015b. Unpublished manuscript

Ministry of Agriculture, Animal Husbandry and Fisheries. Pesticides import data 2015. 2016. Unpublished manuscript

NIMOS. Second national communication to the United Nations framework convention on climate change. Paramaribo: Ministry of Labour, Technological Development and Environment; 2013.

NVWA. Residuen van gewasbeschermingsmiddelen op groente en fruit: Overzicht van uitkomsten NVWA-inspecties januari 2010–december 2011. Utrecht, the Netherlands: Nederlandse Voedsel en Waren Autoriteit Ministerie van Economische Zaken; 2012.

NVWA. Residuen van gewasbeschermingsmiddelen op groente en fruit: Overzicht van uitkomsten NVWA-inspecties juli 2011–juni 2013. Utrecht, the Netherlands: Nederlandse Voedsel en Waren Autoriteit Ministerie van Economische Zaken; 2013.

NVWA. Residuen van gewasbeschermingsmiddelen op groente en fruit: Overzicht van uitkomsten NVWA-inspecties januari 2011–juli 2013. 2014a. Unpublished manuscript

NVWA. Residuen van gewasbeschermingsmiddelen op groente en fruit: Overzicht van uitkomsten NVWA-inspecties januari 2012–december 2013. Utrecht, the Netherlands: Nederlandse Voedsel- en Warenautoriteit Ministerie van Economische Zaken; 2014b.

NVWA. Residuen van gewasbeschermingsmiddelen op groente en fruit: Overzicht van uitkomsten NVWA-inspecties juli 2012–juni 2014. Utrecht, the Netherlands: Nederlandse Voedsel- en Warenautoriteit Ministerie van Economische Zaken; 2014c.

NVWA. Residuen van gewasbeschermingsmiddelen op groente en fruit: Overzicht van uitkomsten NVWA-inspecties juli 2013–juni 2015. Utrecht, the Netherlands: Nederlandse Voedsel en Waren Autoriteit Ministerie van Economische Zaken; 2015.

Stockholm Convention. Text of the convention. 2015. Retrieved from http://chm.pops.int/TheConvention/Overview/TextoftheConvention/tabid/2232/Default.aspx

US EPA. Chemical concentration data near the detection limit. USA: U.S. Environmental Protection Agency; 1991.

US EPA. Persistent organic pollutants: a global issue, a global response. 2009. Retrieved from https://www.epa.gov/international-cooperation/persistent-organic-pollutants-global-issue-global-response

US EPA. Setting tolerances for pesticide residues in foods. 2016a. Retrieved from https://www.epa.gov/pesticide-tolerances/setting-tolerances-pesticide-residues-foods

US EPA. SW-846 test method 8081-B: organochlorine pesticides by gas chromatography. 2016b. Retrieved from https://www.epa.gov/hw-sw846/sw-846-test-method-8081b-organochlorine-pesticides-gas-chromatography

US EPA. Exposures factors handbook 2011 edition (final report). 2017. Retrieved from https://cfpub.epa.gov/ncea/risk/recordisplay.cfm?deid=236252

Makovi, CM., McMahon, BM., editors. US FDA. Pesticide analytical manual volume I. 3. USA: U.S. Department of Health and Human Services, Public Health Service Food and Drug Administration; 1999.

USDA. Sampling procedures for pesticide data program. USA: United States Department of Agriculture Agricultural Marketing Service; 2016.

Van Sauers, A. Endosulfan and lindane prohibition in Suriname. Abdoel Wahid, F., editor. Paramaribo, Suriname: 2015.

Weber J, Halsall CJ, Muir D, Teixeira C, Small J, Solomon K, Bidleman T. Endosulfan, a global pesticide: a review of its fate in the environment and occurrence in the arctic. The Science of the Total Environment. 2010; 408(15):2966–2984. DOI: 10.1016/j.scitotenv.2009.10.077 [PubMed: 19939436]

WHO. Codex alimentarius: commodities. 2016. Retrieved from http://www.fao.org/fao-who-codexalimentarius/standards/pestres/commodities/en/

Table 1

Production Surinamese produce items in tons (Ministry of Agriculture, Animal Husbandry and Fisheries 2015b)

Produce item	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**
Paddy	182,877	229,370	226,686	235,298	224,127	262,029
Corn	27	24	35	32	29	47
Roots and tubers	4119	4650	5121	4279	5783	9401
Peanuts (in pod)	17	27	32	26	38	33
Lentils (brown)	49	104	92	66	39	98
Other pods	16	36	37	24	25	68
Vegetables	12,518	12,344	13,717	13,791	11,435	18,695
Watermelon	1.228	1.582	2.103	1.514	1.219	1.615
Banana	88,724	82,267	94,272	85,017	92,391	85,584
Plantain	9384	14,493	12,330	13,025	18,622	23,426
Pineapple	300	300	425	350	336	432
Passion fruit	279	220	190	208	1288	1146
Papaya	277	393	346	262	264	660
Coconut	8508	9014	8709	4389	4090	12,509
Oranges	13,454	12,709	15,138	16,118	15,566	17,502
Grapefruit	1141	1252	1314	1544	1040	1171
Pomelo	1543	1253	1216	1386	1877	2496
Other citrus	2982	2755	2809	2524	1964	2701
Avocado	133	153	140	103	102	102
Mango	996	1.639	1.149	767	649	2.567
Cherries	163	306	260	601	572	693
Other perennials	1607	2392	2167	1372	1332	1650
Total	330,342	377,283	388,288	382,696	382,788	444,625

Table 2

Production Surinamese vegetables in tons (Ministry of Agriculture, Animal Husbandry and Fisheries 2015b)

Produce item	**2011**
Leafy vegetables	
Tannia	1548
Cabbage	851
Chinese cabbage	217
Clarion	Not available
Cestrum latifolium	Not available
Fruit vegetables	
Okra	1468
Chillies	1462
Bitter gourd	1242
Yard long beans	1228
Eggplant	1163
Tomatoes	741

Table 3

Selected produce items for the initial evaluation of pesticide residues in phase I

Leafy vegetables	**Brassica vegetables**	**Legume vegetables**	**Fruiting vegetables**	**Cereal grains**	**Root/tuber vegetables**	**Fruits**
Tannia (*Xanthosoma brasiliense*)	Head cabbage (*Brassica oleracea*)	Yard long beans (*Vigna unguiculata*)	Habanero pepper (*Capsicum chinense*)	Rice (*Oryza sativa*)	Sweet potato (*Ipomoea batatas*)	Banana (*Musa species*)

Table 4

Selected produce items for the expanded evaluation of pesticide residues in phase II

Leafy vegetables	Brassica vegetables	Legume vegetables	Fruiting vegetables	Cereal grains	Root/tuber vegetables	Fruits
Tannia (*Xanthosoma brasiliense*)	Head cabbage (*Brassica oleracea*)	Yard long beans (*Vigna unguiculata*)	Tomatoes (*Solanum lycopersicum*)	–	Sweet potato (*Ipomoea batatas*)	–
	Chinese cabbage (*Brassica rapa chinensis*)					

Table 5

Total amounts top 10 most imported pesticides 2009–2013

Pesticides	Imported in kg
Paraquat dichloride 20–27% (herbicide)	1,292,014
Glyphosate 41–48% (herbicide)	1,225,762
2,4-d-Amine (herbicide)	288,982
Mancozeb 80% (fungicide)	154,498
Lambda cyhalothrin 2.5–5% (insecticide)	152,218
Alpha cypermethrin 10% (insecticide)	142,804
Imidacloprid 20% (insecticide)	109,495
Malathion 57% (insecticide)	107,846
Isoprothiolane 40% (fungicide)	84,616
Diazinon 60% (insecticide)	57,911

Table 6

Selected pesticides for pesticide residue analysis of the produce items in phase I and phase II

Insecticides				**Fungicides**
Organophosphates	**Organochlorines**	**Carbamates**	**Pyrethoids**	
Carbophenothion	Aldrin	Carbofuran[a]	Alpha cypermethrin	Chlorothalonil
Chlorpyrifos	Benzene hexachloride		Bifenthrin	Etaconazole
Dimethoate	Chlordane		Cypermethrin	Fluzilazole
Ethion	DDD		Lambda cyhalothrin	Imazalil
Malathion	DDE		Permethrin	Myclobutanil
Ethyl parathion	DDT		Pydrin	Paclobutarol
Parathion	Endrin			Penaconazole
Phosdrin	Endosulfan I			Propiconizole
Terbufos	Endosulfan II			Thiabendazole
Thimet	Endosulfan sulfate			Triadimefon
Diazinon[a]	Heptachlor			Triadimenol
	Heptachlor epoxide			Tridemorph
	Lindane			Carbendazim[a]
	Methoxychlor			
	Mirex			
	Toxaphene			

[a] This was added to the panel of phase I

Table 7

Detected pesticide residues in selected produce items in phase II

Source and commodity	Pesticide residue levels (in µg/g)										
	Organochlorines				Pyrethroids						
	Endosulfan sum		Lindane		Cypermethrin				Lambda cyhalothrin		
	PRL ± SD	MRL EU	PRL ± SD	MRL EU	PRL ± SD	MRL EU	MRL USA	MRL WHO	PRL ± SD	MRL EU	MRL USA
Centrale Markt											
Tannia	0.04 ± 0.03	0.05	*0.02* ± 0.01	0.01	ND	–	–	–	ND	–	–
Tomato	ND	–	ND	–	*0.32* ± 0.20	0.50	0.20	0.20	ND	–	–
Covezomag											
Tannia	ND	0.05	*0.03* ± 0.02	0.01	ND	–	–	–	ND	–	–
Chinese cabbage	ND	–	ND	–	ND	–	–	–	*1.08* ± 0.71	1.00	0.40

PRLs exceeding MRLs are presented in italics

PRL pesticide residue level, *SD* standard deviation, *MRL* maximum residue limit, *ND* non-detect

Table 8

Critical intake rates, hazard quotient and level of concern for endosulfan and lindane in tannia

Tannia	RfD (mg/kg/day)	EU MRL (mg/kg)	Highest PRL (mg/kg)	IR using EU MRL (kg/day)	IR using highest PRL (kg/day)	HQ using highest PRL	LoC (mg/kg)
Endosulfan	0.006	0.05	0.07	7.2	5.1	0.07	1.0
Lindane	0.0003	0.01	0.03	1.8	0.6	0.6	0.05

RfD reference dose, *MRL* maximum residue limit, *PRL* pesticide residue level, *IR* intake rate, *HQ* hazard quotient, *LoC* level of concern