

# Occurrence of Pesticide Residues and Dietary Exposure Assessment in Vegetables from Senegal's Niayes Horticultural Zone

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## Abstract

Small-scale horticulture plays a major role in food security in Senegal, particularly in ensuring the supply of vegetables to local populations. The Niayes area represents one of the country's main horticultural production zones owing to its favourable agroclimatic conditions. However, inadequate pesticide management and poor compliance with good agricultural practices may compromise the sanitary quality of horticultural products and increase consumer exposure to chemical hazards. This study aimed to assess farmers' agricultural practices, determine pesticide residue levels in vegetables, and evaluate associated dietary risks. A field survey was conducted among 331 vegetable producers using the Wyckhuys and O'Neil approach. At the same time, 90 composite vegetable samples were tested for residues of 20 active pesticide ingredients using gas chromatography coupled with mass spectrometry (GC-MS). Of these substances, 19 were detected in at least one sample. Dietary risk assessment was performed using national vegetable consumption data to estimate contribution to pesticide exposure. The results showed that profenofos (87%) was the most frequently used pesticide, followed by emamectin benzoate (77%), lambda-cyhalothrin (73%), acetamiprid (72%), cypermethrin (51%), dimethoate (48%), and deltamethrin (47%), mainly applied during the pre-rainy season. Caterpillars were identified as the most prevalent pest (80% of citations), while pesticide management practices remained largely inconsistent with recommended agricultural standards. Cabbage was the most cultivated crop, followed by onion, potato, tomato and bitter eggplant. Residues exceeding Maximum Residue Limits (MRLs) were detected in 100% of okra samples, 93% of cabbage, 80% of turnip, 66% of bitter eggplant, and 62% of onion samples,

whereas lower exceedance rates were observed for pepper (8%), potato (8%), and tomato (26%). The highest dietary risk was associated with lindane in carrot, onion and bitter eggplant, followed by dimethoate in cabbage, onion, carrot and okra. Overall, carrot and onion were identified as the vegetables posing the greatest potential health risk to consumers.

## Keywords

Pesticide Residues, Vegetables, Use Practices, Dietary Exposure, Senegal

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## 1. Introduction

Developing countries are experiencing rapid population growth, raising concerns about the capacity of agricultural systems to meet the increasing demand for food. This challenge is further exacerbated by climate change, which negatively affects agricultural productivity, particularly in Africa [1]. In Senegal, studies on food consumption reported that fruits and vegetables accounted for 21% of national food expenditure, ranking first among all food categories [2] [3].

These findings underline the strategic importance of vegetables in the Senegalese diet. A substantial part of this production originates from small and medium-scale farms located in the peri-urban Niayes area, which is recognized as one of the country's most productive horticultural regions owing to favourable agroecological conditions [4] [5]. However, its major economic activities, such as horticulture and livestock farming, and artisanal fisheries, are increasingly constrained by rapid urbanization, pressure on water resources, and declining productivity associated with climate variability and change.

To overcome these constraints and sustain agricultural yields, producers have increasingly relied on chemical pesticides whose proper management has contributed substantially to reducing crop losses caused by pests and diseases and to improving agricultural productivity [6]. In the Sahel region, nearly 300 commercial pesticide formulations corresponding to approximately 80 active substances are currently used, although only 189 have been officially approved by the Sahelian Pesticides Committee (CSP) [7]. Repeated, uncontrolled, and intensive pesticide application has generated significant concerns regarding traceability and pesticide management, resulting in serious threats to human and animal health, food safety, and environmental sustainability [4] [8] [9].

According to the World Health Organization (WHO), more than 600 million people worldwide become ill and approximately 420,000 die annually after consuming food contaminated by bacteria, viruses, parasites, toxins, and chemical hazards [10]. In Africa, pesticide-related poisoning remains a major public health concern. Between January 1992 and December 2007, the Moroccan Poison Control Center recorded more than 2609 poisoning cases [11]. In Benin, between May 2007 and July 2008, 105 poisoning cases, including nine deaths (case fatality rate: 9%), associated with endosulfan exposure were reported [12]. In Mali, annual pes-

ticide intoxications were estimated at approximately 329 acute cases, with 30 to 210 deaths and between 1150 and 1980 chronic poisoning cases reported each year. In Senegal, 258 pesticide poisoning cases were documented by PAN Africa between 2002 and 2005 [13] [14].

In this context, the present study aimed to evaluate farmers' pesticide management practices, assess the sanitary quality of horticultural products through pesticide residue analysis, and estimate the associated dietary exposure risks. The findings are expected to support the development of scientifically informed strategies for the environmentally sound management of pesticides and contribute to strengthening food safety in Senegal.

## 2. Materials and Methods

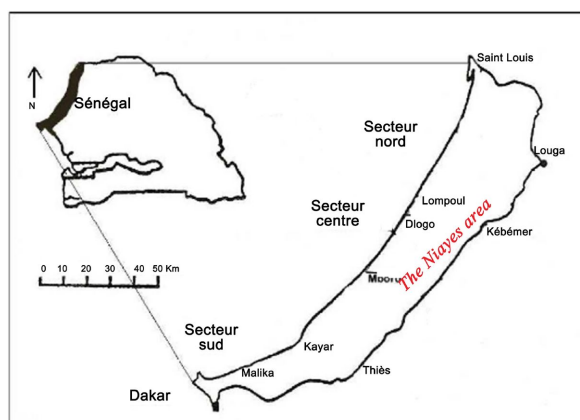
### 2.1. Study Design and Area

This study, conducted in the Niayes area, was designed as a cross-sectional, descriptive, and prospective analytical investigation combining field surveys, vegetable sampling, and laboratory analyses.

The Niayes area is located along the northern coastal belt of Senegal and extends across four regions (Dakar, Thiès, Louga, and Saint-Louis), which together account for more than 48% of the national population [15]. Covering approximately 510 km<sup>2</sup>, the area benefits from favorable climatic, pedological, and hydrogeological conditions that support intensive agricultural production.

The landscape consists of a succession of depressions and dune systems associated with a shallow groundwater table, historically sustaining lakes and wetlands that favor vegetation development despite the Sahelian environment. Annual rainfall generally remains below 500 mm.

Unlike most parts of Senegal characterized by a tropical Sahelian climate, the Niayes area benefits from a sub-Canarian microclimate influenced by maritime trade winds, resulting in relatively mild temperatures (19°C - 22°C) and stable humidity conditions during much of the year. These favorable environmental characteristics make it the country's main horticultural production area and a major supplier of vegetables to the Senegalese population [16] (Figure 1).



**Figure 1.** Location of the Niayes area [17].

## 2.2. Chemicals, Reagents and Equipment

The materials used in this study included equipment for field surveys, sample collection, and laboratory analysis.

For the survey and sampling activities, data collection forms, sample bags, insulated coolers, and permanent markers were used to ensure proper identification, handling, and transport of vegetable samples.

Laboratory analyses were carried out using a refrigerated centrifuge (Sigma 6K15, 5100 rpm), a Genius Sartorius® precision analytical balance, a Robot Coupe 20 L homogenizer, a Fiocchetti freezer, a Multi reax vortex shaker, a mechanical shaker, and a gas chromatography-mass spectrometry system (GC-MS 5975, Agilent Technologies). Data processing and statistical analyses were performed using SPSS and Microsoft Excel software.

Analytical-grade solvents and reference substances were used throughout the study. These included acetonitrile, magnesium sulfate, sodium sulfate, distilled water, and certified pesticide reference standards. All chemicals and analytical standards were supplied by VWR, Sigma-Aldrich, and Dr. Ehrenstorfer.

## 2.3. Methods

### 2.3.1. Survey

The survey was conducted over three consecutive years using participatory approaches previously described in the literature [18]-[20]. The target population consisted of vegetable producers operating within the Niayes area. A total of 331 farmers were selected according to the data saturation principle [18] [21]. This study was conducted under the supervision of the Ministry of Agriculture, which provided the funding. Field data collection was carried out with the informed consent of farmers in the Niayes region, whose voluntary participation and cooperation contributed to the quality of the information gathered and the reliability of the results. Verbal informed consent was obtained from all participants prior to the start of data collection. In accordance with applicable national regulations, no formal approval from an ethics committee was required for this type of observational agricultural survey.

The questionnaire collected information on socio-demographic characteristics (sex, age, farming experience, and educational level), the environmental status of the production area, ecological characteristics of agricultural systems (field size, pest types, attack frequency, and critical infestation periods), and crop management practices, with particular emphasis on fertilization and plant protection strategies.

### 2.3.2. Sampling

Sampling was conducted over two consecutive campaigns (2022 and 2023) across four horticultural sites in the Niayes area: Dakar (9 farms), Thiès (18 farms), and Louga and Saint-Louis combined (18 farms), totalling 45 farms per campaign. Farms were selected based on four criteria: importance of market-gardening activity, presumed pesticide use intensity, plot accessibility, and crop availability at

the time of sampling. Within each farm, one plot per crop was randomly selected with the landowner's consent and georeferenced using GPS coordinates.

A total of 90 composite vegetable samples were generated from 630 primary samples, with seven primary samples collected per plot at harvest. Primary samples from each plot were combined in a single bowl to form a bulk sample, which was thoroughly homogenised. A 5 kg aliquot was then taken as the final sample, placed in a labelled bag bearing the GPS coordinates of the sampling point, transported under cold-chain conditions in insulated coolers with ice packs, and stored at  $-18^{\circ}\text{C}$  until analysis. Twelve vegetable commodities were targeted, with the following sample distribution: onion ( $n = 16$ ), tomato ( $n = 10$ ), cabbage ( $n = 12$ ), turnip ( $n = 8$ ), sweet eggplant ( $n = 8$ ), carrot ( $n = 6$ ), potato ( $n = 7$ ), okra ( $n = 6$ ), lettuce ( $n = 5$ ), bitter eggplant ( $n = 4$ ), bell pepper ( $n = 4$ ), lemon ( $n = 2$ ), parsley ( $n = 2$ ).

### 2.3.3. Pesticide Residue Analysis

Pesticide extraction was performed using the QuEChERS method in accordance with NF EN 15662.

Residue determination was carried out using gas chromatography coupled with mass spectrometry (GC-MS) employing an Agilent Technologies 7890A gas chromatograph coupled to an Agilent 5975C inert Mass Selective Detector (MSD). Chromatographic separation was achieved on an HP-5MS capillary column (30 m) under the following operating conditions: carrier gas helium (ultra-high purity) at a linear velocity of 35 cm/s, injector temperature  $250^{\circ}\text{C}$ , splitless injection mode, and purge flow of 45 mL/min after 0.5 min. The oven temperature program started at  $50^{\circ}\text{C}$ , increased to  $100^{\circ}\text{C}$  at  $25^{\circ}\text{C}/\text{min}$ , then from  $100^{\circ}\text{C}$  to  $300^{\circ}\text{C}$  at  $7.5^{\circ}\text{C}/\text{min}$ , followed by a 3 min holding time at  $300^{\circ}\text{C}$ .

Mass spectrometric detection was performed under Electron Ionization (EI, 70 eV) operating in Selected Ion Monitoring (SIM) mode, with source and quadrupole temperatures maintained at  $230^{\circ}\text{C}$  and  $180^{\circ}\text{C}$ , respectively.

Quantification was performed using a five-point external calibration curve (0.05, 0.1, 0.2, 0.5, and 1.0 ppm) prepared from certified pesticide standards. PCB 28 was used as the internal standard.

### 2.3.4. Dietary Exposure Assessment

Chronic dietary exposure was estimated based on the average concentrations of pesticide residues detected in vegetable samples. The calculations were performed using the equation below. The dietary consumption data used were obtained from the Senegalese Institute for Agricultural Research and from national dietary consumption surveys conducted by the National Agency for Statistics and Demography. Exposures were assessed separately for each pesticide-vegetable combination, and contributions to the Acceptable Daily Intake (ADI) were calculated individually. Samples in which no residues were detected were not included in the calculation of average concentrations or in the exposure estimate. No assessment of cumulative exposure associated with the simultaneous consumption of several

vegetables was carried out.

The daily exposure (mg/kg body weight/day) was estimated according to the following equation:

$$\text{Dietary Exposure} = (C \times IR)/BW$$

where:

C = concentration of pesticide residue in vegetables (mg/kg);

IR = average daily vegetable intake (kg/day);

BW = body weight fixed at 70 kg.

The contribution of each pesticide residue to dietary exposure was expressed as:

$$\text{Contribution (\% ADI)} = (\text{Dietary Exposure} \times 100)/ADI$$

### 2.3.5. Statistical Analysis

Statistical analyses of data were performed using SPSS and Microsoft Excel software. Descriptive statistics were applied to calculate averages and identify overall trends in agricultural practices, pesticide use patterns, contamination levels, and estimated dietary exposure.

The spatial distribution of samples exceeding the Maximum Residue Limits (MRLs) was visualized through georeferenced mapping using Geographic Information Systems (GIS) based on GPS coordinates recorded during sampling.

## 3. Results

### 3.1. Socio-Demographic Characteristics of Vegetable Producers

The socio-demographic characteristics of vegetable producers in the Niayes area are summarized in **Table 1**. The results indicate that horticultural production was mainly carried out by a relatively young population, with farmers aged 25 - 34 years (41.4%) and 18 - 24 years (33.5%) representing the dominant age groups. Older producers were less represented.

Most respondents had substantial farming experience, with 48.8% reporting more than 15 years of experience and 31.7% having between 10 and 15 years, reflecting the long-standing importance of horticulture in the study area.

Regarding educational level, the population was characterized by limited formal education. Attendance at Quranic schools predominated (72.6%), whereas only 1.7% had completed higher education and none had formal training in agronomy. In addition, 18.8% had participated in literacy programs.

### 3.2. Vegetable Producers and Crop Protection Practices

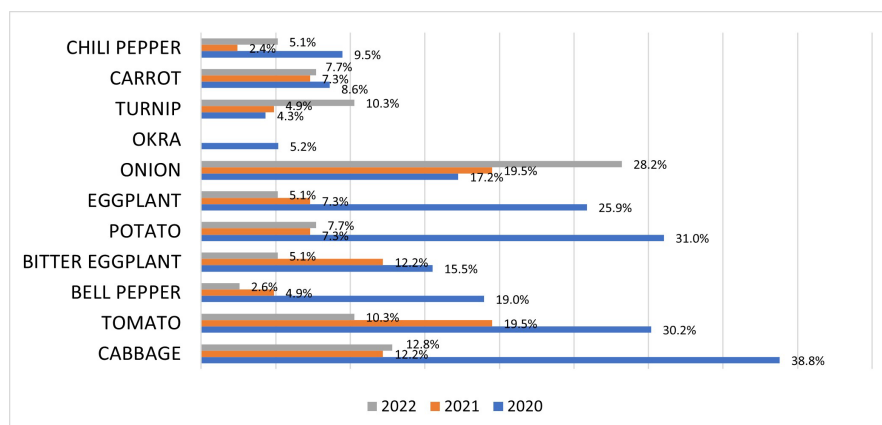
The distribution of cultivated crops in the Niayes area is presented in **Figure 2**. The results showed that cabbage was the most cultivated crop, followed by onion, potato, tomato, and bitter eggplant, confirming the dominant role of vegetable production systems in the study area.

Regarding pest pressure and crop protection practices (**Table 2**), caterpillars were identified as the most frequently reported pests (80%), followed by butterflies (32%)

and nematodes (18%). The most frequently used pesticide active substances were profenofos (87%), emamectin benzoate (77%), lambda-cyhalothrin (73%), acetamiprid (72%), cypermethrin (51%), dimethoate (48%), and deltamethrin (47%). These compounds were mainly insecticides, reflecting the predominance of insect pest control in horticultural production systems.

**Table 1.** Socio-demographic characteristics of vegetable producers in the Niayes area.

|                             | 2020  | 2021 | 2022 | Average |
|-----------------------------|-------|------|------|---------|
| <b>Age group of farmers</b> |       |      |      |         |
| Under 18                    | 3.6   | 0    | 0    | 1.2     |
| 18 - 24                     | 10.8  | 48.8 | 41   | 33.5    |
| 25 - 34                     | 42.3  | 51.2 | 30.8 | 41.4    |
| 35 - 49                     | 32.4  | 0    | 17.9 | 16.8    |
| 50 - 64                     | 9.9   | 0    | 2.6  | 4.2     |
| 65 - 80                     | 0.9   | 0    | 7.7  | 2.9     |
| <b>Years of experience</b>  |       |      |      |         |
| Under 5                     | 7.7   | 13.3 | 7.7  | 9.8     |
| 5 - 10                      | 15.4  | 0    | 15.4 | 9.8     |
| 10 - 15                     | 61.5  | 20   | 15.4 | 31.7    |
| More than 15                | 15.4  | 66.6 | 61.5 | 48.8    |
| <b>Education</b>            |       |      |      |         |
| Agronomy                    | 0     | 0    | 0    | 0       |
| Higher education            | 1.7   | 0    | 3    | 1.6     |
| Middle school               | 2.6   | 0    | 3    | 1.9     |
| Elementary school           | 10.04 | 5    | 0    | 5.7     |
| Koranic school              | 45    | 88   | 85   | 72.6    |
| None                        | 3.45  | 0    | 0    | 1.1     |
| Literacy                    | 35.3  | 12.2 | 9    | 18.8    |



**Figure 2.** Distribution of cultivated vegetable crops in the Niayes area.

Pesticide applications were mainly concentrated during the pre-rainy season (93%), although treatments were also commonly applied throughout the horticultural campaign (84%) and during pest infestation periods (82%).

The results further indicated that pesticide use practices were largely based on local habits (100%) rather than manufacturers' recommendations, highlighting limited adherence to good agricultural practices. In addition, unused pesticide products were frequently abandoned in the environment (88.9%), and all empty pesticide containers were reportedly left in the fields (100%). The use of biopesticides remained very limited (2%).

**Table 2.** Pesticide use and management practices among vegetable producers in the Niayes area.

|                                                 | 2020 | 2021 | 2022 | Average |
|-------------------------------------------------|------|------|------|---------|
| <b>Most active pests</b>                        |      |      |      |         |
| Caterpillar/earthworm                           | 38.5 | 100  | 100  | 80      |
| Butterfly                                       | 23.1 | 56.1 | 17.9 | 32      |
| Unidentified insect                             | 100  | 58.5 | 100  | 86      |
| Nematode                                        | 10.6 | 26.8 | 17.9 | 18      |
| Snow                                            | 4.8  | 36.6 | 7.7  | 16      |
| <b>Most commonly used pesticide molecules</b>   |      |      |      |         |
| Profenofos                                      | 100  | 61   | 100  | 87      |
| Emamectin benzoate                              | 89   | 65   | 77   | 77      |
| Acetamiprid                                     | 82   | 67   | 67   | 72      |
| Lambda-cyhalothrin                              | 80   | 77   | 63   | 73      |
| Deltamethrin                                    | 70   | 35   | 37   | 47      |
| Dimethoate                                      | 71   | 46   | 27   | 48      |
| Cypermethrin                                    | 54   | 52   | 48   | 51      |
| Ethyl chlorpyrifos                              | 32   | 11   | 19   | 21      |
| Tebuconazole                                    | 23   | 18   | 14   | 18      |
| Pendimethalin                                   | 27   | 22   | 23   | 24      |
| Bensulfuron-methyl                              | 22   | 17   | 22   | 20      |
| Propanil                                        | 27.3 | 13   | 17   | 19      |
| Methomyl                                        | 11   | 7    | 10   | 9       |
| Azoxystrobin                                    | 9    | 2    | 2    | 4       |
| Dicofol                                         | 6    | 0    | 0    | 2       |
| <b>Period of use for pesticide formulations</b> |      |      |      |         |
| Pre-winter period                               | 80   | 100  | 100  | 93      |
| During the growing season                       | 52   | 100  | 100  | 84      |
| In case of infestation                          | 46   | 100  | 100  | 82      |
| When the shoots emerge                          | 3    | 5    | 2    | 3       |

## Continued

| Instructions for use of the formulations     |      |      |     |      |
|----------------------------------------------|------|------|-----|------|
| According to the manufacturer's instructions | 0    | 0    | 0   | 0    |
| According to local customs                   | 100  | 100  | 100 | 100  |
| What happens to the remaining products?      |      |      |     |      |
| Landfilling                                  | 0    | 0    | 0   | 0    |
| Incineration                                 | 33.3 | 22.2 | 5   | 20.2 |
| Storage                                      | 11.1 | 33.3 | 0   | 14.8 |
| Dumping in the wild                          | 66.7 | 100  | 100 | 88.9 |
| What happens to empty packaging?             |      |      |     |      |
| Landfilling                                  | 0    | 0    | 0   | 0    |
| Burning                                      | 0    | 0    | 0   | 0    |
| Storage                                      | 0    | 0    | 0   | 0    |
| Leaving in the field                         | 100  | 100  | 100 | 100  |
| What happens to expired products             |      |      |     |      |
| Landfilling                                  | 81.8 | 100  | 100 | 94   |
| Dumping in the wild                          | 18.2 | 100  | 100 | 6    |
| Use of biopesticides                         |      |      |     |      |
| No                                           | 93.7 | 100  | 100 | 98   |
| Yes                                          | 2.3  | 0    | 0   | 2    |

### 3.3. Pesticide Residue Levels in Vegetables

The concentrations of pesticide residues detected in vegetable samples are presented in **Table 3**. Overall, the results revealed widespread contamination of horticultural products, with considerable variability according to crop type and active substance.

Among the 20 targeted pesticide active substances, 19 compounds were detected at concentrations exceeding the corresponding MRLs. These included bifenthrin, bromacil, chlorpyrifos, chlorpyrifos-methyl, cyhalothrin, cypermethrin, deltamethrin, dicofol, diflubenzuron, dimethoate, esfenvalerate, fenitrothion, fenvalerate, iodofenphos, lambda-cyhalothrin, lindane, parathion-methyl, pendimethalin, and trifluralin. Heptachlor is the only substance that was not detected in any of the samples.

The highest frequencies of MRL exceedance were observed in okra (100%), followed by cabbage (93%), turnip (80%), bitter eggplant (66%), and onion (62%). In contrast, lower exceedance rates were recorded for tomato (26%), pepper (8%), and potato (8%), suggesting lower contamination levels in these crops.

Several active substances showed recurrent occurrence across multiple vegetables. In particular, dimethoate, lambda-cyhalothrin, deltamethrin, and parathion-methyl were detected in several crop categories, indicating extensive use and possible repeated application during cultivation.

**Table 3.** Pesticide residue concentrations (mg/kg) in vegetables from the Niayes area.

| Pesticide           | Vegetable         |                    |                |                |               |                 |                 |                |                 |                |               |                |                |
|---------------------|-------------------|--------------------|----------------|----------------|---------------|-----------------|-----------------|----------------|-----------------|----------------|---------------|----------------|----------------|
|                     | Sweet<br>eggplant | Bitter<br>eggplant | Carrots        | Cabbage        | Lemon         | Okra            | Turnip          | Onion          | Bell<br>pepper  | Potato         | Parsley       | Lettuce        | Tomato         |
| Bifenthrin          | -                 | -                  | 0.02 +<br>0.08 | -              | -             | -               | -               | -              | -               | -              | -             | -              | -              |
| Bromacil            | -                 | -                  | 0.04 +<br>0.07 | -              | -             | -               | 0.08 +<br>0.07  | 0.2 +<br>0.07  | -               | -              | -             | 0.52 +<br>0.07 | -              |
| Chlorpyrifos-Ethyl  | -                 | -                  | 0.34 +<br>0.01 | -              | -             | -               | -               | -              | -               | -              | -             | 0.2 +<br>0.01  | -              |
| Chlorpyrifos-Méthyl | -                 | -                  | -              | -              | -             | -               | 0.5 +<br>0.04   | -              | -               | -              | -             | -              | -              |
| Cyhalodiamide       | -                 | -                  | -              | -              | -             | -               | -               | 0.07 +<br>0.01 | -               | -              | -             | -              | -              |
| Cyperméthrin        | -                 | -                  | -              | -              | 0.6 +<br>0.05 | -               | -               | -              | -               | -              | -             | -              | -              |
| Deltaméthrin        | -                 | 0.09 +<br>0.01     | -              | 0.6 +<br>0.01  | -             | 0.1 +<br>0.01   | 0.1 +<br>0.01   | -              | -               | -              | -             | -              | -              |
| Dicofol             | -                 | -                  | -              | -              | -             | -               | -               | -              | -               | -              | -             | 0.07 +<br>0.01 | -              |
| Diflubenzuron       | 0.09 +<br>0.006   | -                  | -              | 0.8 +<br>0.006 | -             | 0.02 +<br>0.006 | 0.02 +<br>0.006 | 0.4 +<br>0.006 | 0.12 +<br>0.006 | -              | -             | -              | 0.3 +<br>0.006 |
| Dimethoate          | -                 | -                  | 0.8 +<br>0.07  | 0.5 +<br>0.07  | -             | 0.5 +<br>0.07   | -               | 0.9 +<br>0.07  | -               | -              | -             | -              | -              |
| Esfenvalérate       | -                 | -                  | -              | 0.03 +<br>0.04 | -             | -               | 0.03 +<br>0.04  | -              | 0.04 +<br>0.04  | -              | -             | -              | -              |
| Fénitrothion        | -                 | -                  | 0.1 +<br>0.01  | 0.05 +<br>0.01 | -             | -               | -               | -              | -               | -              | -             | -              | 0.05           |
| Fenvalérate         | -                 | -                  | -              | 0.01 +<br>0.01 | -             | -               | 0.01 +<br>0.01  | -              | 0.02 +<br>0.01  | -              | -             | -              | -              |
| Iodofenphos         | 0.06 +<br>0.01    | -                  | 0.1 +<br>0.01  | -              | -             | -               | 0.7 +<br>0.01   | -              | 0.06 +<br>0.01  | -              | -             | -              | -              |
| Lambda-Cyhalothrin  | 0.06 +<br>0.01    | 0.08 +<br>0.01     | 0.8 +<br>0.01  | 0.8 +<br>0.01  | -             | -               | -               | -              | 0.07 +<br>0.01  | -              | 0.8 +<br>0.01 | -              | 0.05 +<br>0.01 |
| Lindane             | -                 | 0.05 +<br>0.01     | 0.05 +<br>0.01 | -              | -             | -               | -               | 0.3 +<br>0.01  | -               | -              | -             | -              | -              |
| Parathion-Méthyl    | -                 | -                  | 0.06 +<br>0.02 | 0.2 +<br>0.02  | -             | 0.02 +<br>0.02  | 0.02 +<br>0.02  | 0.35 +<br>0.02 | -               | -              | -             | -              | -              |
| Pendiméthalin       | -                 | -                  | -              | -              | -             | -               | 0.8 +<br>0.01   | 0.8 +<br>0.01  | -               | 0.01 +<br>0.01 | -             | -              | 0.1 +<br>0.01  |
| Trifluralin         | 0.1 +<br>0.01     | 0.1 +<br>0.01      | -              | 0.1 +<br>0.01  | -             | -               | 0.04 +<br>0.01  | 0.8 +<br>0.01  | -               | -              | -             | -              | -              |

3.4. Pesticide Contribution to the Dietary Exposure

The highest contributions were observed for dimethoate in carrots (90%) and onions (150%). These values can be explained both by the relatively high levels of residues detected in these vegetables and by the low ADI for dimethoate, which automatically increases its contribution to dietary risk. Thus, even when measured concentrations remain low in absolute terms, they can represent a significant proportion of the ADI, as is the case for chlorpyrifos in carrots (3.5%) and onions (3.7%). Deltamethrin also made a relatively significant contribution in cabbage

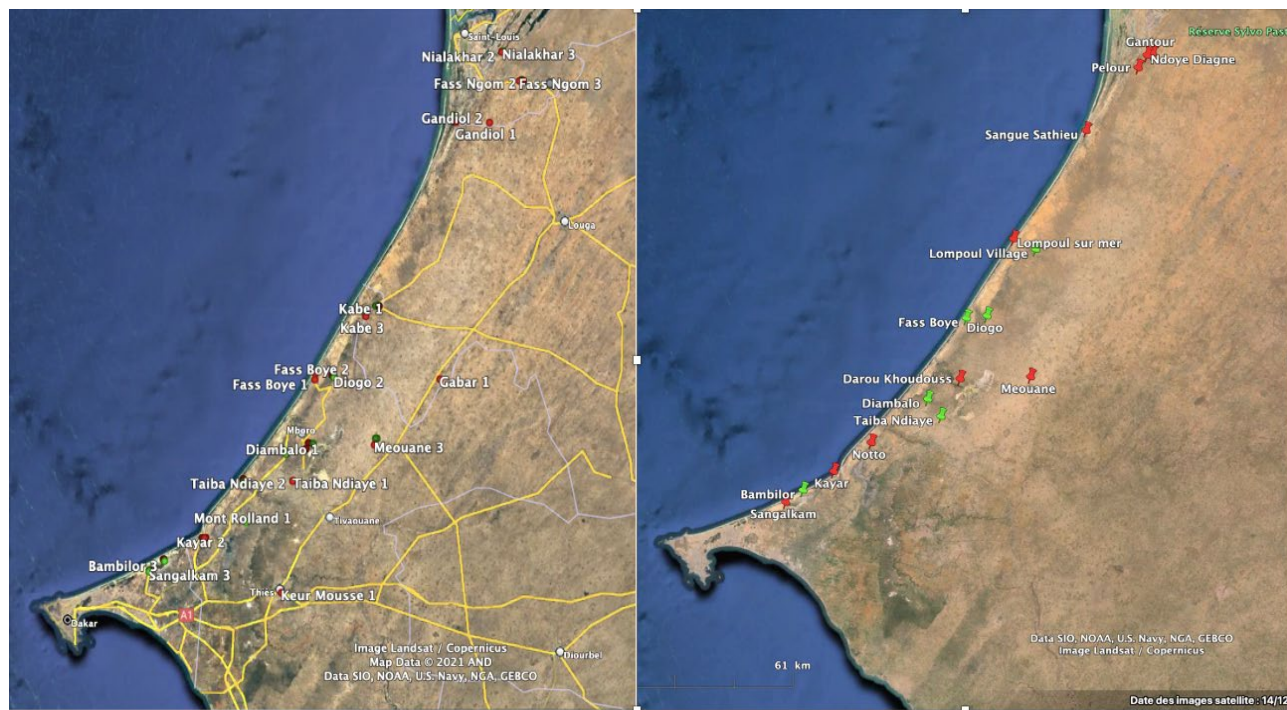
(16.7%), compared with the other crops studied. In contrast, the contributions of bifenthrin in carrots (0.15%), trifluralin in Bitter eggplant (0.12%) and pendimethalin in turnips (0.62%) remained low. Residues of diflubenzuron in sweet eggplant (0.11% - 0.23%) and fenvalerate in cabbage (0.5%) also contributed marginally to dietary exposure. These results show that onions, carrots and cabbage are the main sources of pesticide exposure among the vegetables studied (Table 4).

Table 4. Estimated dietary exposure and contribution of pesticide residues to the acceptable daily intake (ADI).

| Molecule            | Vegetable       | Exposition | ADI    | Contribution    | Molecule           | Vegetable       | Exposition | ADI   | Contribution  | Molecule    | Vegetable      | Exposition | ADI    | Contribution |   |
|---------------------|-----------------|------------|--------|-----------------|--------------------|-----------------|------------|-------|---------------|-------------|----------------|------------|--------|--------------|---|
| Bifenthrin          | Carrots         | 0.00005    | 0.015  | 0.15            | Trifluralin        | Bitter Eggplant | 0.00001    | 0.015 | 0.12          | Dimethoate  | Carrots        | 0.0009     | 0.001  | 90           |   |
|                     | Carrots         | 0.0004     | 0.19   | 0.21            |                    | Sweet Eggplant  | 0.0001     | 0.015 | 0.8           |             | Cabbage        | 0.0001     | 0.001  | 10           |   |
| Bromacil            | Turnip          | 0.00008    | 0.19   | 0.41            |                    | Cabbage         | 0.0003     | 0.015 | 2             |             | Okra           | 0.0003     | 0.001  | 30           |   |
|                     | Onion           | 0.0004     | 0.19   | 0.21            |                    | Turnip          | 0.00004    | 0.015 | 0.26          |             | Onion          | 0.0015     | 0.001  | 159          |   |
|                     | Lettuce         | 0.00001    | 0.19   | 0.07            | Onion              | 0.001           | 0.015      | 6.67  | Carrots       |             | 0.0009         | 0.001      | 88     |              |   |
| Chlorpirifos        | Carrots         | 0.0004     | 0.01   | 3.52            | Pendimethalin      | Turnip          | 0.0008     | 0.125 | 0.62          |             | Sweet Eggplant | 0.00007    | -      | -            | - |
|                     | Onion           | 0.0003     | 0.01   | 3.74            |                    | Onion           | 0.001      | 0.125 | 1.12          |             | Carrots        | 0.0001     | -      | -            | - |
| Chlorpirifos méthyl | Turnip          | 0.00005    | 0.01   | 0.5             |                    | Tomato          | 0.0003     | 0.125 | 0.22          | Turnip      | 0.0007         | -          | -      | -            |   |
| Cyhalodiamide       | Onion           | -          | -      | -               |                    | Potato          | 0.0001     | 0.125 | 0.01          | Bell pepper | -              | -          | -      | -            |   |
| Cyperméthrin        | Lemon           | -          | 0.005  | -               | Carrots            | 0.00007         | 0.003      | 2.33  | Cabbage       | 0.00008     | 0.00008        | 0.0175     | 0.48   |              |   |
| Deltaméthrin        | Bitter Eggplant | 0.00008    | 0.01   | 0.84            | Cabbage            | 0.0006          | 0.003      | 20    | Esfenvalerate | 0.00003     | 0.0175         | 0.175      | 0.17   |              |   |
|                     | Cabbage         | 0.0016     | 0.01   | 16.7            | Turnip             | 0.00006         | 0.003      | 2     | Bell pepper   | 0.0001      | 0.0001         | 0.0175     |        |              |   |
|                     | Okra            | 0.00006    | 0.01   | 0.61            | Okra               | 0.00001         | 0.003      | 0.040 | Carrots       | 0.0001      | 0.0001         | 0.005      | 2.20   |              |   |
|                     | Turnip          | 0.0001     | 0.01   | 0.97            | Onion              | 0.0006          | 0.003      | 20    | Cabbage       | 0.0001      | 0.0001         | 0.005      | 2.78   |              |   |
| Dicofol             | Lettuce         | 0.000002   | 0.0022 | 0.09            | Lambda-Cyhalothrin | Onion           | 0.0006     | 0.003 | 2.8           | Fenvalerate | 0.00001        | 0.0125     | 0.0125 | 0.022        |   |
|                     | Sweet Eggplant  | 0.0001     | 0.1    | 0.11            |                    | Sweet Eggplant  | 0.0007     | 0.025 |               | Turnip      | 0.00001        | 0.0125     | 0.0125 | 0.077        |   |
| Cabbage             | 0.0002          | 0.1        | 0.23   | Bitter Eggplant |                    | 0.0007          | 0.025      | 3     | Bell pepper   | -           | 0.0125         | -          | -      |              |   |
| Okra                | 0.0001          | 0.1        | 0.13   | Carrots         |                    | 0.0009          | 0.025      | 3.6   |               |             |                |            |        |              |   |
| Turnip              | 0.0001          | 0.1        | 0.19   | Parsley         |                    | 0.0001          | 0.025      | 0.4   |               |             |                |            |        |              |   |
| Diflubenzuron       | Onion           | 0.0007     | 0.1    | 0.7             | Bell pepper        |                 | 0.025      | -     | -             |             |                |            |        |              |   |
|                     | Bell pepper     |            | 0.1    |                 | Tomato             |                 | 0.025      | 0.4   |               |             |                |            |        |              |   |
|                     | Tomato          | 0.0008     | 0.1    | 0.84            |                    |                 |            |       |               |             |                |            |        |              |   |
|                     |                 |            |        |                 |                    |                 |            |       |               |             |                |            |        |              |   |

### 3.5. Spatial Distribution of Contamination

The spatial distribution of pesticide contamination exceeding the Maximum Residue Limits (MRLs) is illustrated in **Figure 3**. Geographic coordinates collected during sampling and processed using Geographic Information Systems (GIS) enabled the georeferencing and visualization of contamination hotspots across the study area.



**Figure 3.** Spatial distribution of vegetable samples exceeding Maximum Residue Limits (MRLs) in the Niayes area.

The results showed a heterogeneous distribution of contaminated samples and several locations exhibited recurrent exceedances of MRLs across different vegetable crops.

The spatial analysis also revealed that contamination was not uniformly distributed among crops. Vegetables with the highest frequencies of MRL exceedance, particularly okra, cabbage, turnip, onion, and bitter eggplant, were concentrated in specific production zones, whereas crops such as pepper, potato, and tomato showed fewer exceedances and a more limited spatial distribution of contamination.

## 4. Discussion

### 4.1. Socio-Demographic Characteristics

Among the 331 vegetable producers surveyed, considerable social diversity was observed across the study sites in terms of age, geographical origin, and years of farming experience. Most producers were seasonal workers and belonged predominantly to younger age groups, while having accumulated several years of practical

experience in horticultural activities.

These findings are consistent with previous studies conducted in the same area. Ngom *et al.* (2012) reported that vegetable producers in the Niayes zone originated from different regions of Senegal as well as neighboring countries, reflecting the attractiveness of this production system [8]. Similarly, Diao (2004) described horticulture as an important livelihood opportunity for urban populations affected by chronic unemployment and rural populations involved in seasonal migration [23]. The predominance of young producers observed in the present study is also consistent with the findings of [24].

Despite their practical experience, most producers had limited formal education and had not received advanced agricultural training. Discussions conducted during focus groups revealed that although farm owners were generally aware of the institutions responsible for providing technical support and agricultural extension services, field workers involved in irrigation, pesticide application, and harvesting were often unaware of these structures. Furthermore, these workers had not received training on Good Agricultural Practices (GAPs).

Similar observations were previously reported by Cissé *et al.* (2003), who highlighted the difficulties in organizing and raising awareness among agricultural workers regarding good agricultural practices due to their high mobility [4]. Limited access to training and technical supervision may contribute to the persistence of inappropriate farming and pesticide management practices, thereby increasing potential risks for food safety and environmental sustainability.

## 4.2. Cropping Systems and Pesticide Management Practices

The predominance of cabbage, potato, tomato, and onion among cultivated crops in the Niayes area reflects both the strong market demand from nearby urban centers such as Dakar, Thiès, and Saint-Louis and the economic attractiveness of these horticultural commodities. These findings are consistent with national production statistics reported by the Directorate of Horticulture, which indicated that vegetables accounted for more than 80% of total horticultural production, with onion (33%), cabbage (14%), and potato (12%) representing the main crops [25].

Regarding pest pressure, caterpillars were identified as the most prevalent pests and were recognized by virtually all producers, followed by butterflies, aphids, and other insect groups, while nematodes were less frequently reported. Farmers also described the occurrence of “snow”, a pest symptom resembling a spider web on plants. The high pest pressure observed may be explained by the favorable climatic conditions of the Niayes area, which support pest development and proliferation. Similar observations were reported by Cissé *et al.* (2021), who identified aphids, caterpillars, flies, and nematodes as the main crop enemies in horticultural systems [26].

The study also revealed a strong dependence on chemical pesticides. Profenofos was the most frequently cited active substance, followed by acetamiprid, emamectin benzoate, and lambda-cyhalothrin, while dimethoate, cypermethrin, and deltamethrin were also widely used. Additional active substances included chlorpyrifos-ethyl, malathion, dicofol, azoxystrobin, methomyl, propanil, bensulfuron-methyl,

pendimethalin, and tebuconazole. All these products were reported as authorized by the Sahelian Pesticides Committee (CSP) [14]. These findings are broadly consistent with those reported by Ly *et al.* (2021), who also identified profenofos and dimethoate among the most commonly used pesticides [27]. Nevertheless, the frequencies of use observed in this study do not necessarily reflect national registration patterns, where herbicides account for 67.8% of approved formulations, followed by insecticides and fungicides (12.2% each) [28].

Despite the widespread use of pesticides, the adoption of best practices remained limited. None of the farmers surveyed reported following the manufacturer's instructions, and treatments were applied at a fixed dose, regardless of the level of crop infestation or the size of the plots. Only seven farmers reported following retailers' recommendations. Furthermore, the consistent use of personal protective equipment was rare. These practices of improper pesticide use are consistent with those reported in several studies conducted in Africa [29]-[31]. Similar inappropriate pesticide use practices have been widely documented across Africa [29]-[31]. Recent findings by Ngom *et al.* (2014) also highlighted that intensive horticultural systems often operate without sufficient mastery of technical production practices [32].

Poor management of pesticide waste was also observed. Empty pesticide containers were abandoned in fields by 100% of surveyed producers, while remaining products were either discarded (88.9%), burned (20.2%), or stored (14.8%). Expired products were mainly buried (94%). Comparable practices were reported in Cameroon, where 29% of producers reused empty pesticide containers for other purposes [33]. The persistence of such practices despite repeated awareness campaigns may reflect insufficient collection systems and limited access to safer disposal mechanisms.

Finally, the use of biopesticides remained extremely limited, with only 2% of producers reporting the use of natural products such as *Azadirachta indica* (Neem), whereas 98% relied exclusively on synthetic pesticides. This situation may be explained by the greater availability, faster perceived effectiveness, and better familiarity associated with chemical pesticides compared with alternative pest management approaches, consistent with observations reported by Williamson *et al.* (2008) [34].

### 4.3. Pesticide Residue Contamination and Dietary Exposure

The analytical results revealed the presence of 19 pesticide active substances in the vegetable samples, namely bifenthrin, bromacil, chlorpyrifos, chlorpyrifos-methyl, cyhalodiamide, cypermethrin, deltamethrin, dicofol, diflubenzuron, dimethoate, esfenvalerate, fenitrothion, fenvalerate, iodofenphos, lambda-cyhalothrin, lindane, parathion-methyl, pendimethalin, and trifluralin. Among these compounds, trifluralin, diflubenzuron, lambda-cyhalothrin, pendimethalin, and bromacil were the most frequently detected.

These findings indicate changes in pesticide usage patterns compared with pre-

vious studies. Diop *et al.* (2013) reported that the compounds most frequently detected above Maximum Residue Limits (MRLs) were dicofol, dimethoate, and chlorpyrifos [35]. While dimethoate remains among the predominant residues detected in the present study, dicofol and chlorpyrifos appear to be declining, whereas newer compounds such as pendimethalin are becoming increasingly prevalent.

Among the analyzed commodities, carrot and turnip showed the highest diversity of pesticide residues within a single matrix, suggesting repeated treatments and potential co-exposure to multiple active substances.

Overall, pesticide residue concentrations exceeded the corresponding MRLs in 50 out of the 90 analyzed samples. The highest frequencies of exceedance were observed in okra (100%), cabbage (93%), turnip (80%), and onion (62%), whereas pepper and potato were the least contaminated crops, with only 8% of samples exceeding regulatory limits. Comparable findings were reported by Bempah *et al.* (2012) in Ghana, where 75% of vegetables collected from supermarkets contained detectable pesticide residues and 35% exceeded MRLs [36].

The high number of pesticide residues detected may be explained by the widespread use of pesticide mixtures by producers. Indeed, Ngowi *et al.* (2007) and Sibanda *et al.* (2000) reported the use of pesticide cocktails containing up to five different active substances in a single spray tank, increasing the probability of multiple residues in harvested products [29] [37]. However, exceeding an MRL does not necessarily mean that there is a toxicological risk to the consumer. This is because MRLs are regulatory thresholds linked to good agricultural practices, whereas health risk is assessed on the basis of dietary exposure and its comparison with the ADI. Consequently, some instances of MRL exceedance may occur without the ADI being exceeded. The assessment of chronic dietary risk showed that the majority of contributions to the ADI were below the 100% threshold of concern, suggesting an overall acceptable risk for Senegalese consumers. However, high contributions were observed for dimethoate in carrots (90%) and, in particular, in onions (150%), making these crops the main sources of exposure in this study. These results can be explained by the relatively high residue concentrations measured, as well as by the low toxicological reference value for dimethoate ( $ADI = 0.002 \text{ mg/kg bw/day}$ ), which significantly increases its contribution to the risk. Deltamethrin also made a significant contribution in cabbage (16.7%), although it remained below the ADI. Similar observations have been reported in several West African countries where vegetables constitute a major route of exposure to pesticides, particularly for organophosphates such as chlorpyrifos and dimethoate. Studies conducted in Ghana by Darko and Akoto, in Nigeria by Fatunsin, and in Cape Verde by Acosta-Dacal have shown that residues of certain organophosphate pesticides found in tomatoes and eggplants may pose a potential risk to consumers, even when the measured concentrations comply with current regulatory standards [38]-[40]. Furthermore, several studies conducted in Ghana and Nigeria concluded that, despite the frequent presence of residues in vegetables, dietary

exposure levels generally remained below toxicological reference values, whilst highlighting the need for regular monitoring of residues [38] [39]. These findings confirm that vegetables widely consumed in Senegal, notably onions, carrots and cabbage, can contribute significantly to dietary exposure when certain substances are used intensively. They highlight the importance of adhering to good agricultural practices and strengthening residue monitoring programmes in Senegalese vegetable production. This assessment nevertheless has certain limitations, notably the use of a reference body weight of 70 kg applicable to adults, which may underestimate exposure in children, as well as the failure to take into account cumulative exposure to several pesticides that may be ingested simultaneously.

## 5. Conclusions

Field surveys conducted among vegetable producers revealed that good agricultural practices are substantially weakened by a combination of social, economic, and climatic constraints. These conditions directly affect the sanitary quality of primary agricultural production and consequently increase potential health risks for consumers.

The results demonstrated widespread occurrence of pesticide residues in horticultural products, with some vegetables contributing substantially to dietary exposure, particularly through active substances such as dimethoate and lindane. These findings highlight the close relationship between agricultural practices, contamination of food products, and consumer exposure.

Given that food safety is a critical determinant of public health and population well-being in Senegal, pesticide risk assessment should be expanded beyond residue monitoring to include broader exposure assessment across food commodities and strengthen surveillance, awareness, and sustainable pesticide management strategies.

## Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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