

Pesticide residues and Salmonella contamination in lettuce (*Lactuca sativa*) sold in Bamako, Mali

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Abstract

Background

Urban agriculture is practiced in certain neighborhoods of the city of Bamako to meet the food needs of a constantly growing population. This practice relies on the intensive use of pesticides and wastewater for irrigation. These practices can compromise the food safety of vegetables, particularly lettuce (*Lactuca sativa*), which is often consumed raw. The objective of this study was to assess the prevalence of residues of four pesticides (deltamethrin, endosulfan A, endosulfan B, and o,p'-DDT) and *Salmonella* spp. in lettuce samples collected from four markets in Commune I of Bamako. Eighty composite lettuce samples were randomly collected between January and February 2026 at the Banconi, Korofina, Djélibougou, and Boulkassoumbougou markets, at a rate of twenty samples per site. Pesticide residues were extracted using the QuEChERS method, then purified by dispersive solid-phase extraction (d-SPE) prior to quantification by gas chromatography equipped with an electron capture detector (GC- μ ECD). Detection of *Salmonella* spp. was performed in accordance with standard NF EN ISO 6579.

Results

Of the 80 samples analyzed, 54/80 (66.7%) contained pesticide residues. Deltamethrin was the most frequently detected pesticide (30 samples; 0.07–0.173 mg/kg), followed by o,p'-DDT (12 samples; 0.09–0.35 mg/kg). endosulfan A and endosulfan B were each detected in six (6) samples. The results showed that *Salmonella* spp. was isolated in 46 of the 80 samples analyzed (58.3%). The highest levels of contamination were observed at the Korofina and Boulkassoumbougou markets.

Conclusion

This study highlights chemical and microbiological contamination of lettuce sold in the markets studied, posing a risk to public health. Strengthening health inspections, promoting good agricultural practices, and improving the quality of irrigation water are essential.

Background

Rapid population growth in sub-Saharan Africa, and specifically in Bamako, has spurred the development of urban and peri-urban agriculture to meet the growing demand for fresh produce. In Mali, the Bamako district has experienced significant population growth, rising from approximately 3,337,122 inhabitants in 2009 [1] to 4,227,569 according to the latest general population and housing census conducted in 2022 [2]. Faced with this continuous population growth, urban and peri-urban agriculture has emerged as a vital solution for feeding these populations while creating jobs and recycling certain types of waste [3]. In West Africa, vegetable farming has emerged as a key component of urban and peri-urban agriculture, playing a vital role in the economic development of cities [4].

However, these production systems are often associated with health risks. First, market gardeners frequently use pesticides to protect their crops from pests, but these products can leave residues on vegetables. Studies conducted in Ouagadougou, for example, detected residues of organochlorine insecticides (notably DDT, which is banned) on samples of lettuce, cabbage, and tomatoes [5]. The World Health Organization (WHO) estimates that thousands of people are poisoned by chemical pesticides each year, resulting in more than 20,000 deaths annually worldwide [6], primarily among farmers and their families [7]. Second, the use of untreated wastewater for irrigation is a common practice that can contaminate vegetables with enteric pathogens, such as *Salmonella* spp., *Escherichia coli*, and *Vibrio cholerae* [8]. The consumption of these vegetables, which are often eaten raw, exacerbates these risks.

In West Africa, foodborne illnesses caused by *Salmonella* are of particular concern. Previous studies have reported a prevalence of *Salmonella enterica* of 17.9% in street food sold in Ouagadougou [9] and a 50% contamination rate of lettuce samples with *Salmonella* in produce irrigated in lettuce samples irrigated with reservoir water [10]. Although raw lettuce is a recognized vector of microbiological risks [9, 11, 12] and despite regional studies on chemical and bacteriological contamination of vegetables, no recent study has simultaneously assessed these two types of contamination in lettuce sold in Bamako.

The objective of this study was therefore to determine the bacteriological and toxicological quality of lettuce sold in Commune I of Bamako, focusing on the detection of *Salmonella* spp. and the quantification of organochlorine pesticides.

Methods

• Study Area and Period

The study was conducted in Commune I of the Bamako district, one of the six communes of the Malian capital. Located on the left bank of the Niger River, in the northeastern part of the Bamako metropolitan area, this commune covers an area of 35.5 km². Its population was estimated at 513,863 inhabitants during the fifth General Population and Housing Census (RGPH) conducted in 2022 [2]. Samples were collected at four markets randomly selected within the municipality: Banconi, Korofina, Djelibougou, and Boulkassoumbougou.

• Sampling

Between January and May 2026, twenty composite samples of lettuce (*Lactuca sativa*), weighing approximately 600 g each, were randomly collected from each of the four markets in Commune I (Banconi, Korofina, Djelibougou, and Boulkassoumbougou), for a total of yielding eighty (80) samples (20 samples × 4 markets). The sample size was determined based on protocols from similar studies on lettuce quality, recommending 10 to 20 samples for bacteriological and chemical analyses. This sample size allows for a satisfactory level of statistical confidence while adhering to the laboratory's analytical constraints. Each sample was divided into two separate portions:

- 300 g for the analysis of pesticide residues (four target compounds)
- 300 g for testing for *Salmonella* spp.

The samples were immediately wrapped in aluminum foil, individually labeled, placed at + 4°C in an insulated cooler, and then transported to the Central Veterinary Laboratory (CVL) in Bamako, where they were stored until analysis.

• Analysis of Pesticide Residues

Sample Pretreatment

Each 300-gram sample of lettuce was cut into small pieces, then ground and homogenized using a blender. A 10 g portion of the resulting ground sample was taken for extraction.

Extraction using the QuEChERS method

The QuEChERS extraction protocol of the Central Veterinary Laboratory was applied to the lettuce samples by following the steps detailed in Table 1, in accordance with the provisions of standard NF EN 15662 [13]. After grinding and homogenization, 10 g of sample were weighed into a 50 mL polypropylene tube. Ten mL of acetonitrile were added, followed by a salt mixture (MgSO_4 , NaCl, and citrates) to induce phase separation and remove water. After manual shaking and centrifugation, the upper organic phase was transferred to a tube containing solid-phase dispersion purification (dSPE) agents: MgSO_4 (drying agent), PSA (to remove of fatty acids and sugars), and graphitized carbon black (GCB) to retain chlorophyll pigments. After a second centrifugation and filtration, the extract was ready for chromatographic analysis.

Table 1
Lettuce sample extraction procedure using the QuEChERS method

Step	Operation	Details & Reagents
1	Grinding and Homogenization	10 g of ground lettuce sample + 10 mL of acetonitrile
2	Addition of salts	4 g of anhydrous MgSO_4 + 1 g of NaCl + 1 g of trisodium citrate + 0.5 g of disodium citrate
3	Shaking	Vortex for 1 minute, followed by mechanical shaking for 5 minutes
4	Centrifugation	4,000 rpm for 5 minutes
5	Dispersive solid-phase extraction (dSPE)	6 mL of supernatant + 150 mg MgSO_4 + 50 mg PSA + 50 mg GCB, given the high chlorophyll pigment content of the lettuce
6	Second centrifugation	4,000 rpm for 5 minutes
7	Filtration	Using a 0.22 μm syringe filter (PTFE or nylon)

Analytical Standard Solutions

Individual analytical reference standards for four pesticides, with purities ranging from 96.3% to 98.5%, were obtained from Ehrenstorfer GmbH (Augsburg, Germany). An individual stock solution of each standard was prepared for identification and quantification by diluting reference standard in hexane for residue analysis ("residue" grade). A mixed solution containing the four standards was prepared by dissolving appropriate amounts in hexane to obtain a concentration of 5 mg/L. Subsequently, a five-point calibration series with the following concentrations of 0.0125, 0.25, 0.5, 0.1, and 0.125 $\mu\text{g/mL}$ was prepared and used for GC calibration. The characteristics of the four target pesticides are summarized in Table 2.

Table 2
Characteristics of the targeted pesticides

Pesticide	Chemical formula	Chemical family	WHO Class
Deltamethrin	$\text{C}_{22}\text{H}_{19}\text{Br}_2\text{NO}_3$	Pyrethroid	II (Moderately hazardous)
Endosulfan A	$\text{C}_9\text{H}_6\text{Cl}_6\text{O}_3\text{S}$	Organochlorine	II (Moderately hazardous)
Endosulfan B	$\text{C}_9\text{H}_6\text{Cl}_6\text{O}_3\text{S}$	Organochlorine	II (Moderately hazardous)
op'-DDT	$\text{C}_{14}\text{H}_9\text{Cl}_5$	Organochlorine	II (Moderately hazardous)

Chromatographic Analysis

The extracts were analyzed by gas chromatography (GC) using an Agilent Technologies 7890A chromatograph coupled with a micro-electron capture detector (μ ECD). The chromatographic conditions were as follows: HP-5MS capillary column, 30 m $\times$ 0.25 mm $\times$ 0.25 μ m, with nitrogen as the carrier gas at a make-up flow rate of 60 mL/min and a column flow rate of 1.6 mL/min. The oven temperature program consisted of three ramps: from an initial temperature of 70 to 150°C, then to 200°C, and a finally to 280°C. The detector was set to a temperature of 300°C and the injected sample volume was 1 μ L. Compound identification was performed by comparing the retention times observed in the chromatograms of the analyzed samples with those of the analytical standards. For each sample, the measured concentrations were compared with the maximum residue limits (MRLs) established by national health standards and international references (WHO/FAO).

The limits of detection (LOD) and quantification (LOQ), determined for each pesticide and expressed in mg/kg, are shown in Table 3.

Table 3
Retention times, LOD, and LOQ for the four target pesticides

Pesticide	Retention time (minutes)	Limit of Detection (LOD)(mg/kg)	Limit of Quantification (LOQ) (mg/kg)
Deltamethrin	13.101	0.00185	0.00309
Endosulfan A	29.294	0.00194	0.00324
Endosulfan B	31.602	0.00167	0.00278
op'-DDT	31.875	000197	0.00328

- **Detection of Salmonella spp.**

The detection of Salmonella spp. was performed in accordance with the horizontal standard NF EN ISO 6579 : 2002, which involved the following steps:

Pre-enrichment

A total of 25 g of lettuce was inoculated into 225 mL of buffered peptone water and incubated at 37°C $\pm$ 1°C for 24 h $\pm$ 3 h to revive potentially stressed bacterial cells.

Selective enrichment

One mL of the pre-enriched culture was transferred to 10 mL of sodium selenite broth and incubated at 37°C $\pm$ 0.5°C for 21 h $\pm$ 3 h to inhibit competitive flora while promoting the growth of Salmonella.

Isolation

Aliquots of the enrichment culture were then spread on *Salmonella-Shigella* (SS) agar and incubated at $37^{\circ}\text{C} \pm 1^{\circ}\text{C}$ for $24 \text{ h} \pm 3 \text{ h}$.

Interpretation

Colonies suspected of being *Salmonella* (colorless, with a black center characteristic of H_2S production) were streaked onto Tryptone Soy Agar. Identification was confirmed by the absence of oxidase activity, glucose fermentation without gas production, the absence of fermentation of lactose and sucrose, H_2S production (except for *S. typhi*), as well as the absence of urease and indole (using the API 20E biochemical panel). In accordance with standard NF EN ISO 6579, the presence of at least one colony confirmed as *Salmonella* spp. classified the sample as “non-compliant,” while the absence of any confirmed colonies classified it as “compliant.”

• Ethical Considerations

No ethical approval was required of this study because it did not involve human or animal subjects. Samples were collected at public markets without interfering with commercial activities.

Results

• Prevalence and Concentrations of Pesticide Residues

Four pesticides were analysed in the 80 lettuce samples. Concentrations below the limit of quantification (LOQ) were considered undetected. The overall prevalence of samples containing at least one pesticide residue at a concentration above the LOQ was 68.8% (55/80), while 31.2% (25/80) showed no detectable residues above the LOQ. Deltamethrin was the most frequently detected pesticide (47.5%, 38/80), followed by *o,p'*-DDT (27.5%, 22/80), Endosulfan A (18.8%, 15/80), and Endosulfan B (12.5%, 10/80). Concentrations ranged from 0.01 to 0.82 mg/kg, with the highest maximum concentration observed for *o,p'*-DDT (0.82 mg/kg). Exceedances of the maximum residue limit (MLR) were observed for Deltamethrin (2.5% of samples) and *o,p'*-DDT (5.0% of samples), while no sample exceeded the MLR for either endosulfan.

Results by Pesticide

Table 3 summarizes the analytical results for the four pesticides analyzed. For each compound, it reports the number and percentage of samples with detected residues ($> \text{LOQ}$), the observed concentration range, the median concentration, and, where applicable, the proportion of samples noncompliant with the maximum residue limit (MRL).

Of the 55 contaminated samples ($> \text{LOQ}$), the situation is as follows: the distribution of contamination is presented in Table 4

Table 4
Descriptive Summary of the Samples' status (n = 80)

Situation	Number of Samples	Percentage (sur 80)
A single pesticide was detected (> LOQ)	26	32.5%
Two or more pesticides (> LOQ)	29	36.25%
No residues detected (< LOQ)	25	31.2%
Total contaminated samples (> LOQ)	55	68.8%

The results show that the prevalence of residues > LOQ varies considerably depending on the compound :

Deltamethrin was the most frequently detected pesticide, with 47.5% of samples contaminated (38/80). This high prevalence may be explained by its common use in vegetable farming to control insect pests, particularly on leafy crops such as lettuce.

o,p'-DDT (a DDT metabolite) was found in 27.5% of samples (22/80). Its presence, although less frequent than that of deltamethrin, remains concerning because DDT has been banned in most countries for several decades. This detection suggests either exceptional environmental persistence (soil contaminated for years) or recent illicit use.

Endosulfan A and B had lower prevalences, at 18.8% (15/80) and 12.5% (10/80), respectively. Endosulfan is also an organochlorine banned in many countries, but its presence in lower proportions than o,p'-DDT could reflect historical residual contamination or more limited use.

Concentration Levels (min, max, median)

The measured concentrations are generally low (ranging from 0.01 to 0.82 mg/kg), but certain values warrant specific comments: o,p'-DDT showed the highest maximum concentration (0.82 mg/kg) and a median of 0.09 mg/kg. This indicates that some samples are significantly more contaminated than the average, suggesting "hot spots" of contamination (specific agricultural plots or particular farming practices). Deltamethrin showed a maximum concentration of 0.45 mg/kg and a median of 0.07 mg/kg, which remains moderate but significant. Endosulfans A and B had lower concentrations (max 0.31 and 0.18 mg/kg) and low medians (0.04 and 0.03 mg/kg), consistent with their lower prevalence

Exceedances of MRLs (maximum residue limits)

Deltamethrin: 2.5% of samples (2 out of 80 samples) exceed the MRL. While this rate remains low, it warrants vigilance, especially if these samples come from a specific area or supplier.

o,p'-DDT: 5.0% of samples (4 out of 80) exceed the MRL. This is the highest non-compliance rate in the table. For a banned pesticide (via its metabolite), any exceedance is particularly concerning and should

trigger an investigation into the source.

Endosulfan A and B: 0%. No sample exceeded the MRL, despite the presence of detectable residues. These levels, although not exceeding regulatory limits, indicate past residual contamination or chronic exposure to low doses.

- **Screening for Salmonella**

Overall Prevalence of Salmonella spp.

Of the 80 samples collected, the overall prevalence of Salmonella spp. (presence of typical colonies on SS agar: colorless with a black center) was 57.5% (46/80).

Variation in prevalence by sampling site

The prevalence of Salmonella spp. varied significantly by sampling site ($p < 0.01$). The highest values were observed in Boulkassoumbougou and Korofina, each with 65% of positive samples (13/20). Prevalences of 50% (10/20) were recorded in Djélibougou and Banconi, respectively. All detailed results by site are presented in Table 5 and illustrated in Fig. 1.

Table 5
Prevalence of Salmonella spp. by sampling site

Sampling site	Number of Samples (n)	Positive samples (n)	Prevalence (%)
Boulkassoumbougou	20	13	65
Korofina	20	13	65
Djélibougou	20	10	50
Banconi	20	10	50
Total	80	46	57.5

The differences between sites were statistically significant ($p < 0.05$). These spatial variations may be attributed to differences in hygiene practices, the type of organic fertilizers used, and the quality of the irrigation water.

Discussion

- **Pesticides residues**

The detection of pesticide residues in nearly 70% of samples from Bamako's urban and peri-urban agriculture is a significant warning sign, reflecting intensive and often inadequately controlled use of plant-protection products. This observation aligns with the broader context of Sub-Saharan Africa, where the intensification of urban agriculture, driven by rapid population growth and food demand, leads

farmers to rely heavily on pesticides to secure their production and income [14]. Our findings are corroborated by recent work in the same region. For instance, a 2024 study of the Baguineda irrigated perimeter and the Bamako district found that although a majority (89%) of pesticides used were approved, 11% were not, and detected Lambda-cyhalothrin and Acetamiprid in vegetable samples [15]. This indicates that pesticide use and residue detection persist in the area.

The high prevalence of deltamethrin, a WHO Class II pyrethroid (moderately hazardous), aligns with its widespread availability and frequent use against pests in vegetable crops. Its repeated detection, even at levels below the Maximum Residue Limits (MRLs), raises significant concerns about potential chronic health effects [8]. While acute toxicity is a risk, cumulative dietary exposure to pyrethroids is linked to chronic effects such as neurotoxicity and endocrine disruption. This is a regional pattern; for example, a study in the Niayes region of Senegal detected deltamethrin in all vegetable samples analyzed, though often at levels below the established MRLs [16].

The detection of o,p'-DDT, albeit less frequent, is a particularly concerning result. This organochlorine pesticide has been banned in most countries for decades due to its high environmental persistence and toxicity [17]. The detection of o,p'-DDT in our samples can be attributed to two scenarios:

Residual soil contamination: Due to its long half-life, which can exceed 15 years in soil, DDT residues can persist in the environment from historical agricultural use, leading to its uptake by plants long after its prohibition.

Recent illicit use: More worryingly, its presence could indicate ongoing, unreported, and illegal application by farmers to protect their crops.

The fact that 5% of samples exceeded the MRLs for certain compounds, as you noted, strongly reinforces the hypothesis of active persistence or recent use in specific production areas. This is not an isolated Malian issue; studies in Ghana have widely detected banned organochlorines such as p,p'-DDT, p,p'-DDE, and Endosulfan in vegetables such as cabbage and lettuce [18]. A study in Burkina Faso also detected a variety of banned organochlorine pesticides in water, soils, and sediments, often during the rainy season, suggesting their ongoing presence in the regional environment [19]. These observations from neighboring countries lend significant weight to our findings and point to a widespread regional challenge.

Similarly, the detection of Endosulfan A and B (18.8% and 12.5% of samples, respectively), another class of pesticides banned in many nations, is indicative of either residual environmental contamination from past use or, as with DDT, the possibility of continued unreported usage [20]. While none of the samples exceeded the MRLs for endosulfan, its presence is a serious cause for concern. The "cocktail effect" of multiple residues, even at low concentrations, is poorly understood but represents a significant, unquantified risk to human health. This aligns with the findings in Senegal, where Endosulfan was detected in samples from the Niayes region [16, 21] and in Burkina Faso, where similar endosulfan compounds were found in water and sediment samples [19].

The high prevalence of both currently used (deltamethrin) and banned organochlorine pesticides (DDT, endosulfan) points to a multifaceted problem. It confirms the intensive use of accessible pesticides in urban agriculture and simultaneously highlights a legacy of contamination and the potential for illegal, unregulated practices. This cocktail of residues, often present simultaneously, presents a complex public health challenge that demands immediate and continued attention.

- **Salmonella spp**

The overall prevalence of *Salmonella* spp. (57.5%, 46/80) is alarmingly high and demonstrates widespread fecal contamination of lettuce sold in Bamako. This rate is consistent with regional findings; *Salmonella* was isolated in 50% of lettuce samples irrigated with reservoir water in Ouagadougou [22] and up to 56% in Niger [23]. While a lower prevalence (17.9%) was reported in street foods in Burkina Faso [9], leafy vegetables consistently show higher contamination rates due to raw consumption and irrigation practices.

Significant spatial variations were observed ($p < 0.05$), with the highest prevalence in Korofina and Boulkassoumbougou (65% each) compared to Banconi and Djélibougou (50% each). These disparities likely stem from differences in irrigation water quality frequently untreated wastewater or surface water contaminated with human/animal feces as well as the use of uncomposted manure and poor post-harvest hygiene [12, 22]. The high prevalence at specific markets suggests supply chains with less rigorous agricultural practices.

From a public health perspective, lettuce consumed raw poses a direct risk of salmonellosis. The situation is exacerbated by the simultaneous detection of pesticide residues (68.8% of samples), creating a dual chemical and biological hazard. This combination highlights the urgent need for integrated interventions targeting water quality, farming practices, and market hygiene to protect consumer health

Conclusion

This first integrated assessment in Commune I of Bamako reveals significant contamination of lettuce by both chemical and microbiological hazards. Pesticide residues were detected in nearly 70% of samples, with deltamethrin being the most prevalent (47.5%). Critically, banned organochlorines *o,p'*-DDT (27.5%) and endosulfans (12.5–18.8%) were found, with 5% of samples exceeding MRLs for *o,p'*-DDT, indicating either environmental persistence or ongoing illegal use. Concurrently, *Salmonella* spp. contaminated 57.5% of samples, with rates reaching 65% in certain markets, confirming poor irrigation and hygiene practices.

Consuming this raw vegetable exposes the population to chronic chemical risks and acute gastrointestinal infections. To mitigate these threats, this study recommends: (i) strengthening health inspections and residue monitoring; (ii) promoting Good Agricultural Practices (GAPs), including safe pesticide use and composted manure; (iii) improving irrigation water quality through wastewater

treatment; (iv) educating consumers on proper washing and disinfection of vegetables; and (v) establishing an integrated "One Health" surveillance system for chemical and biological contaminants in the food chain.

Abbreviations

API 20E

Analytical Profile Index 20E

CVL

Central Veterinary Laboratory

DDT

Dichlorodiphenyltrichloroethane

d-SPE

Dispersive solid-phase extraction

FAO

Food and Agriculture Organization

GC

Gas chromatography

GC- μ ECD

Gas chromatography with micro-electron capture detector

GCB

Graphitized carbon black

IER

Institute of Rural Economics

INSP

National Institute of Public Health

LOD

Limit of detection

LOQ

Limit of quantification

MRL

Maximum residue limit

PSA

Primary secondary amine

SS agar

Salmonella-Shigella agar

WHO

World Health Organization

Declarations

Consent for publication

Not applicable. This study does not contain any individual person's data in any form (including individual details, images, or videos).

Availability of data and materials

The datasets generated and/or analyzed during the current study are available from the corresponding author upon reasonable request. The data are not publicly available due to institutional restrictions.

Competing interests

None of the authors have any competing financial or other interests that could influence or bias the contents of this paper.

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Authors' contributions

BMM (Boubacar Madio dit Aladiogo MAÏGA) conceived and designed the study, performed the pesticide residue analyses using the QuEChERS method and GC- μ ECD, analyzed the chemical data, and drafted the manuscript. IB, FD and MD supervised the sampling, performed the pesticide residue extractions and chromatographic analyses, and participated in data interpretation. AS, NC and KMK performed the *Salmonella* spp. Detection, biochemical confirmation tests (API 20E) and supervised the statistical analysis, interpreted the data, and critically revised the manuscript for important intellectual content. All authors read and approved the final version of the manuscript.

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Figures

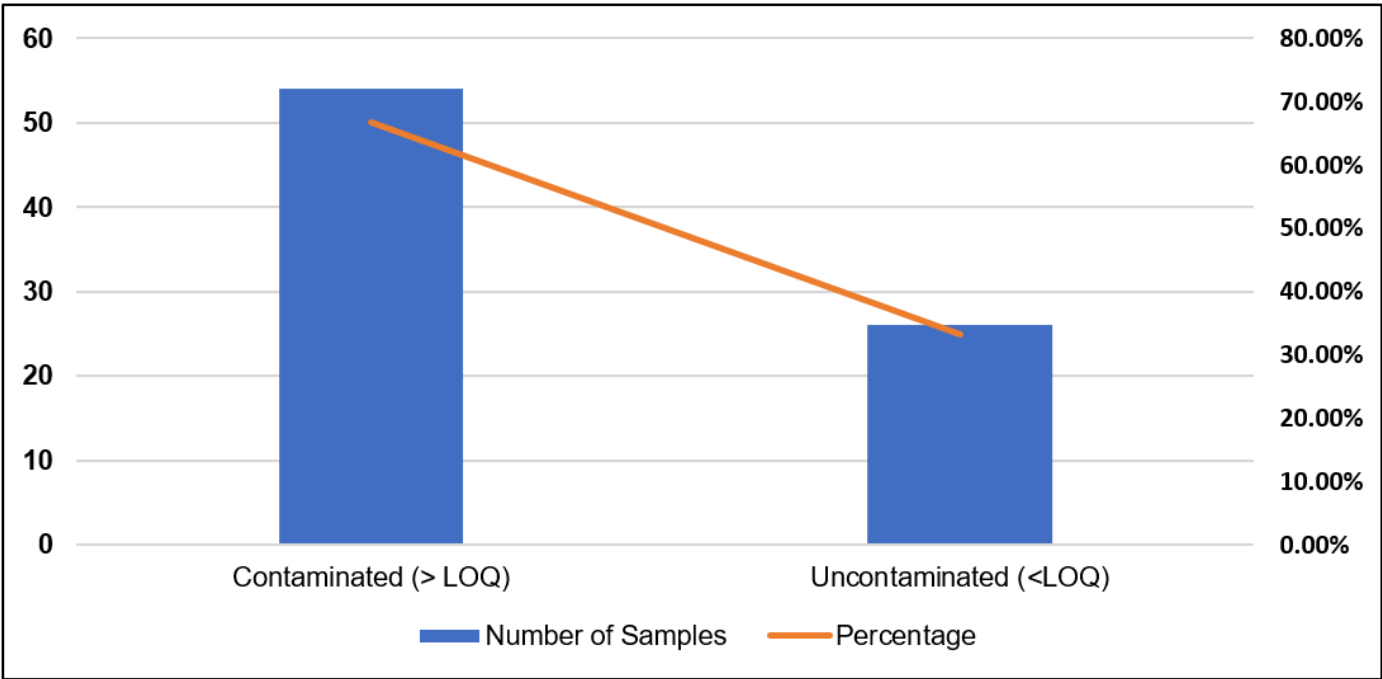


Figure 1

Prevalence of pesticide residues in lettuce: comparison between contaminated samples (> LOQ) and uncontaminated samples (< LOQ)

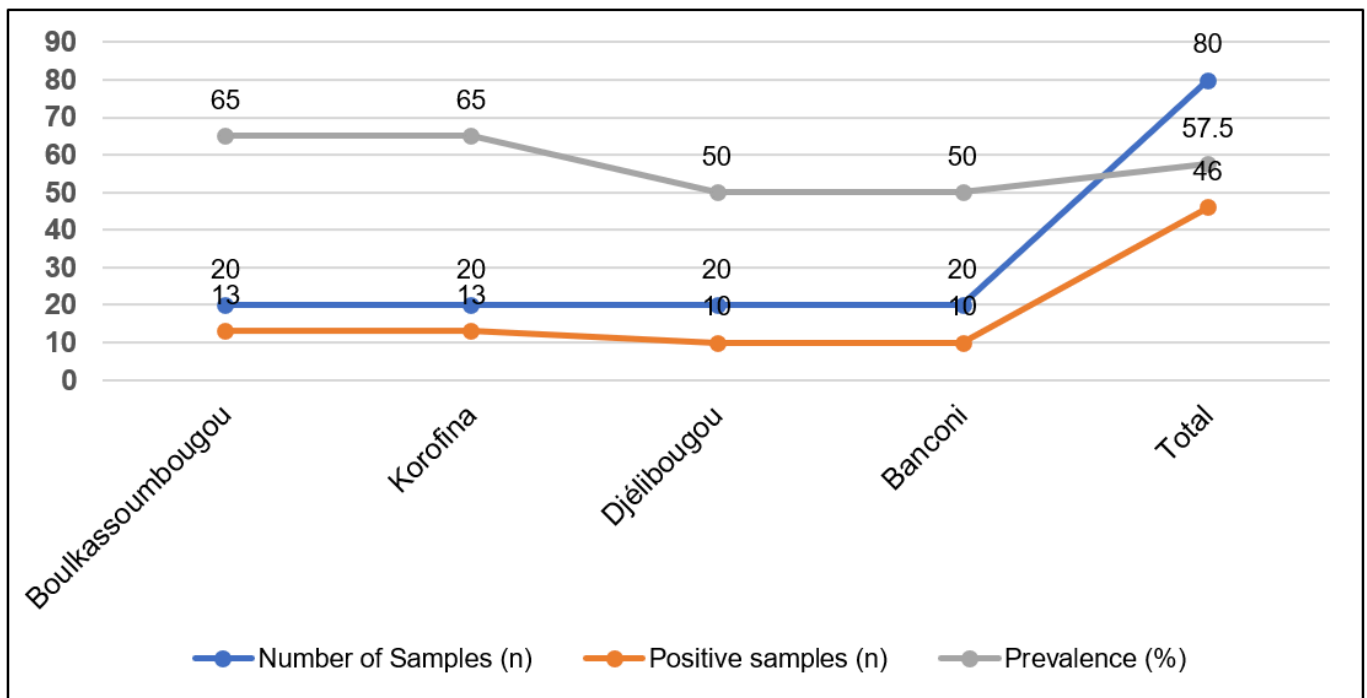


Figure 2

Prevalence of Salmonella spp. (%) by sampling site in Bamako, Mali.