

MARKET-BASED PESTICIDE RESIDUE SURVEILLANCE IN NEPAL: TEMPORAL TRENDS, COMMODITY PROFILES, AND GEOGRAPHIC TRACEBACK ANALYSIS FROM THE KALIMATI FRUITS AND VEGETABLE MARKET

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ABSTRACT

In Nepal, commercial vegetable production relies heavily on chemical pesticides; yet long-term market-level residue data remain scarce. This study presents a 12-year (FY 2014/15–FY 2025/26) analysis of pesticide residue screening at the Kalimati Fruits and Vegetable Market using the Rapid Bioassay for Pesticide Residue (RBPR), a method that detects organophosphate and carbamate residues through acetylcholinesterase (AChE) inhibition. Of 25,799 samples screened, 98.76% showed AChE inhibition below the RBPR action threshold, while 0.47% and 0.78% were classified as Yellow (quarantine) and Red (non-compliant), respectively. Red-category detection rates varied considerably among years, peaking in FY 2022/23 (1.60%; 16.0 per 1,000 samples), FY 2024/25 (1.43%), and FY 2016/17 (1.08%), but Mann-Kendall trend analysis indicated no statistically significant long-term monotonic trend ($\tau = 0.309$, $p = 0.213$). Trace-back of 154 Red-category samples (2021–Feb 2026) identified pronounced commodity- and location-specific concentration, with broadleaf mustard ($n = 36$; 23.4%) and cauliflower ($n = 21$; 13.6%) most frequently disposed. Geographic risk was concentrated in Bhaktapur, Sarlahi, and Dhading districts (50.6% of detections), while Lalbandi, Madhyapur Thimi, and Dhunibesi Municipalities emerged as critical production hotspots. Imported produce from India accounted for 7.8% ($n = 12$) of traced detections. A moderate, statistically significant positive correlation ($r = 0.61$, $p = 0.048$, $n = 11$) was observed between annual national insecticide imports and combined Yellow- and Red-category detections, although the exploratory nature of this analysis (11 annual observations) warranted cautious interpretation. These findings highlight the continued value of RBPR-based market surveillance and traceback investigations, while underscoring the need for commodity- and location-specific extension interventions and complementary confirmatory testing (e.g., GC–MS, LC–MS/MS) to address pesticide residue risks not captured by RBPR screening.

Keywords: Acetylcholinesterase inhibition, food safety, Kalimati wholesale market, Mann-Kendall trend test, Nepal, pesticide residue

INTRODUCTION

Pesticide application is a widespread agricultural practice in Nepal, driven by the need to maintain productivity and protect crops from insect pests, diseases, and weeds in increasingly intensive farming systems. Globally, total pesticide use reached approximately 3.73 million tons of active

ingredients in 2023, with Asia accounting for a major share of global consumption (FAO, 2025). In Nepal, pesticide use has increased steadily over the past decades, particularly in commercial vegetable production systems, where Vegetable account for the largest proportion of pesticide consumption among agricultural commodities (Sharma, 2015; Aryal et al., 2020). Although pesticides play an important role in safeguarding crop yields and quality, improper application practices, excessive dosages, inappropriate pesticide selection, and failure to observe recommended pre-harvest intervals may result in elevated pesticide residues in marketed produce, posing potential risks to consumers, farmers, and the environment (Atreya et al., 2012; GC & Neupane, 2019).

Monitoring pesticide residues in fresh produce has, therefore, become an important component of food safety and pesticide management programs worldwide. In Nepal, market-level pesticide residue surveillance relies primarily on the Rapid Bioassay for Pesticide Residue (RBPR), a rapid screening method that detects neurotoxic organophosphate and carbamate insecticides through inhibition of acetylcholinesterase (AChE) activity derived from the house fly, *Musca domestica* (Chiu et al., 1991; CAL, 2018). The use of house fly-derived AChE as a biological indicator is based on its sensitivity to inhibition by organophosphate and carbamate compounds, which interfere with normal cholinesterase activity (Chiu et al., 1991). The RBPR method was originally developed by the Taiwan Agricultural Research Institute (TARI) as an in vitro screening technique for rapid detection of pesticide contamination in agricultural commodities and has been used in Taiwan since the mid-1980s as part of a broader pesticide residue monitoring system (Kao et al., 2010; Aryal et al., 2020).

In Nepal, RBPR technology was introduced through the Entomology Division (latest name: National Entomology Research Centre) of the Nepal Agricultural Research Council (NARC) following specialized training conducted at TARI in June 2012. Subsequently, the first RBPR laboratory in Nepal was established at the Entomology Division, NARC, where testing of vegetable and tea samples for organophosphate and carbamate residues was initiated (Aryal et al., 2020). The successful implementation of the technique at the research level led to its adoption for routine market surveillance. As part of the Government of Nepal's efforts to strengthen pesticide residue monitoring and food safety regulation, a dedicated RBPR laboratory was established at the Kalimati Fruits and Vegetable Market on 18 June 2014 under the supervision of the Plant Protection Directorate (latest name: Plant Quarantine and Pesticide Management Centre) (Adhikari, 2018; Aryal et al., 2020). Since then, the laboratory has served as the principal facility for rapid screening of vegetable samples entering Nepal's largest wholesale market.

The RBPR assay is based on the inhibition of AChE activity. In uncontaminated samples, normal enzyme activity catalyzes a color-forming reaction that produces a yellow coloration, whereas the presence of organophosphate and carbamate residues inhibits enzyme activity and reduces color intensity. Based on AChE inhibition levels, samples showing less than 35% inhibition are classified as compliant under the RBPR screening system, samples exhibiting 35–45% inhibition are subjected to a quarantine period before market release, and samples exceeding 45% inhibition are classified as non-compliant and unsuitable for market distribution under the RBPR protocol (CAL, 2018). It is important to note, however, that these classifications apply only to pesticide groups detectable by the RBPR method and should not be interpreted as confirmation of the absence of residues from all pesticide classes. For samples exceeding the 45% threshold, the Kalimati Fruits and Vegetable Market Development Board (KFVMD) undertakes formal disposal procedures and records the

reported production origin of the commodity. These traceback records are subsequently used to identify potential sources of contamination and support targeted farmer counseling, awareness programs, and extension interventions aimed at promoting safer pesticide use practices (KFVMD, 2026).

Despite its operational advantages, RBPR has several limitations. The technique functions as a rapid screening assay rather than a confirmatory residue analysis and primarily detects organophosphate and carbamate insecticides through their inhibitory effects on AchE activity. Consequently, pesticide groups that do not inhibit AchE, including neonicotinoids, diamides, avermectins, many fungicides, herbicides, and other non-cholinesterase-inhibiting compounds, may not be detected through the AchE-based RBPR screening (CAL, 2017). Given the increasing use of newer pesticide chemistries in Nepalese vegetable production systems, RBPR results should, therefore, be interpreted as an indicator of potential contamination by AchE-inhibiting pesticides rather than a comprehensive assessment of all pesticide residues. Definitive identification and quantification of pesticide residues require confirmatory analytical techniques such as gas chromatography–mass spectrometry (GC–MS) or liquid chromatography–mass spectrometry (LC–MS/MS) (Aryal et al., 2020; Thapa & Pandey, 2025).

Although RBPR surveillance has been conducted continuously at Kalimati for more than a decade, the resulting information has generally been reported through annual summaries and administrative reports, with limited synthesis of long-term trends. Consequently, there remains a lack of published evidence describing temporal patterns of residue exceedance, commodity-specific occurrence, and geographic distribution of non-compliant samples over extended periods. Such information is essential for identifying priority commodities, targeting extension interventions, and strengthening evidence-based pesticide management strategies.

The Kalimati Fruits and Vegetable Market is the largest wholesale produce market in Nepal and serves as a major distribution hub supplying Vegetable to the Kathmandu Valley and surrounding regions. Owing to its central role in the national vegetable supply chain, the market provides a unique platform for monitoring pesticide residue issues in commercially traded produce. This study presents a 12-year analysis of RBPR surveillance data generated at the Kalimati market and integrates routine screening results with traceback records of non-compliant samples. Specifically, the objectives of this study were to: (i) characterize temporal trends in RBPR-based pesticide residue screening results at the Kalimati Fruits and Vegetable Market during FY 2014/15–FY 2025/26; (ii) examine the relationship between annual national insecticide import volumes and market-level Red-category detection rates; (iii) identify the vegetable commodities most frequently associated with Red-category (>45% AchE inhibition) detections; and (iv) characterize the district- and municipality-level geographic distribution of Red-category samples using traceback records.

MATERIALS AND METHODS

Study Site and Data Sources

This study utilized secondary surveillance and traceback datasets generated at the Kalimati Fruits and Vegetable Market (KFVWM), Kathmandu, Nepal. Two complementary datasets were used. The first

dataset consisted of annual pesticide residue surveillance records generated by the Rapid Bioassay for Pesticide Residue (RBPR) Laboratory located at KFVWM and operated by the Central Agricultural Laboratory (CAL), Ministry of Agriculture and Livestock Development. The dataset covered the period from 18 June 2014 to 28 February 2026 and included annual numbers of fruit and vegetable samples screened and classified into Green, Yellow, and Red categories according to the national RBPR operational guidelines. A total of 25,799 samples were screened during the study period. Data for 2025/26 represent samples analyzed up to February 2026. The surveillance dataset was obtained from annual reports and institutional records maintained by CAL.

The second dataset comprised traceback records maintained by the Kalimati Fruits and Vegetable Market Development Board (KFVMDB) as part of regulatory actions taken against non-compliant consignments. These records covered the period from January 2021 to February 2026 and contained information on commodity type, district and municipality/rural municipality of production, source country for imported produce, and RBPR inhibition results. During this period, 161 Red-category detections were reported, of which complete traceback information was available for 154 cases. The remaining seven records with incomplete origin information were excluded from geographic analyses.

The surveillance and traceback datasets were accessed with administrative permission from CAL and KFVMDB for research purposes. The study utilized institutional monitoring records and did not involve human participants.

RBPR Screening and Traceback Procedure

The present study used data generated exclusively from the insecticide-detection component of the RBPR system. The RBPR technique is a rapid screening method originally developed by the Taiwan Agricultural Research Institute for detection of organophosphate and carbamate insecticides through inhibition of acetylcholinesterase (AChE) activity obtained from house fly (*M. domestica*) tissue (Chiu et al., 1991). The method measures the toxicological effect of AChE-inhibiting insecticides rather than quantifying individual pesticide residues.

Samples were collected and analyzed according to the Standard Operating Procedures for Rapid Bioassay of Pesticide Residue Analysis Laboratory (CAL, 2017). Briefly, representative produce samples were collected from consignments arriving at the wholesale market, processed in the laboratory, and subjected to an AChE inhibition assay. Based on the percentage inhibition of enzyme activity, samples were classified as Green (<35% inhibition), Yellow (35–45% inhibition), or Red (>45% inhibition). The fungicide-detection component of RBPR was not included in this study.

When a sample was classified as Red, CAL formally notified KFVMDB for regulatory action. KFVMDB subsequently disposed of the affected consignment in accordance with national RBPR guidelines and conducted traceback investigations to identify the collector, trader, and production source associated with the consignment. Information on commodity type and production origin was recorded and communicated to the relevant Agriculture Knowledge Center (AKC), Agriculture Development Office, or local government agriculture unit for follow-up extension and awareness activities.

Statistical Analysis

Annual frequencies and percentages of Green, Yellow, and Red samples were calculated to describe surveillance outcomes over time. Temporal trends in Red-category detection rates were evaluated using simple linear regression and the Mann–Kendall trend test. Commodity-wise and geographic distributions of Red-category samples were summarized using frequencies, percentages, and ranked frequency distributions. The relationship between annual national insecticide imports (active ingredient, kg) and annual Yellow plus Red-category detection rates was examined using Pearson correlation analysis. Descriptive statistics were used to summarize inhibition percentages of Red-category samples. All analyses were performed using IBM SPSS Statistics version 20 and Microsoft Excel, and statistical significance was evaluated at $\alpha = 0.05$.

Study limitation: This study was based on routine surveillance and traceback records generated at a single wholesale market and utilized Rapid Bioassay of Pesticide Residue (RBPR) screening data, which primarily detects organophosphate and carbamate insecticides through acetylcholinesterase (AChE) inhibition. In addition, traceback information was available only for Red-category detections. Therefore, the findings should be interpreted within the scope of the RBPR surveillance system and may not fully represent pesticide-related risks across all pesticide groups, commodities, and production regions of Nepal.

RESULTS

Temporal Trends in RBPR Screening Results

Between FY 2014/15 and FY 2025/26, a total of 25,799 fruit and vegetable samples were screened using the insecticide-detection component of the Rapid Bioassay for Pesticide Residue (RBPR) system (Table 1). Green-category samples constituted the vast majority of samples screened throughout the study period, representing between 97.40% and 99.80% of annual samples. In contrast, Yellow- and Red-category samples consistently constituted less than 2% of the total samples tested annually. When pooled across all years, 98.76% of samples were classified as Green, 0.47% as Yellow, and 0.78% as Red.

Table 1. Annual RBPR screening outcomes for fruit and vegetable samples at the Kalimati Fruits and Vegetable Market, FY 2014/15–2025/26

Fiscal Year	Samples tested (N)	Green (Consumable) n (%)	Yellow (Quarentine) n (%)	Red (Discard) n (%)
2014/15	1,490	1,473 (98.86)	14 (0.94)	3 (0.20)
2015/16	1,857	1,840 (99.08)	8 (0.43)	9 (0.48)
2016/17	1,673	1,650 (98.62)	5 (0.30)	18 (1.08)
2017/18	1,510	1,507 (99.80)	1 (0.07)	2 (0.13)
2018/19	1,816	1,812 (99.78)	2 (0.11)	2 (0.11)
2019/20	1,876	1,850 (98.61)	9 (0.48)	17 (0.91)

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Fiscal Year	Samples tested (N)	Green (Consumable) n (%)	Yellow (Quarantine) n (%)	Red (Discard) n (%)
2020/21	2,044	2,026 (99.12)	10 (0.49)	8 (0.39)
2021/22	1,907	1,893 (99.27)	8 (0.42)	6 (0.31)
2022/23	2,883	2,808 (97.40)	29 (1.01)	46 (1.60)
2023/24	1,657	1,637 (98.79)	8 (0.48)	12 (0.72)
2024/25	4,189	4,104 (97.97)	25 (0.60)	60 (1.43)
2025/26*	2,897	2,879 (99.38)	1 (0.03)	17 (0.59)
Total	25,799	25,479 (98.76)	120 (0.47)	200 (0.78)

N = total number of samples tested; n = number of samples classified into the respective RBPR category. Percentages in parentheses are calculated based on the total number of samples tested (N) within each fiscal year. *FY 2025/26 data represent samples screened through February 2026. Green = <35% acetylcholinesterase (AChE) inhibition; Yellow = 35–45% AChE inhibition; Red = >45% AChE inhibition according to the RBPR operational guidelines (Sources: CAL (2024); KFVMDb (2026)).

The proportion of Red-category samples exhibited considerable year-to-year variation, ranging from 0.11% in FY 2018/19 to 1.60% in FY 2022/23. The highest Red-category detection rates were observed in FY 2022/23 (1.60%), FY 2024/25 (1.43%), and FY 2016/17 (1.08%), whereas the lowest rates occurred in FY 2018/19 (0.11%) and FY 2017/18 (0.13%). Although periodic peaks in Red-category detections were observed, Mann–Kendall trend analysis indicated no significant monotonic trend over the study period (Kendall's $\tau = 0.309$, $Z = 1.246$, $p = 0.213$). These findings suggest substantial inter-annual variability in high-AChE-inhibition detections but no evidence of a sustained long-term increase or decrease in Red-category occurrence (Fig. 1).

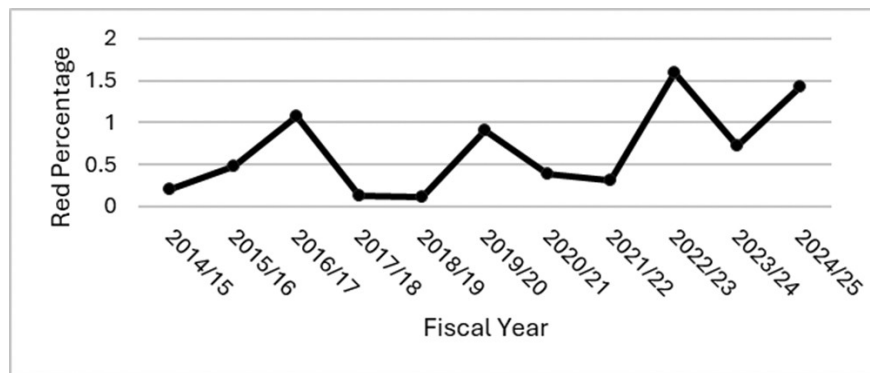


Fig. 1. Trend of Red-category samples (%) detected through RBPR screening at the Kalimati Fruits and Vegetable Market, FY 2014/15–2024/25. Mann–Kendall trend analysis indicated no significant monotonic temporal trend ($\tau = 0.309$, $p = 0.213$).

Relationship Between National Insecticide Imports and Red-Category Detections

National insecticide imports increased from 252,300 kg active ingredient in FY 2014/15 to 516,549 kg in FY 2024/25, representing a 104.7% increase over the study period (Table 2). During the same period, annual Yellow- and Red-category RBPR detections ranged from 3 to 85 samples per year.

Table 2. Annual insecticide imports and combined Yellow and Red-category RBPR detections, FY 2014/15–2024/25

Fiscal Year (AD)	Insecticide Imports (a.i. kg)	Combined Exceedances (Yellow + Red)
2014/15	252,300	17
2015/16	285,100	17
2016/17	312,400	23
2017/18	345,600	3
2018/19	368,200	4
2019/20	382,100	26
2020/21	412,500	18
2021/22	445,300	14
2022/23	478,900	75
2023/24	492,100	20
2024/25	516,549	85
Total	4,291,049	302

Note: Insecticide import data represent national annual imports of insecticide active ingredients (kg). Detection data represent the annual number of Yellow- and Red-category samples identified through RBPR screening at the Kalimati Fruits and Vegetable Market. (Sources: Plant Quarantine and Pesticide Management Centre (PQPMC, 2024) and CAL, 2024))

To explore whether national trends in insecticide availability were associated with market-level detections, Pearson correlation analysis was performed using annual insecticide import volumes and annual Yellow- plus Red-category detections. The analysis revealed a moderate positive association between the two variables ($r = 0.61$, $p = 0.048$, $n = 11$) (Fig. 2). The coefficient of determination ($R^2 = 0.37$) indicated that approximately 37% of the annual variation in Yellow- and Red-category detections was statistically associated with variation in national insecticide import volume.

Because the analysis was based on annual aggregated data with a relatively small number of observations ($n = 11$), the result should be interpreted as an exploratory association rather than evidence of a causal relationship. Additional factors, including pesticide-use practices, compliance with pre-harvest intervals, crop composition, and surveillance intensity, may also contribute to annual variation in RBPR detections.

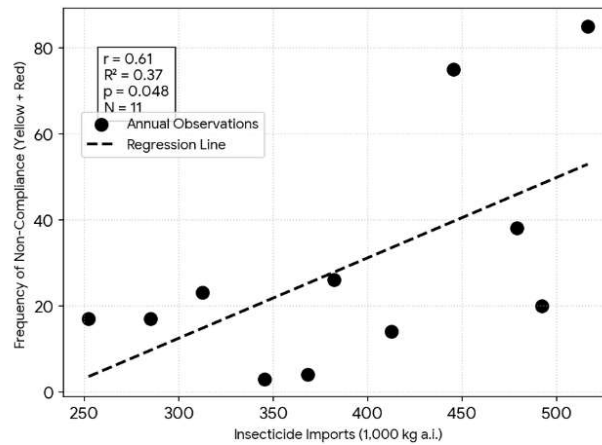


Fig. 2. Relationship between national insecticide imports and annual Yellow- plus Red-category RBPR detections at the Kalimati Fruits and Vegetable Market, FY 2014/15–2024/25.

Commodity-wise Distribution of Red-Category Detections

A total of 154 traceable Red-category samples were recorded between July 2021 and February 2026, representing 27 vegetable commodities (Table 3). The distribution of Red-category detections was highly uneven across commodities, with a relatively small number of crops accounting for the majority of disposals.

Broadleaf Mustard recorded the highest number of Red-category detections ($n = 36$; 23.4%), followed by Cauliflower ($n = 21$; 13.6%), Lablab Bean ($n = 15$; 9.7%), Yardlong Bean ($n = 10$; 6.5%), Broccoli ($n = 9$; 5.8%), and Tomato ($n = 9$; 5.8%). Collectively, these six commodities accounted for 100 of the 154 Red-category detections, representing 64.9% of all recorded disposals.

In contrast, several commodities were represented by only one or two detections during the study period, indicating sporadic occurrence of Red-category findings. For graphical presentation, commodities with two or fewer detections were grouped into an “Others” category.

The concentration of Red-category detections within a limited number of leafy Vegetable, cole crops, and leguminous Vegetable suggests that pesticide non-compliance, as detected by the RBPR screening system, was not uniformly distributed across commodity groups.

Table 3. Commodity-wise distribution of Red-category detections recorded through RBPR screening, July 2021–February 2026

Commodity	Frequency	Percentage (%)
Broadleaf mustard	36	23.38
Cauliflower	21	13.64
Lablab bean	15	9.74
Yardlong bean	10	6.49
Broccoli	9	5.84
Tomato	9	5.84
Akabare chilli	7	4.55
Cucumber	7	4.55
French bean	6	3.90
Others*	34	22.08
Total	154	100.00

*Others include commodities represented by two or fewer Red-category detections during the study period.

Geographic Traceback Analysis of Red-Category Detections

A total of 154 traceback records associated with Red-category detections were available for geographic analysis. The records originated from 12 districts of Nepal and imported consignments from India. The geographic distribution of traceback records was highly concentrated, with a limited number of production areas accounting for the majority of Red-category detections.

At the district level, Bhaktapur recorded the highest number of traceback records ($n = 30$; 19.5%), followed by Sarlahi ($n = 25$; 16.2%) and Dhading ($n = 23$; 14.9%) (Fig. 4). Together, these three districts accounted for 50.6% of all Red-category detections. Chitwan and Makawanpur each contributed 16 cases (10.4%), while Kathmandu and imported consignments from India each accounted for 12 cases (7.8%).

At the municipality level, Lalbandhi Municipality accounted for the largest proportion of traceback records ($n = 22$; 14.3%), followed by Madhyapur Thimi Municipality ($n = 20$; 13.0%) and Dhunibesi Municipality ($n = 19$; 12.3%) (Fig. 5). Thaha Municipality contributed 13 cases (8.4%), while Bharatpur Metropolitan City contributed 10 cases (6.5%). Collectively, these five localities accounted for 54.5% of all traceback records.

Produce imported from India accounted for 12 detections (7.8%) of the total traceback records. Four records lacked sufficiently detailed origin information for assignment to a specific municipality. Overall, traceback records were distributed across 30 municipalities and rural municipalities, although most contributed only a small number of detections.

The concentration of Red-category detections within a limited number of districts and municipalities suggests that pesticide-related non-compliance detected through RBPR screening is geographically clustered within specific production areas supplying the Kalimati Fruits and Vegetable Market.

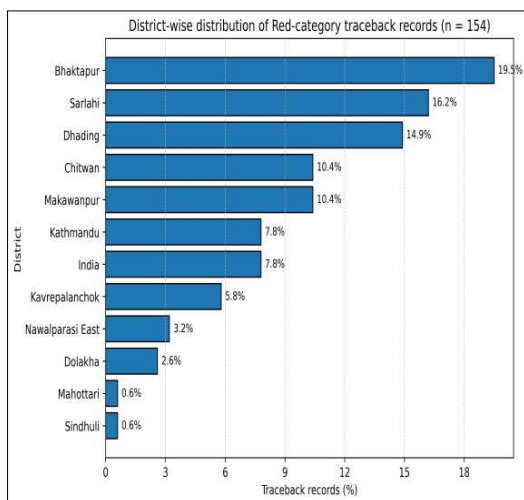


Fig. 4. District-wise distribution (%) of traceback records associated with Red-category RBPR detections at the Kalimati Fruits and Vegetable Market, 2021–2026 Feb. (n = 154).

Note: Percentages are based on 154 traceback records of Red-category samples (>45% AChE inhibition). Imported consignments from India are shown separately.

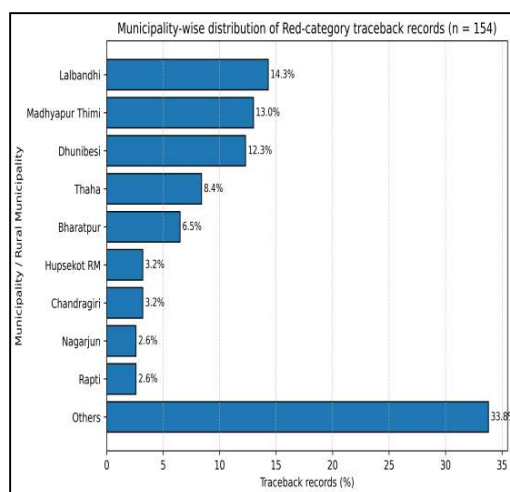


Fig. 5. Municipality-wise distribution (%) of traceback records associated with Red-category RBPR detections at the Kalimati Fruits and Vegetable Market, 2021–2026 Feb. (n = 154).

Note: Municipalities and rural municipalities with fewer than three traceback records were grouped as “Others”. Four records with missing municipality information (NA) were excluded from municipality-level classification.

DISCUSSION

The consistently high proportion of Green-category samples observed throughout the study period suggests that most fruits and Vegetable entering the Kalimati Fruits and Vegetable Market did not exceed the RBPR action threshold for organophosphate and carbamate insecticides. However, the continued occurrence of Yellow- and Red-category detections across all years indicates that pesticide-use practices requiring regulatory attention remain present within the vegetable supply chain. The persistence of these detections despite routine market surveillance highlights the continuing challenge of ensuring compliance with recommended pesticide-use practices at the farm level.

The absence of a significant monotonic trend in Red-category detections suggests that pesticide-related non-compliance has remained relatively stable over time rather than showing a sustained increase or decline. Similar variability in pesticide-use behavior and residue-related concerns has been reported in Nepalese vegetable production systems, where pesticide application practices vary considerably among production areas and growers (Shrestha, Koirala, & Tamrakar, 2010; Koirala et al., 2013). Evidence from commercial vegetable-growing areas of Nepal indicates that repeated

pesticide applications, inadequate use of protective measures, and limited adherence to recommended waiting periods before harvest continue to occur among some farmers (Shrestha et al., 2010). These factors may contribute to the recurring occurrence of Red-category detections observed in the present study.

The high proportion of Green-category samples observed in the present study should be interpreted within the analytical scope of the RBPR technique. Because the monitoring program targets AChE-inhibiting insecticides, the results primarily reflect risks associated with organophosphate and carbamate compounds. As pesticide use patterns continue to diversify in Nepal, complementary monitoring approaches capable of detecting a broader range of active ingredients will become increasingly important for comprehensive food-safety surveillance (Thapa & Pandey, 2025).

Beyond these temporal patterns, the relationship between national insecticide imports and market-level detections offers further context. The positive association between national insecticide import volumes and annual Yellow- and Red-category RBPR detections suggests that years with greater insecticide availability may also experience higher frequencies of pesticide-related detections in marketed produce. However, national import statistics represent aggregate pesticide availability and should not be interpreted as a direct measure of pesticide use or misuse at the farm level. Import volumes do not account for differences in cropping intensity, pest incidence, pesticide selection, application practices, or compliance with recommended pre-harvest intervals.

The moderate strength of the observed association indicates that insecticide availability alone is insufficient to explain annual variation in market-level detections. Consequently, insecticide import trends should be viewed as a broad contextual indicator rather than a direct predictor of pesticide-related detections. Future studies integrating residue surveillance records with farm-level pesticide-use information would provide a more comprehensive understanding of the factors influencing pesticide-related detections in Nepal's vegetable supply chain.

Turning to commodity-specific patterns, the distribution of Red-category detections was highly concentrated among a small number of commodities, with broadleaf mustard, cauliflower, lablab bean, yardlong bean, tomato, and broccoli accounting for nearly two-thirds of all recorded cases. This suggests that residue-related detections were commodity-specific rather than uniformly distributed across vegetable crops.

The predominance of broadleaf mustard may partly reflect the characteristics of leafy Vegetable. Due to their large exposed surface area, leafy Vegetable tend to retain greater amounts of pesticide deposits following spray applications and are therefore frequently identified as higher-risk commodities in residue-monitoring programs (Farha et al., 2018). In contrast, cauliflower and broccoli belong to the Brassica group, crops that commonly experience substantial insect pest pressure and consequently receive frequent insecticide applications during production (Sharma, 2015; Bhandari et al., 2018). Similarly, the relatively high occurrence of detections in lablab bean and yardlong bean may be associated with the repeated harvesting nature of pod Vegetable, although the present dataset does not permit direct evaluation of farm-level pesticide-use practices.

Overall, the findings indicate that residue-management efforts may be more effective when focused on specific high-risk commodity groups rather than applied uniformly across all Vegetable.

Traceback-based surveillance therefore provides a useful mechanism for identifying priority commodities requiring targeted monitoring, extension support, and farmer awareness interventions.

In addition to these commodity-specific patterns, the traceback analysis also revealed a marked geographic concentration of Red-category detections within a relatively small number of production areas supplying the Kalimati Fruits and Vegetable Market. More than half of all traced detections originated from three districts—Bhaktapur, Sarlahi, and Dhading—while five municipalities (Lalbandhi, Madhyapur Thimi, Dhunibesi, Thaha, and Bharatpur) accounted for over half of all traceback records. These findings indicate that pesticide-related non-compliance detected through RBPR screening is spatially clustered rather than evenly distributed across production areas.

The observed clustering is consistent with the concentration of commercial vegetable production in these districts and municipalities. Previous studies have reported that vegetable farming systems supplying major urban markets in Nepal are typically characterized by intensive cultivation, multiple cropping cycles, and comparatively high pesticide use, particularly for insect pest management (Sharma, 2015; Bhandari et al., 2018). Such production systems may increase the likelihood of pesticide-related detections when recommended pesticide-use practices are not consistently followed; a recent survey of vegetable farmers in Madhyapur Thimi Municipality, one of the leading production hotspots identified in this study, similarly reported gaps in farmer knowledge and practice around safe pesticide use (Suwal et al., 2025). However, because the present study analyzed only traceback records associated with Red-category detections, the findings should be interpreted as patterns of geographic origin rather than direct measures of district-level residue risk.

The identification of recurring geographic hotspots has important practical implications for pesticide-risk management. Traceback information can assist regulatory agencies, extension services, and local governments in prioritizing monitoring, farmer training, and awareness programs in production areas that repeatedly contribute to Red-category detections. Similar studies have emphasized the value of targeted interventions, as pesticide-use behaviors, safety practices, and compliance with recommended guidelines often vary among farming communities and production regions (Bhandari et al., 2018; Atreya, 2007). Consequently, integrating traceback-based surveillance with extension and Integrated Pest Management (IPM) programs may improve the effectiveness of efforts to reduce pesticide-related detections in Vegetable entering major wholesale markets.

CONCLUSIONS

This study showed that the vast majority of fruit and vegetable samples screened through the Rapid Bioassay for Pesticide Residue (RBPR) system remained below the action threshold for organophosphate and carbamate insecticides. However, Yellow- and Red-category detections occurred throughout the study period, indicating the continued occurrence of pesticide-related detections within the supply chain. Red-category detections showed substantial year-to-year variation but no significant long-term temporal trend.

Red-category detections were concentrated within a limited number of commodities and production areas, indicating that pesticide-related detections identified through RBPR screening were not uniformly distributed across commodities or production regions. These findings support targeted

surveillance and extension interventions focused on repeatedly implicated commodities and production clusters.

While RBPR provides a practical and cost-effective screening tool for organophosphate and carbamate insecticides, integration with confirmatory multi-residue analytical techniques such as GC–MS and LC–MS/MS would strengthen national pesticide residue monitoring and provide a more comprehensive assessment of food-safety risks in Nepal.

ACKNOWLEDGEMENTS

The authors gratefully acknowledge the Central Agricultural Laboratory (CAL) for providing accessible pesticide residue data and the Kalimati Fruits and Vegetable Market Development Board (KFVMDDB) for internal trace-back records. The insights drawn from these datasets were essential for conducting a comprehensive analysis of market-level pesticide residue trends in Nepal.

REFERENCES

- Adhikari, P. R. (2018). An overview of pesticide management in Nepal. *Journal of Agriculture and Environment*, 18, 95–105. doi:10.3126/aej.v18i0.19894
- Aryal, S., Dangi, N., & Simkhada, R. (2021). Trends in pesticide use in different agricultural commodities and residues in Nepal. In S. L. Shyaula, G. B. Bajracharya, G. B. K. C., S. M. Shakya, & D. Subba (Eds.), *Comprehensive insights in vegetables of Nepal* (pp. 461–483). Khumaltar, Lalitpur, Nepal: Nepal Academy of Science and Technology (NAST).
- Atreya, K. (2007). Pesticide use knowledge and practices: A gender differences in Nepal. *Environmental Research*, 104(2), 305–311. doi:10.1016/j.envres.2007.01.001
- Atreya, K., Sitaula, B. K., Overgaard, H., Bajracharya, R. M., & Sharma, S. (2012). Knowledge, attitude and practices of pesticide use and acetylcholinesterase depression among farm workers in Nepal. *International Journal of Environmental Health Research*, 22(5), 401–415. doi:10.1080/09603123.2011.650154
- Bhandari, G., Atreya, K., Yang, X., Fan, L., & Geissen, V. (2018). Factors affecting pesticide safety behaviour: The perceptions of Nepalese farmers and retailers. *Science of the Total Environment*, 631–632, 1560–1571. doi:10.1016/j.scitotenv.2018.03.144
- Central Agricultural Laboratory (CAL). (2017). *Standard operating procedures for rapid bioassay of pesticide residues analysis laboratory*. Lalitpur, Nepal: Plant Protection Directorate. Retrieved from <https://centralaglab.gov.np/sites/default/files/publication-file/SOP%20of%20RBPR-2075-74608.pdf>
- Central Agricultural Laboratory (CAL). (2018). *Pesticide residue rapid analysis program operation guideline, 2075*. Lalitpur, Nepal: Ministry of Agriculture and Livestock Development. Retrieved from <https://centralaglab.gov.np/sites/default/files/publication-file/विषादी-अवशेष-दुन-विश्लेषण-कार्यक्रम-संचालन-निर्देशिका-२०७५-83551.pdf>

- Central Agricultural Laboratory (CAL). (2024). *Annual progress report, fiscal year 2023/24*. Kathmandu, Nepal: Ministry of Agriculture and Livestock Development. Retrieved from <https://centralaglab.gov.np/sites/default/files/publication-file/Book.pdf>
- Chiu, C. S., Kao, C. H., & Cheng, E. Y. (1991). Rapid bioassay of pesticide residues (RBPR) on fruits and vegetables. *Journal of Agricultural Research of China*, 40(2), 188–203. doi:10.29951/JARC.199106.0008
- Food and Agriculture Organization (FAO). (2025). *Pesticides use and trade, 1990–2023*. Rome, Italy: Food and Agriculture Organization of the United Nations. Retrieved from <https://www.fao.org/statistics/highlights-archive/highlights-detail/pesticides-use-and-trade-1990-2023/en>
- Farha, W., Abd El-Aty, A. M., Rahman, M. M., Jeong, J. H., Shin, H. C., Wang, J., & Shim, J. H. (2018). Analytical approach, dissipation pattern and risk assessment of pesticide residue in green leafy vegetables: A comprehensive review. *Biomedical Chromatography*, 32(1), e4134.
- GC, S., & Neupane, J. (2019). Pesticides use in Nepal and its effects on human health: A review. *Acta Scientific Agriculture*, 3(11), 114–117. doi:10.31080/ASAG.2019.03.0694
- Kalimati Fruits and Vegetable Market Development Board (KFVMD). (2026). *Internal market surveillance and traceback records of pesticide residue monitoring (2014–2026)* [Unpublished internal records]. Kathmandu, Nepal.
- Kao, C. H., Hsieh, Y. S., Chiang, M. Y., & Huang, Y. B. (2010). Residues control by using rapid bioassay of pesticide residues (RBPR) for market inspection and farm education. In C. C. Huang, C. M. Yang, S. K. Ou, & J. J. Chen (Eds.), *Technology on reducing post-harvest losses and maintaining quality of fruits and vegetables: Proceedings of 2010 AARDO Workshop, 3–9 Oct. 2010* (pp. 72–82). Taiwan Agricultural Research Institute, Council of Agriculture, Taiwan, ROC.
- Koirala, P., Tamrakar, A. S., Bhattarai, B. P., Yadav, B. K., Humagain, S., & GC, Y. D. (2013). Use and handling practice of pesticides in vegetables: A case study on some selected districts of Nepal. *Journal of Food Science and Technology Nepal*, 6, 105–109. doi:10.3126/jfstn.v6i0.8270
- Plant Quarantine and Pesticide Management Centre (PQPMC). (2024). *Pesticide import and consumption statistics*. Kathmandu, Nepal: Ministry of Agriculture and Livestock Development, Government of Nepal.
- Sharma, D. R. (2015). Use of pesticides and its residue on vegetable crops in Nepal. *Journal of Agriculture and Environment*, 16, 33–42. doi:10.3126/aej.v16i0.19838
- Shrestha, P., Koirala, P., & Tamrakar, A. S. (2010). Knowledge, practice and use of pesticides among commercial vegetable growers of Dhading District, Nepal. *Journal of Agriculture and Environment*, 11, 95–100. doi:10.3126/aej.v11i0.3656
- Suwal, R., Rajbhandari, A. K., Shrestha, V. L., Bataju, M., Sharma, M., & Khatri, B. (2025). Knowledge, attitude and practice on pesticide use among vegetable farmers in Madhyapur

Thimi Municipality, Nepal: An observational study. *Journal of Nepal Medical Association*, 63(287), 467–473. doi:10.31729/jnma.9110

Thapa, S., & Pandey, P. R. (2025). Monitoring pesticide residues in Nepal's fruits and vegetables: A review of practices, gaps, and solutions. *Nepalese Horticulture*, 19(1), 31–42. doi:10.3126/nh.v19i1.86688