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Impact of Regulatory Interventions on Ethylene Oxide Residues in Chili Powder for Instant Noodles in Indonesia

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ABSTRACT

Ethylene oxide residues in food have become a major global food safety concern and are classified as Group 1 carcinogens by the International Agency for Research on Cancer (IARC). This study aimed to characterize ethylene oxide levels in chili powder used in instant noodles and to evaluate the effectiveness of policy interventions in reducing ethylene oxide residues. A descriptive-comparative design was applied, using laboratory testing data collected before and after policy implementation. Data were derived from the National Agency for Drug and Food Control (NADFC/BPOM) surveillance in 2023 and from GC-MS/MS analyses of chili powder samples obtained from supermarkets and e-commerce platforms. The results demonstrated a substantial reduction in ethylene oxide residues, with mean levels decreasing from 4.923 µg/kg to 0.463 µg/kg and maximum levels from 25 µg/kg to 1.5 µg/kg. The difference was statistically significant (Mann–Whitney U test, $p < 0.05$). All post-policy samples complied with the established maximum residue limits. These findings indicate a change in the ethylene oxide residue profile that is consistent with strengthened contaminant control following policy implementation and underscore the importance of continuous risk-based food safety management.

1. INTRODUCTION

Food safety is critical to ensuring that food consumed by the public is safe, hygienic, high-quality, nutritious, and consistent with the community's religious, cultural, and traditional values. Safe food must be protected from physical, chemical, and microbiological hazards that could endanger human health. Managing these hazards has become increasingly complex because even minor changes in the production chain can significantly affect product safety (Motarjemi *et al*., 2023). One chemical contaminant of current international concern is ethylene oxide (EtO). This compound is widely used as a sterilizing agent and fumigant due to its ability to control pathogenic microorganisms, particularly in dry foodstuffs such as grains and spices (Dudkiewicz *et al*., 2022).

Ethylene oxide is a reactive epoxide used to produce chemicals such as ethylene glycol, glycol ethers, ethanolamine, ethoxylates, and acrylonitrile, as well as for the sterilization of food, spices, and medical equipment. Ethylene oxide is considered carcinogenic in animals based on observations of increased tumor incidence in rats exposed to EtO (Kirman *et al*., 2021; Lynch *et al*., 2022).

Ethylene oxide is known to induce tumors in laboratory animals through oral and inhalation exposure and to form adducts with proteins and DNA in humans and animals. The International Agency for Research on Cancer (IARC) upgraded the status of EtO from Group 2A (probably carcinogenic to humans) to Group 1 (carcinogenic to humans) in 1994, based on increasing epidemiological evidence (Fowles *et al*., 2001). Research indicates that EtO can cause tumors in both laboratory animals and humans through direct genotoxic mechanisms resulting from exogenous exposure, including from the environment and EtO-contaminated food (IARC, 2008; Jinot *et al*., 2018).

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The use of EtO in food has been banned in several regions, including the European Union, since 1991 (Fowles *et al*., 2001). However, EtO contamination in food products continues to be reported through the Rapid Alert System for Food and Feed (RASFF), particularly in sesame seeds, spices, and spice-based processed products (Pigłowski, 2022).

The 2020 case of EtO contamination in sesame seeds in Europe triggered the detection of EtO residues in various other food commodities, including spices, food additives, and processed food products (Kowalska & Manning, 2022). From September 2020 to February 2025, more than 900 EtO notifications were reported in the RASFF system, including several notifications regarding food products from Indonesia (Chung & Buchanan, 2026).

The urgency of this research is reinforced by the high consumption of instant noodles in Indonesia. Indonesia is the world's second-largest consumer of instant noodles, with consumption increasing from 12.64 billion servings in 2020 to 14.68 billion servings in 2024 (WINA, 2025). National consumption of 80 g packaged instant noodles ranges from 44.11 to 49.72 packs per capita per year during the 2020-2024 period (PUSDATIN, 2024). Data on annual national instant noodle production remains limited. The scale of this industry is also reflected in the production capacity of one of Indonesia's major instant noodle manufacturers, which reaches 30-34 billion packs per year. High consumption and substantial industrial capacity underscore the importance of monitoring chemical contaminants in instant noodles, including accompanying ingredients such as chili powder.

Spices such as chili powder are commodities at high risk of microbiological contamination, particularly by *Salmonella*, so fumigation is often performed to ensure product safety (Bourdoux *et al*., 2016). Foods with low moisture content, including spices, can serve as a medium that allows *Salmonella* to survive in dry conditions for extended periods (Wason *et al*., 2021). The use of EtO in such fumigation processes can lead to residues if not properly controlled.

The issue of EtO contamination in Indonesia gained attention following notifications in the RASFF system regarding several instant noodle products during the 2022–2025 period. In response, the government, specifically the National Agency for Drug and Food Control (NADFC/BPOM), established risk mitigation policies for EtO contaminants in food products, including maximum residue limits (MRLs) and strengthened oversight.

Although several studies have reported EtO residues in spices and dried food products across various countries, empirical evidence on EtO residues in chili powder used in instant noodles in Indonesia remains very limited. This gap is important because instant noodles are widely consumed in Indonesia. As a spice-based dry food matrix, chili powder may be a critical control point for EtO residues, especially if raw materials undergo fumigation without adequate residue control. The primary gap in the literature is the limited availability of laboratory-based evaluations measuring changes in the EtO concentration profile of chili powder in instant noodles before and after the implementation of risk mitigation policies in Indonesia. Consequently, the effectiveness of these policies in supporting EtO residue control in marketed products has not yet been adequately assessed. This study addresses that gap by analyzing EtO concentration profiles in chili powder used in instant noodles and assessing preliminary indications of the effectiveness of regulatory implementation in reducing residues, based on laboratory test data collected before and after the implementation of risk mitigation policies. The results are expected to provide empirical evidence to support food safety policy evaluations and strengthen the chemical contaminant monitoring system for processed food products in Indonesia.

2. MATERIALS AND METHODS

The study was conducted from February to December 2024. Samples were collected from supermarkets and convenience stores in the Greater Jakarta area and from e-commerce platforms in other regions of Indonesia. Sample testing was conducted at the LPPOM MUI laboratory in Bogor, which is accredited by the National Accreditation Committee.

2.1. Tools and Material

The tools used in this study included Gas Chromatography-Mass Spectrometry/GC-MS/MS (GC-2030 Nexis/TQ8050, Shimadzu), Agilent QuEChERS Dispersive SPE high pigment clean-up kit (150 mg primary and secondary amines, 850 mg magnesium sulphate, 45 mg GCB), analytical balance, volumetric flasks, vortex mixer, beakers, 20 mL headspace vials, centrifuge (DM0412, DLAB), 15 ml shaking tubes (MPS-1, Biosan), volumetric pipettes, and dropper pipettes.

The materials used in this study were chili powder samples from domestically produced instant noodle products (n = 74) obtained from supermarkets and convenience stores in the Greater Jakarta area and e-commerce platforms in other regions of Indonesia, along with data from NADFC reports on EtO residue surveillance of chili powder in instant noodles. Other materials used for EtO testing included acetonitrile (chromatography grade, CAS No. 75-05-8, Merck), helium gas (ultra-high purity grade, CAS No. 7440-59-7, Merck), and argon gas (ultra-high purity grade, CAS No. 7440-37-1, Merck). Data were processed quantitatively using Microsoft Excel and SPSS Version 27.

2.2. Research Design

This study was conducted in four stages: (1) collection and processing of 2023 surveillance data from the NADFC; (2) identification and selection of instant noodle samples for testing in 2024; (3) testing of EtO in chili powder samples using the GC–MS/MS method; (4) descriptive comparative analysis to evaluate differences in EtO residue concentrations between the 2023 NADFC surveillance results and the 2024 testing results.

2.2.1. Collection and Processing of NADFC Surveillance Data

This study used data from NADFC surveillance of EtO residues in chili powder in instant noodle products conducted in 2023. The data were obtained from testing and surveillance of imported and exported processed foods in Indonesia, collected by the NADFC Center for Drug and Food Studies. EtO testing of chili powder samples was performed using the solid phase extraction (SPE) with QuEChERS and GC-MS/MS.

2.2.2. Identification and Selection of Instant Noodle Samples

Sample identification was based on data on instant noodle products registered with the NADFC and available in the Indonesian market in 2024. The sample size (n) was determined from population size (N) using the Slovin method with a 10% sampling error (ε), based on the total population of products available in Indonesia (Pourhoseingholi *et al*, 2020), using the following formula:

$$n = \frac{N}{1+N\varepsilon^2} \quad (1)$$

Sampling was conducted using a market-based purposive sampling approach with the following criteria: instant noodle products registered with the NADFC and available in Indonesia; products containing a separate chili powder packet; products within their expiry date; products with clear identification; and products available at the sampling sites during the study period. This approach was used because the study focused on chili powder as a matrix at risk for EtO residues. Samples were obtained from supermarkets and convenience stores in the Greater Jakarta area, as well as e-commerce platforms covering other regions of Indonesia.

2.2.3. Ethylene Oxide Testing of Chili Powder

Ethylene oxide testing was conducted at the LPPOM MUI laboratory in Bogor using the GC-MS/MS method in accordance with the guidelines of the European Reference Laboratories for Residues of Pesticides (Perestrelo *et al*., 2019). A total of 20 chili powder packets from each instant noodle brand with the same batch number were combined and homogenized to obtain a composite sample. The composite approach was used to obtain the average EtO content of the tested samples and meet the minimum sample requirement for laboratory analysis. This approach has limitations because it may reduce the ability to detect content variations between batches. Therefore, the test results should be interpreted as the EtO content of the composite sample, not as batch-level variation.

Exactly 1 g sample was extracted using 1-2 mL of acetonitrile and homogenized using a shaker for 15 min at 20°C. The sample was then centrifuged for 5 minutes at 5,000 rpm at 10°C. A total of 100 µL of the supernatant was pipetted into a 20 mL headspace vial and analyzed quantitatively by GC–MS/MS to determine the EtO concentration. Ethylene oxide standard solutions were prepared through serial dilution of a 50,000 mg/L stock solution with acetonitrile until a 0.1 mg/L working standard solution was obtained. A blank solution was prepared using acetonitrile without the analyte. The limit of detection (LOD) for EtO was 0.19 µg/kg, while the limit of quantification (LOQ) was 0.94 µg/kg.

2.2.4. Data Analysis

Ethylene oxide concentrations are presented as the minimum value, the 5th percentile (P5), the mean, the 95th percentile

(P95), and the maximum value. Data with undetectable results (below the LOD) were imputed as ½ LOD when they accounted for 60% or less of the total samples (Hwang *et al*., 2023).

Data analysis was conducted using descriptive-comparative methods to evaluate changes in EtO residue concentrations in chili powder used in instant noodles from 2023 (based on NADFC surveillance) to 2024 (based on testing of samples), before and after the implementation of the EtO health risk mitigation policy. The 2023 and 2024 testing data represent sampling results intended to describe the EtO concentration profile in instant noodle products circulating in Indonesia; they do not constitute a paired comparison of the same brands. Comparisons were made using the aggregate of all samples rather than specific brands. The EtO residue testing results were compared with the MRLs established under NADFC Head Decision No. 229 of 2022, which was implemented in 2023, to assess product compliance with applicable standards.

Data analysis was performed statistically using the Mann–Whitney U test to determine significant differences in EtO residue concentrations between the periods before and after the policy implementation. The test was conducted at a 95% significance level ($\alpha = 0.05$). All data processing was performed using Microsoft Excel and SPSS Version 27.

3. RESULTS AND DISCUSSION

3.1. Identification of Types of Instant Noodles in Indonesia

According to 2024 data from the NADFC, 1,400 instant noodle products were registered, comprising 985 domestic (MD) and 415 imported (ML) products. A survey of products in circulation found that 700 products were currently on the market, comprising 590 domestic products and 110 imported products. The profile of registered and circulating instant noodle products in Indonesia is shown in Figure 1 and 2 for domestic and imported products, respectively.

The largest manufacturer of MD products with marketing authorization is PT Indofood CBP Sukses Makmur Tbk, accounting for 39% of registered MD products and 42% of circulating MD products. The largest importer of ML products is PT Koin Bumi (24% of registered ML products). In comparison, the most widely distributed ML products are imported by PT Sukanda Djaya (15% of circulating ML products). This aligns with previous research indicating that Indonesia's instant noodle industry is dominated by PT Indofood CBP Sukses Makmur Tbk, one of the food companies with an extensive production and distribution network across domestic and international markets (Wibowo *et al*., 2024).

The discrepancy between the number of registered products and those in circulation reflects the dynamics of the food supply chain and market distribution, which are influenced by logistics systems, consumer demand, and supply chain management focused on product safety and quality (Patidar *et al*., 2022). This discrepancy has implications for risk-based surveillance strategies. Products with marketing authorization are not necessarily available in the indonesian

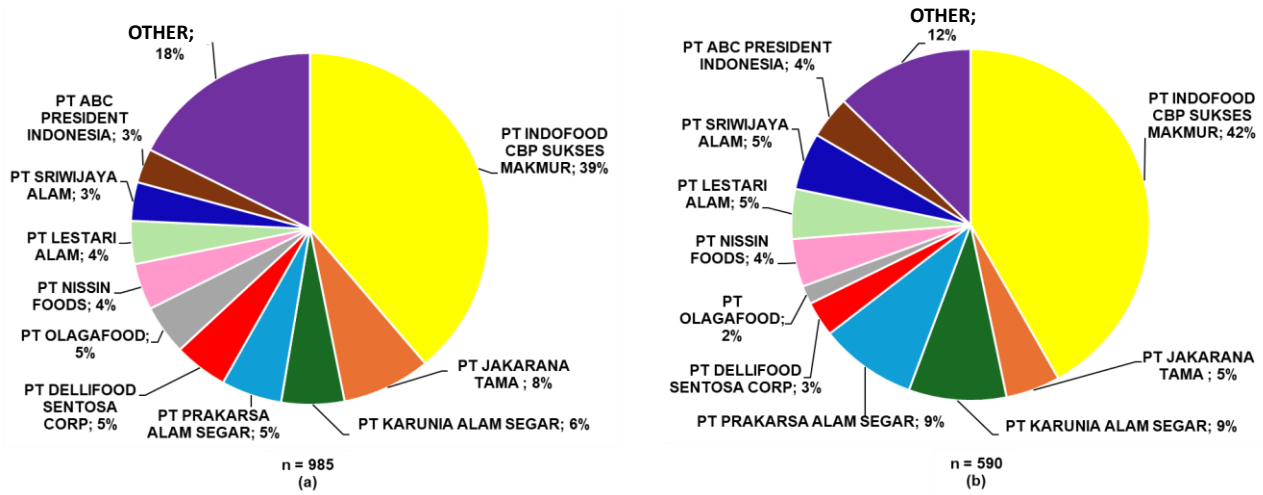


Figure 1. Profile of domestic instant noodle products in Indonesia: (a) registered products, (b) products in circulation

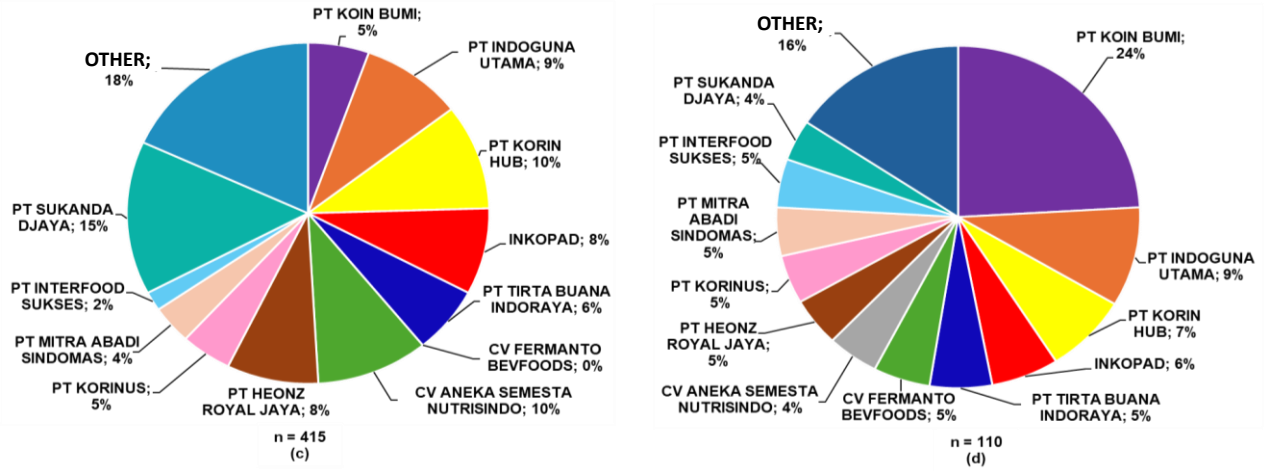


Figure 2. Profile of imported instant noodle products in Indonesia: (a) registered products, (b) products in circulation

market. Sampling products that are in circulation is therefore important for identifying more relevant risks. The dominance of certain manufacturers or importers also indicates that surveillance should consider not only the number of products but also the distribution scope, circulation volume, and each business operator's contribution to potential population exposure. Product profile data can serve as a basis for setting risk-based sampling priorities, particularly for products with wide distribution and high-risk raw material components such as chili powder.

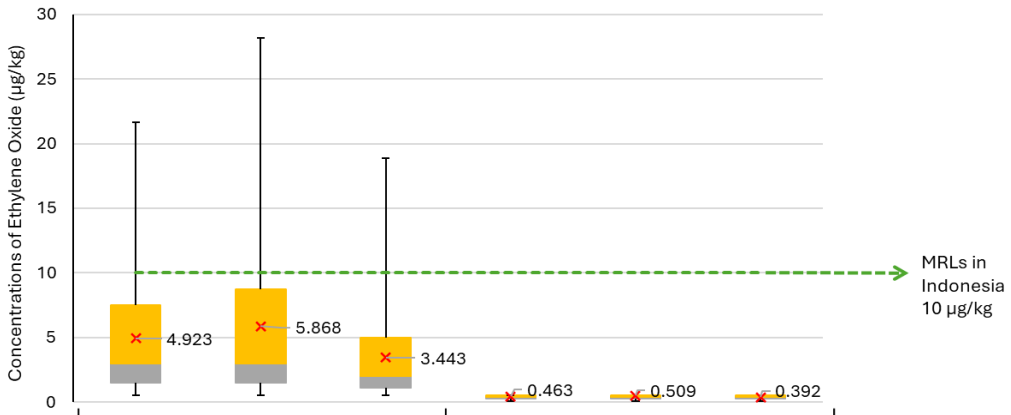
3.2. Ethylene Oxide Concentrations in Chili Powder of Instant Noodles

Based on the results of the NADFC 2023 surveillance of 77 instant noodle samples, EtO residues in chili powder ranged from undetectable (<1 µg/kg) to 25 µg/kg, with a mean of 4.923±5.273 µg/kg (Figure 2). The maximum EtO concentration in chili powder was 25 µg/kg, indicating that EtO levels can be relatively high under certain conditions. This maximum concentration exceeds the MRLs established in Indonesia. EtO residue concentrations in chili powder were higher in soup-based instant noodles than in fried instant noodles. This pattern may be due to differences in seasonings composition. Seasoning in soup-based instant noodles is generally in powder form and contains a relatively high proportion of spices, including chili powder as a flavour-forming component. In contrast, the flavour of fried instant noodles is supported not only by dry seasoning but also by other components such as oil, sauce, and soy sauce. As a result, the proportion of chili powder used in fried instant noodles tends to be lower (Nseobong *et al*., 2023).

The wide range of residue concentrations, from undetectable to high, indicates that EtO in food is influenced by processing practices and the handling of raw materials (Bessaire *et al*., 2023; Lee *et al*., 2025). EtO residues may be detected in chili powder because pesticide residues can enter food through contaminated leaves, fruits, soil, or water, or through treatments during storage and distribution (Pekmezci *et al*., 2025). A review of global regulations also indicates that decontamination processes for spices and herbs are a critical component of international processing and trade systems. However, such processes can contribute to residues in the final product (Fisher, 2019).

These findings underscore the importance of comprehensive oversight across the entire supply chain, particularly for high-risk raw materials such as spices, and the need to implement stricter processing practices to minimize EtO residues in the final product. Sampling of instant noodles for testing was conducted at supermarkets and convenience stores in the Greater Jakarta area and through e-commerce platforms for other regions of Indonesia. Instant noodle products with ML marketing authorization were excluded because they did not contain chili powder, the subject of the study. Sampling, therefore, focused on products with MD marketing authorization or domestically produced products, as these were the main group containing chili powder in the research matrix.

The population used as the basis for sample selection comprised 590 instant noodle products with MD marketing authorization available in Indonesia, produced by 27 manufacturers, including 351 soup-based instant noodle products and 239 fried instant noodle products. A total of 74 samples of instant noodles with MD marketing authorization were



	NADFC Surveillance Data			2024 Testing Results		
	Total Instant Noodles	Noodles Soup	Fried Noodles	Total Instant Noodles	Noodles Soup	Fried Noodles
Sample Size	77	47	30	74	45	29
Mean	4.923	5.868	3.443	0.463	0.509	0.392
Standard Deviation	5.273	6.063	3.294	0.303	0.348	0.392
Minimum	0.500	0.500	0.500	0.095	0.095	0.095
5^{th} percentile	0.500	0.500	0.500	0.095	0.118	0.095
95^{th} percentile	15.600	17.400	8.000	1.200	1.232	0.700
Maximum	25.000	25.000	15.500	1.500	1.500	0.730

Figure 2. Ethylene oxide concentrations in chili powder based on NADFC surveillance in 2023 and sample testing in 2024

collected, comprising 45 types of soup-based and 29 fried instant noodle types, based on calculations using the Slovin formula with a 10% sampling error.

The population used as the basis for sample selection comprised 590 instant noodle products with MD marketing authorization available in Indonesia, produced by 27 manufacturers, including 351 soup-based instant noodle products and 239 fried instant noodle products. A total of 74 samples of instant noodles with MD marketing authorization were collected, comprising 45 types of soup-based and 29 fried instant noodle types, based on calculations using the Slovin formula with a 10% sampling error.

Test 2024 test results showed that EtO was detected in 66 of 74 chili powder samples (89%), with levels ranging from below the detection limit (<0.19 µg/kg) to 1.5 µg/kg and a mean of 0.463±0.303 µg/kg. All concentrations obtained in 2024 were below the EtO MRLs established in Indonesia. These findings are consistent with reports from several countries regarding EtO. The Singapore Food Agency (SFA) announced the recall of two instant noodle products from Indonesia due to the presence of EtO. The Hong Kong Center for Food Safety also reported the detection of EtO in instant noodle product samples from Indonesia. The Hong Kong Consumer Council reported the presence of EtO residues in samples of noodles, seasonings, and chili powder.

All 2024 test results were below the MRLs established in Indonesia. However, the presence of EtO in most samples indicates that the source of residues has not been eliminated from the supply chain. Compliance with MRLs does not necessarily imply the absence of risk, as EtO is a carcinogen in humans. The 2024 test results indicate an improvement in regulatory compliance, but further efforts are still needed to control sources of residues in spice raw materials.

The 2024 test results show a significant decrease in EtO concentrations, both in the average (4.923 µg/kg to 0.463 µg/kg) and the maximum value (25 µg/kg to 1.5 µg/kg), as shown in Figure 2. The 2023 surveillance results for maximum concentrations were above the MRLs, whereas all 2024 test results were below the MRLs established in Indonesia. The decrease in the average value and maximum concentration of EtO residues between the 2023 surveillance data and the 2024 testing results indicates an improvement in the EtO residue profile, consistent with strengthened contaminant control following the implementation of risk mitigation policies.

These findings may encourage business operators to strengthen their controls by ensuring the suitability of raw materials, improving production processes, and testing for EtO residues before products are distributed. The 2024 EtO residue profile can be interpreted as an initial indication of strengthened controls following regulatory implementation. However, these results are not intended to serve as sole causal evidence, as the data were derived from sampling rather than direct comparisons of the same brand. Instead, the findings provide an initial indication of the implementation of EtO monitoring policies for chili powder in instant noodles. The causal effectiveness of the policy requires further verification through repeated monitoring with a consistent sampling design, standardized testing methods, and analysis by brand, batch, or raw material supply chain.

The comparison between the 2023 and 2024 data has limitations because different testing methods and laboratories were used. Both laboratories are accredited by the National Accreditation Committee (KAN), and the LPPOM MUI laboratory is recognized by the NADFC. The test results can still be used as supporting data for regulatory oversight. EtO testing at the NADFC laboratory has a LOD of 0.001 mg/kg, an LOQ of 0.003 mg/kg, and a recovery rate of 90.8%, whereas testing at the LPPOM MUI laboratory has an LOD of 0.00019 mg/kg, an LOQ of 0.00094 mg/kg, and a recovery rate of 94.02%. The recovery values for both methods fall within the acceptable range of 70–120%, generally meeting recovery acceptance criteria. The lower LOD and LOQ values of the LPPOM MUI testing method indicate higher test sensitivity. Nevertheless, comparisons between the two testing periods should be interpreted with caution, as no method harmonization or interlaboratory equivalence testing was conducted.

Ethylene oxide has been discussed by both the Codex Committee on Contaminants in Foods (CCCF) and the Codex Committee on Pesticide Residues (CCPR). The risk assessment of EtO was transferred to the Joint FAO/WHO Expert Committee on Food Additives (JECFA) because there was no agreement to include EtO in the priority list for evaluation by the Joint FAO/WHO Meeting on Pesticide Residues (JMPR). At its 17th session in 2024, the Codex Committee on food contaminant included EtO in the priority evaluation list, covering toxicological and exposure assessments. However, implementation remains pending due to data availability, JECFA readiness, and other work priorities (Codex Alimentarius Commission, 2024).

Regulations on EtO in food vary among countries, as shown in Table 1. These differences can contribute to export rejections in several countries, including rejections involving instant noodles from Indonesia. Differences in maximum EtO limits among countries reflect differences in risk management and regulatory approaches, including risk assessment, residue definitions, and the use of fumigants. These differences can pose challenges in international trade, as products that meet the requirements in one country may not necessarily be accepted in another. Strengthening EtO oversight in Indonesia is important to protect consumers while supporting the competitiveness and marketability of processed food products in the global market.

A decrease in EtO residue concentrations may indicate improved control within the spice raw material supply chain. Since the EtO contamination incident involving sesame seeds in the European Union in 2020, many countries and food industry stakeholders have intensified monitoring of fumigant use in the processing of dry foodstuffs, including spices (Kowalska & Manning, 2022). EtO control policies in Indonesia were strengthened following export notification for instant noodle products in the international food safety system. These policies not only establish EtO MRLs in food products but also regulate risk mitigation measures across the food chain, from the implementation of Good Agricultural Practices (GAP) and Good Manufacturing Practices (GMP) to oversight during export and import stages (BPOM, 2022). These conditions have contributed to improvements in processing practices and residue control in Indonesia's food industry. The implementation of GAP and GMP, together with risk-based oversight, has helped reduce EtO residues.

Spices such as chili powder are known to be susceptible to EtO contamination because they often undergo post-harvest treatments to control microbiological contamination, particularly *Salmonella*. Several studies have reported that EtO fumigation is still used in spice processing to ensure microbiological safety (Dudkiewicz *et al*., 2022; Wei *et al*., 2021). However, without optimal aeration process after fumigation, EtO use may leave residues (EFSA *et al*., 2022).

The EtO concentrations detected in the 2024 testing were relatively lower compared to international reports. Fowles *et al*. (2001) reported that EtO residues in fumigated spices can reach much higher levels if process control is not properly implemented. Incidents of EtO contamination in the European Union also indicate that high residue levels can lead to widespread product recalls when they exceed the applicable MRLs (Kowalska & Manning, 2022).

Table 1. Comparison of regulatory approaches to ethylene oxide in food products in several countries

Country	Commodity	Regulatory Limit Number	Key Approaches and Provisions	References
European Union	Food commodities as classified by the MRLs, including sesame seeds, spices, nuts, and processed products	0.01–0.1 mg/kg, depending on the commodity and the definition of residues	Regulated as a pesticide residue under the MRLs framework. If no specific MRLs are established, the default MRLs of 0.01 mg/kg apply. The use of EtO in food is not permitted	European Commission (2005)
United States	Dried herbs and spices, sesame seeds, dried vegetables, walnuts, and certain other commodities	EtO: 7 mg/kg for dried herbs and spices, sesame seed, and dried vegetables; 50 mg/kg for walnuts. 2-chloro-ethanol: 940 mg/kg for certain commodities	Regulated as post-harvest pesticide/fumigant residue limits. EtO and its derivative, 2-chloroethanol, are regulated separately.	U.S. EPA (2024)
Canada	Certain commodities, including spices and natural seasonings	No single general limit is presented for all processed foods	Regulated under the framework for pest control products/fumigants and commodity-based MRLs	Health Canada (2024)
Hongkong Taiwan, and Thailand	Food products currently on the market or imported	Not permitted in food	Prohibition/non-acceptance of EtO in food products. Products containing EtO may be rejected or withdrawn from circulation	Centre for Food Safety (2023); Taiwan FDA (2023); MOPH, (2017).
Singapore	Spices	50 mg/kg in spices	EtO is permitted for the sterilization of spices within certain maximum limits.	Singapore Food Agency, 2022
South Korea and Japan	Agricultural/food products containing pesticide residues	0.01 mg/kg for pesticides that do not have specific residue limits	Use a commodity-based MRL system and a positive list system. If there is no specific residue standard, an MRLs of 0.01 mg/kg applies.	MFDS Korea (2026); MHLW Japan (2023)
Indonesia	Processed food	0.01 mg/kg	Regulated through policies on the mitigation of health risks associated with ethylene oxide (EtO) in processed foods. The MRLs are used as a reference for monitoring and risk mitigation.	BPOM (2022)

Overall, these findings indicate that the issue of EtO in chili powder in instant noodles is not limited to MRLs compliance. All EtO concentrations in 2024 were below the MRLs and lower than those observed in 2023. However, EtO residues were still detected in most samples, which indicates that control of contamination sources in the spice supply chain remains necessary. Continuous monitoring is therefore needed to ensure food safety.

3.3. Statistical Analysis of the Effectiveness of Policy Implementation

A statistical analysis was conducted to evaluate differences in EtO residue profiles in chili powder used in instant noodles before and after the implementation of the EtO residue control policy in Indonesia. The normality test results (Table 2) showed that the concentration data in both groups were not normally distributed ($p < 0.05$). Therefore, the nonparametric Mann–Whitney U test was used to compare the two independent data groups (Mishra *et al*., 2019). This test was appropriate because the analyzed data originated from two different testing periods, were not treated as paired data, and did not meet the normality assumption. Such asymmetric data distributions are common in food contaminant data and indicate high variability influenced by the heterogeneity of raw materials and production processes (Lukashkin & Araslanov, 2023).

Table 2. Results of the normality test using SPSS version 27

	Groups	Kolmogorov-Smirnov[a]			Shapiro-Wilk		
		Statistic	df [b]	Sig.	Statistic	df [b]	Sig.
EtO concentrations	Surveillance Data 2023	0.212	77	0.000	0.787	77	0.000
	Testing Data 2024	0.208	74	0.000	0.850	74	0.000

Notes: a. Lilliefors Significance Correction; b. degrees of freedom

The first group represents data from the NADFC's 2023 surveillance before policy implementation, while the second group represents the 2024 testing results after policy implementation. The results of the Mann–Whitney U test showed a statistically significant difference in the distribution of EtO concentrations between the two groups (U = 395.5; Z = -9.161; $p < 0.001$). A p-value of <0.001 indicates that the difference in EtO concentrations between the two periods is highly unlikely to have occurred by chance. The direction of the difference, indicated by the comparison of descriptive values and group rankings, suggests that EtO concentrations in the 2024 group were lower than those in the 2023 group, consistent with the decrease in the mean and maximum values.

The interpretation of the results is based not only on statistical significance but also on effect size. An effect size of $r = 0.75$ indicates a large effect, meaning that the difference in EtO levels is both statistically significant and practically meaningful. This indicates a big difference in the concentration distribution between the 2023 surveillance results and the 2024 testing results. This finding is reinforced by the fact that, in 2023, maximum EtO concentrations exceeded the MRLs, whereas all 2024 testing results were below the MRLs established in Indonesia. Therefore, these statistical results indicate a change in the EtO residue profile consistent with a downward trend in concentrations following the policy implementation.

The difference in these concentration distributions can be interpreted as an early indication of improved control over EtO residues in chili powder in instant noodles following policy implementation. The EtO residue control policy implemented in 2023 may encourage business operators to strengthen raw material controls, conduct residue testing before product distribution, and improve verification of compliance with MRLs. The 2024 test results, all of which were below the MRLs, can be viewed as findings consistent with the stronger implementation of EtO monitoring and control policies for processed food products.

However, these statistical results must be interpreted with caution. The analyzed data were obtained from surveillance sampling conducted in two different periods and do not constitute a paired comparison of the same brands, batches, or products. Therefore, the Mann–Whitney U test results cannot be used to conclude that regulation directly reduces EtO concentrations across all instant noodle products available in Indonesia. Differences in raw material sources, product formulations, processing practices, spice treatments, and sample distribution may influence variations in EtO residue concentrations. Previous studies have shown that EtO residues in food products are significantly influenced by post-harvest handling and the global distribution chain, particularly in dry commodities such as spices and food additives (Lukashkin & Araslanov, 2023). Changes in production processes or the implementation of decontamination technologies by manufacturers may also reduce EtO concentrations in the final product.

Increased industry oversight and awareness of food safety issues, particularly following international notifications regarding EtO in food products, can drive improvements in production practices and quality control (Dudkiewicz *et al*., 2022). In general, regulatory strengthening, increased testing frequency, and risk management measures are crucial components in controlling hazardous chemical contaminants in food (EFSA *et al*., 2022). This aligns with previous research emphasizing the importance of integrated monitoring systems for identifying and controlling sources of contamination in the food chain (Lukashkin & Araslanov, 2023).

The results of this analysis indicate differences in the distribution of EtO concentrations in the tested samples before and after policy implementation and provide initial evidence that policy implementation is aligned with strengthened residue control. However, this finding still needs to be confirmed through continuous monitoring with a more structured sampling design.

This study provides a novel contribution by comparing national surveillance data with post-intervention laboratory results to assess changes in ethylene oxide residue profiles in chili powder used in instant noodles in Indonesia. The

integration of regulatory compliance assessment, nonparametric statistical analysis, and effect-size estimation offers initial empirical evidence for evaluating EtO risk mitigation measures and strengthening risk-based food safety surveillance.

4. CONCLUSIONS

The profile of instant noodles reveals a discrepancy between the number of registered products and the number of products currently on the market. This study indicates that EtO residues were still detected in most chili powder samples from instant noodles in 2024; however, all detected concentrations were below the MRLs established in Indonesia. The 2024 test results showed decreases in the mean and maximum concentrations of EtO residues compared with the 2023 NADFC surveillance data, and the concentration distribution differed significantly between the two periods. These findings indicate a change in the EtO residue profile consistent with strengthened control following the implementation of risk mitigation policies. However, they cannot yet be considered direct causal evidence that these policies reduced residue concentrations across all instant noodle products on the market. The results of this study can serve as an initial framework for evaluating regulatory implementation and strengthening EtO residue monitoring in processed food products, particularly in spice-based ingredients such as chili powder. Interpretation of the results must consider several limitations: the data were derived from sampling conducted in two distinct periods rather than from paired comparisons of the same brand, batch, or product; and the 2023 surveillance data and 2024 testing used different methods, which may affect the comparability of the results. Future research should use a more structured sampling design, standardized testing methods across periods, a broader scope of product types and sampling regions, and quantitative health risk assessment to strengthen the basis for food safety policy decisions.

DECLARATION OF GENERATIVE AI AND AI-ASSISTED TECHNOLOGIES IN THE MANUSCRIPT PREPARATION

During the preparation of this work the authors used AI-assisted language tools (ChatGPT) to improve grammar and readability of the text. After using this tool/service, the authors reviewed and edited the content as needed and took full responsibility for the content of the publication.

AUTHOR CONTRIBUTION

Author	C	M	So	Va	Fo	I	R	D	O	E	Vi	Su	P	Fu
AY	✓	✓			✓	✓	✓	✓	✓	✓	✓			✓
PEG	✓	✓		✓	✓					✓		✓	✓	
NAN	✓	✓		✓	✓					✓		✓		

C: Conceptualization	Fo: Formal Analysis	O: Writing - Original Draft	Fu: Funding Acquisition
M: Methodology	I: Investigation	E: Writing - Review & Editing	P: Project Administration
So: Software	D: Data Curation	Vi: Visualization	
Va: Validation	R: Resources	Su: Supervision	

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