EFFECTIVENESS OF FUMIGATION TREATMENT IN BOOSTING COFFEE EXPORTS

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Highlight
Effective fumigation is essential for Indonesian coffee exports, but currently faces challenges like tidal flooding and cost variations. This study recommends standardizing treatment protocols and implementing real-time monitoring to overcome these barriers and ensure compliance with international safety standards.

Abstract
Coffee has become a major export commodity in Indonesia. Actions to maintain the quality of export products and meet the quarantine and safety standards set by the destination countries are carried out through fumigation treatment. This study aims to analyses the effectiveness of fumigation treatment in increasing coffee commodity exports. The research method employed is a descriptive quantitative approach, using a case study design in Central Java, Indonesia. Data collection was conducted through in-depth interviews with informants, including the Indonesian Quarantine Agency, the Central Java Animal, Fish, and Plant Quarantine Centers, fumigator companies, and exporters, supported by observational and documentary data. Data analysis used the 6 suitable principles, with each indicator developed into several questions or statements assessed using a Likert scale from 1 to 5. The research results indicate that the coffee fumigation actions at Tanjung Emas Port, Semarang, were carried out quite effectively, with an average score of 60%, meeting the 6 suitable Principles (right place, time, price, procedure, administration, and quality). Several obstacles, including delays in collecting record sheets, the risk of tidal flooding in the Tanjung Emas Port area, limited warehouse space for exporters, variations in costs set by fumigation companies, and the need for ongoing improvement in fumigator competence, affect export smoothness. This research provides input on the need for improvements in time management, storage location diversification, dosage policy and fumigation treatment cost standardization, real-time monitoring technology implementation in the fumigation process, and continuous training of fumigator competencies.

Keywords
Coffee, Effectiveness, Export, Fumigation, 6 Suitable Principles.

Introduction

The performance of the national economy cannot be separated from the performance of the agricultural sector, one of which is agricultural commodity international trade (exports/imports) (Agustian et al., 2024). The higher the export performance, the greater the positive economic growth benefits obtained (Nurhayati et al., 2019). Agricultural exports can impact agricultural economic growth by expanding markets and providing access to significant foreign markets (Seok & Moon, 2021). These benefits can increase demand and ultimately boost agricultural production (Mamba & Ali, 2022). Coffee is an important export commodity that influences industrialization, as explained by Murindahabi et al. 2019), who stated that the coffee trade affects the overall economic development of coffee-exporting countries. Coffee also contributes to the increase in national income through foreign exchange earnings from coffee exports, which are crucial for the initiation of industrialization (Barros et al., 2019). In Indonesia, coffee has become a major export commodity is essential for economic progress and poverty reduction (Amrulloh et al., 2021). This assumption is reinforced by data from the Central Statistics Agency (2024) that coffee is among the top 5 commodities contributing to plantation commodity exports, alongside palm oil, rubber, cocoa, and coconut (Purwanto et al., 2023). Data on the development of Indonesia's export value in June 2025 shows an achievement of US $3.44 billion, an increase of 11.29% compared to June 2024 exports (YtoY), with the agriculture, forestry, and fisheries sectors experiencing a 49.55% increase due to coffee exports (BPS, 2025). This indicates that the export volume performance of the food crops and plantation subsector in Indonesia has experienced a significant increase (Wahyudi et al., 2024).

Indonesian coffee exports, especially coffee beans, accounted for 99% of total exports from 2018 to 2022, ranking 11th globally (Ministry of Agriculture, 2023). Central Java is a province known as a center for robusta coffee production, which dominates Indonesia's coffee exports. Based on calculations from 2019 to 2023, Central Java contributed 4.06% with an average production of 22.52 thousand tons/year (Ministry of Agriculture, 2023).

Central Java has a total coffee plantation area of 50,153 hectares, calculated from the area of state-owned large plantations, private large plantations, and people's plantations, producing a total coffee output of 27,227 tons/year (BPS, 2024). This indicates that coffee has great potential in driving the continuously developing global market integration in the future, supported by geographical conditions, the role of the community as business actors, and government regulations that significantly influence the success of Indonesian coffee exports (Amrulloh et al., 2021).

The potential of coffee as one of Indonesia's leading export commodities has not yet been able to compete with coffee from Vietnam and the Philippines because it faces challenges in meeting quality standards, ultimately leading to export rejections in destination countries (Widiyanto et al., 2024). Fluctuations in global prices and climate change also hinder coffee export activities, with the presence of plant pests and diseases reducing harvest yields and negatively impacting farmers and consumers (Legesse, 2022). Meanwhile, specific regulatory changes from the destination countries significantly affect Indonesian coffee exports due to increasingly stringent regulations (H. C. S. Z. Nugroho & Suryadi, 2014).

One of the challenges in Indonesia's coffee export activities is maintaining security and resilience during transportation to the destination country. The products destined for export undergo a series of processes before reaching the destination country. Food safety is one of the important aspects considered to prevent the spread of pests from one country to another and to avoid the risk of decreasing the quantity and quality of products (Tasrif et al., 2021). The Agricultural Quarantine Agency oversees the regulations for quarantine procedures for the export of plants and plant products originating from Indonesia, as stipulated in the Republic of Indonesia Law Number 21 of 2019 concerning Animal, Fish, and Plant Quarantine and Presidential Regulation Number 45 of 2023 concerning the Indonesian Quarantine Agency. Efforts to prevent the entry and spread of plant pests and diseases (OPTK) and animal pests and diseases (HPHK) are conducted through strict quarantine and biosecurity monitoring in Indonesia.

The series of export quarantine processes includes the requirements from each destination country, known as import permits, and goes through several steps, such as entry application, sampling, and fumigation treatment (Nurhayati et al., 2019). Fumigation is crucial to ensure that export products meet the quarantine and safety standards set by the destination countries (Anrina & Pramahayekti, 2023). Fumigation treatment is performed when live insects are found during health inspections or as a requirement of the destination country. Fumigation is performed if the destination country requests it (Fuadi et al., 2022) or if live insects are found during a health inspection by the plant quarantine team. One of them is sulfur fumigation, which is used to avoid bacterial contamination, mold growth, and insect infestations and to make the product look more attractive (Yan et al., 2021).

Fumigation is carried out by spraying gas into the container space to eliminate any remaining pests and insects in the product, after which sealing is done, and it is ready for shipment (Rustina et al., 2022). Although fumigation improves the quality and durability of export products, many challenges remain. Issues with the fumigation process hinder export activities and result in losses for Indonesian producers. Food safety aspects, such as fumigant gas residues, pest resistance, monitoring and surveillance, limited technology, and varying regulations and standards in each destination country, pose several challenges that require special attention.

The preparation of the documents required before the export shipment also includes the fumigation certificate (Ramadhani, 2022). Several cases have been found where the condition of the products received in the destination country did not match the fumigation documents issued, resulting in the products being returned to the country of origin. However, ensuring safe distribution procedures through fumigation actions in the supply chain process is critical for the company to implement. Preventing product defects is an important goal of an efficient distribution process, as the company's objective is to provide high-quality products that meet consumer demand (Amira, 2023).

Research related to fumigation on coffee products has rarely been conducted. Alfaro-Bernardino et al. (2024) researched fumigation policies to minimize the risk of mosquito-borne diseases, Follett (2018) studied irradiation for controlling coffee berry borer quarantine, and Nugroho (2014) only analysed the impact of food safety standards on coffee exports in Indonesia. Based on the aforementioned studies, no research has yet been conducted on the effectiveness of fumigation on coffee to increase exports. Effectiveness is defined as the degree to which we achieve the established goals (Putri, 2019). Goal achievement correlates directly with the concept of

effectiveness. The concept of effectiveness in programs/activities was first popularized by Rachman et al. (2018) and later adopted by other researchers, such as Hermawan et al. (2021), who stated that a program is considered effective if it meets the 6 Right principles: right target, right time, right quality, right quantity, right cost, and right administration. This study will thoroughly analyse the effectiveness of fumigation treatment in increasing coffee commodity exports, considering the issues mentioned above and the lack of specific research on this topic. Conducting this research is crucial because it provides a fundamental foundation for enhancing quarantine regulations on agricultural commodities, thereby boosting exports.

The importance of effective and efficient fumigation treatment to ensure the quality, safety, and competitiveness of coffee exports from Central Java through Tanjung Emas Port, where field findings show variations in performance on six fumigation principles (Right Place, Punctuality, Appropriate Cost, Correct Procedures, Administrative Precision, Right Quality) that affect compliance with Indonesia's 2025 quarantine standards and food security; therefore, this research examines:

1) How does the fumigation process at Tanjung Emas Port in Central Java ensure both effectiveness (pest mortality and prevention of phosphine resistance) and efficiency (cost, timing, and compliance), and how do the 6 Right Principles contribute to strengthening the competitiveness of Central Java coffee in the global market?
2) How do the six Right Principles (Right Place, Right Time, Right Cost, Right Procedure, Right Administration, and Right Quality) influence the overall effectiveness of methyl bromide fumigation for coffee exports at Tanjung Emas Port, Semarang, in meeting Indonesia's 2025 quarantine standards and ensuring food security?
3) How do deficiencies in Punctuality and administrative Precision reduce the overall effectiveness of methyl bromide fumigation for coffee exports in Central Java, compared with Right Place, Appropriate Cost, Correct Procedures, and Right Quality?

MATERIALS AND METHODS

Study area

The research location was determined purposively based on the researchers' considerations adjusted to the research objectives to be achieved (Perwitasari et al., 2019; Wahyudi et al., 2022; Wardani et al., 2024). This research was conducted at the Tanjung Emas Port in Semarang City and several coffee exporter warehouses located within the Central Java Plant Quarantine Agency's working area. Central Java Province was chosen as the research location because it is one of the largest robusta coffee production centres on the island of Java, and its coffee has a distinctive taste that foreigners Favor.

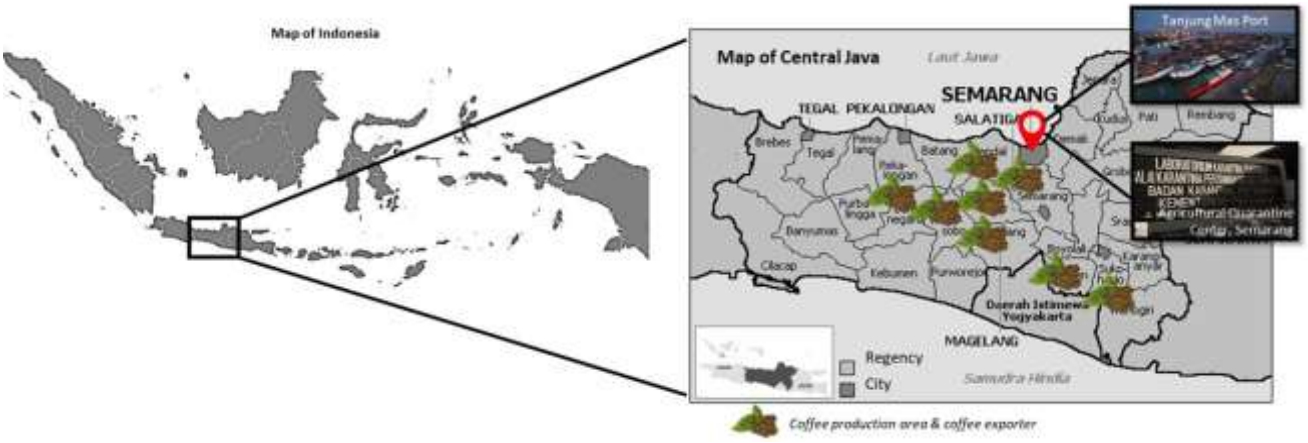

Figure 1. Research Location Map

Procedures

The type of research used is quantitative descriptive research with a case study approach. The case study focuses on a single issue that must be thoroughly examined to uncover the truth about the phenomenon (Assyakurrohim et al., 2022; Wardani et al., 2024). This study aims to assess the effectiveness of the fumigation process for coffee commodities for export treatment in Central Java, Indonesia. The evaluation was conducted based on six principal indicators of the "6 Right (6R)" concept, namely: Right Place, Right Time, Right Price, Right Procedure, Right

Administration, and Right Quality. The types of data used in this research are primary and secondary data. Primary data were collected using in-depth interview techniques (Mazaya & Suliswaningsih, 2023), observation (Bogdan & Biklen, 2017), and a documentation study (Febrianti et al., 2023). The informants in this study include parties located at the Central Office of the Indonesian Quarantine Agency and the Central Java Animal, Fish, and Plant Quarantine Centre, including the Head of the Plant Quarantine Team and the Fumigation Auditor, fumigation companies, including the Technical Manager and Fumigator, and exporting companies.

Data analysis

The collected data were analysed to determine the effectiveness of fumigation implementation in increasing agricultural commodity exports. Data analysis employs quantitative descriptive methods based on the 6 Right Principles, referencing the research findings of Rachman et al. (2018) and Rahmadanih et al. (2023) regarding the effectiveness of the food aid program; Hermawan et al. (2021) concerning the effectiveness of the non-cash aid program; and Mamahit et al. (2021) related to the effectiveness of subsidized fertilizer distribution. Data were analyzed using quantitative descriptive analysis. Each of the 6 indicators was developed into several questions or statements that were assessed using a Likert scale from 1 to 5. The scores from each respondent for the six "6 " indicators were converted into a percentage of effectiveness using the following formula:

$$Effectiveness\ (\%) = \left(\frac{Average\ Score}{5}\right) \times 100$$

Table 1. Categorization of the Effectiveness Levels

Average score (1–5)	Percentage (%)	Categories
1,00-1,99	≤40%	Ineffective
2,00-2,99	41-55%	Less effective
3,00-3,24	56-64%	Quite effective
3,25-3,99	65-80%	Effective
4,00-5,00	81-100%	Very effective

Source: Adopted from Ridwan and Akdon (2013)

RESULTS AND DISCUSSION

Fumigation is one of the most important treatments for maintaining the quality of export commodities, including coffee, from pest and disease attacks. The Indonesian Quarantine Agency conducts fumigation treatment in Central Java Province at the Tanjung Emas Port in Semarang City, and the effectiveness of the fumigation treatment has proven to play a significant role in enhancing the competitiveness of coffee in the international market. As mentioned in the research findings (Plumier et al., 2018), ensuring the effectiveness of fumigation is important, which includes understanding the concentration and movement of fumigants in grain storage silos to address the issue of phosphine resistance.

Fumigation can kill pests that could damage coffee beans during the shipping process, thereby maintaining the product's quality and safety. This is very important, considering the strict global food safety standards, especially in countries that export food. Coffee beans can reach consumers without experiencing a decline in quality by conducting an effective fumigation process, which ultimately enhances international market confidence in Central Java coffee. In addition to effectiveness, efficiency in the fumigation process is also key to increasing coffee exports. A quick fumigation process can reduce production costs and speed up delivery times while still meeting safety standards. This effectiveness is important for Central Java exporters, especially in meeting the continuously increasing global demand. Exporters can offer more competitive prices in the international market with more controlled costs and shorter delivery times. Therefore, the effective implementation of fumigation can directly contribute to the increase in coffee export volume from Central Java, strengthening the commodity's position in the global market. The field research data collection was analysed using the 6 Right Principles.

Table 2. Principle 6: Accurate Assessment of the Effectiveness of the Fumigation Process in Central Java

No.	6 Principles suitable	Description
1.	**Right Place**	The fumigation treatment facility meets the Indonesian Quarantine Agency standards.
2.	**Punctually**	The fumigation process is performed with precise timing to achieve products that meet the standards.
3.	**Appropriate Cost**	Exporters must follow the SOP financing procedures and ensure cost compliance for fumigation treatments.
4.	**Correct Procedures**	The product meets the standards of the destination country in terms of both durability and safety.
5.	**Administrative Precision**	The fumigation process must go through administrative procedures following the SOP.
6.	**Superior Quality**	The product meets the standards of the destination country in terms of both durability and safety.

Source: Preliminary survey analysis adopted from Rachman (2018), Rahmadanih et al. (2023), Hermawan et al. (2021), and Mamahit et al. (2021).

In the context of food security, fumigation ensures that domestically and internationally marketed coffee is safe for consumption and free from the risk of damage that can reduce its nutritional value and flavor. In addition, fumigation helps maintain the stability of coffee production and distribution, especially in meeting strict international export standards. Food security encompasses not only the availability and access to food but also food safety. Coffee exported from Indonesia, particularly Central Java, can compete in the global market and meet food regulatory requirements in the destination countries by maintaining product quality through fumigation. These improvements can directly contribute to the sustainability of the coffee supply chain, from farmers to consumers, and ensure that coffee commodities remain a strong source of income for the local economy. In general, the fumigation at Tanjung Emas Port Semarang has met the quarantine treatment standards required by the Indonesian Quarantine Agency's technical standards for methyl bromide fumigation in 2025. However, in the context of effectiveness and efficiency.

Table 3. Empirical Conditions and Technical Standards for Fumigation Treatment in Central Java Province Based on Effectiveness Analysis (suitable principles)

No.	Analyzing Suitable Principles	6 that occurred (Qualitative Field Description)	Technical Treatment Standard Methyl Bromide Fumigation Indonesian Quarantine Agency (Department for Plant Quarantine Decision Number 225 of 2025)
1.	Right Place	a) The fumigation treatment facility does not meet the standards. b) The fumigation treatment area at the Tanjung Emas port is at risk of tidal flooding. c) The fumigation treatment area at the exporter's warehouse is too small.	**a) The fumigation location should in a safe place away from force majeure events, such as tidal floods.** **b) The fumigation facilities meet the IKT standards of the plant quarantine installation.** **c) A ventilation system and environmental protection against gas leaks and pollution are available.** **d) The arrangement of equipment and materials is conducted according to the SOPs.**
2.	Punctually	a) Fumigation is sometimes carried out close to the departure of the ship. b) It takes a long time to issue the record sheet. These variables can delay the export goods shipping process, alter ship schedules, and increase the risk of pests appearing on the product.	**a) The timeliness of fumigation execution according to the shipping schedule.** **b) The ideal container fumigation duration ranges from 24 to 48 h.** **c) Efficient completion time of administrative procedures (such as record sheets) that does not hinder the export process.** **d) Speed in handling technical difficulties without disrupting the timeline.**
3.	Appropriate Cost	The price difference given to each fumigator affects the product dosage to be exported.	**a) The fumigation service costs are transparent and meet regional standards.** **b) No significant differences were found between fumigation providers for the same treatment.**

No.	Analyzing Suitable Principles	6 that occurred (Qualitative Field Description)	Technical Treatment Standard Methyl Bromide Fumigation Indonesian Quarantine Agency (Department for Plant Quarantine Decision Number 225 of 2025)
			c) The dosage and cost charged to exporters are reasonable.
4.	Correct Procedures	a) Limited human resources for fumigators, competencies not upgraded. b) Personal protective equipment (PPE) not updated. c) Limited number of operational vehicles and risk of corrosion (seawater).	**a) The fumigator has a competency certificate according to the SKKNI.** **b) PPE is used completely and appropriately.** **c) The fumigant volume and dosage are calculated using precision.** **d) Leak detection and monitoring of fumigant concentration** **e)A post-treatment verification and documentation process.**
5.	Administrative precision	a) There are instances in which exporters fail to pay their fees on time. b) An integrated administrative innovation system has not yet been established.	**a) The administrative data (record sheets, fumigation certificates, and monitoring results) are well documented.** **b) An integrated administrative system is available between the fumigator, exporter, and quarantine officers.** **c) There are no delays in payment or document submission.**
6.	**Superior Quality**	Pests were found in exported products even though fumigation had been carried out (NNC case in 2021, coffee beans from exporter PT. X, and the product was returned).	**a) No pests were found in the fumigated product.** **b) Fumigation did not damage the physical or chemical quality of the product (i.e., whole coffee beans were not burnt or moldy).** **c) A monitoring process exists for the safe residual fumigant threshold limit value.** **d) Documentation is available to prevent pest reinfestation.**

Source: Results of research data (2025)

Based on the results of the field analysis, effectiveness was calculated using a Likert scale with a score range of 1–5. We represent an ineffective condition with a score of one and a highly effective condition with a score of five. Scores are obtained from the respondents' evaluations of each tested aspect, such as Right Place, Right Time, Right Price, Right Procedure, Right Administration, and Right Quality. After collecting all individual scores, the average score for each aspect is calculated. This average reflects the overall assessment of a particular aspect by respondents. The percentage calculation results are classified into effectiveness categories. This category helps simplify the interpretation of the results that each aspect can be assessed not only based on numbers but also on the level of achievement in performance quality.

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Table 4. Effectiveness of Fumigation Treatment on Coffee Commodities in Central Java, Indonesia

Aspect 6: Suitable Options	Average scores (1–5)	Affectiveness (%)	Categories
Right Place	3,0	60%	Quite Effective
Punctually	2,7	54%	Less Effective

Appropriate Cost	3,2	64%	Quite Effective
Correct Procedures	3,0	60%	Quite Effective
Administrative precision	2,5	50%	Less Effective
Right Quality	3,5	70%	Effective

Source: Researcher's analysis of data (2025)
Explanation: Likert scale (1–5): 1 = not effective; 2 = less effective; 3 = moderately effective; 4 = effective; 5 = very effective; Very Effective (81%–100%) Effective (65%–80%)Moderately Effective (56%–64%) Less Effective (41%–55%) Not Effective (≤40%).

Right Place
Location is an important aspect in the fumigation process implementation. The right place refers to the fumigation treatment location's suitability with the existing standard regulations. Based on the field analysis results presented in Table 4, the average score of the fumigation treatment process effectiveness on the appropriate location indicator, measured according to the technical standards of methyl bromide fumigation treatment by the Indonesian Quarantine Agency Number 225 of 2025, is an average of 3.0 with an effectiveness level of 60%, which falls into the fairly effective category.

Several fumigation treatment installations in the exporter's warehouse have yet to meet the established standards. This condition allows for the possibility of product contamination that is to be and has already been fumigated. In addition, the fumigation treatment areas in several exporter-owned warehouses are not sufficiently spacious, which affects the fumigation process of the fumigator of the goods to be exported. The fumigation treatment installations, in addition to the exporters' warehouses, are also conducted at Tanjung Emas Port. The problem is that the location of Tanjung Emas Port is an area frequently affected by tidal flooding, which increases the risk of fumigation product contamination.

Therefore, regular evaluation and monitoring are necessary to check the condition of the installation site for fumigation treatment. The fumigation treatment area should be spacious, enclosed, far from residential areas, and equipped with facilities that ensure it is free from the possibility of being affected by pest organisms. This necessitates ensuring proper maintenance of the physical facilities that host fumigation installations, whether situated in exporters' warehouses or at the port. As in the study conducted by Park et al. (2021), which provides knowledge about the potential exposure to methyl bromide around the fumigation treatment locations and its consequences for environmental safety, focusing on the research of variations in the level of methyl bromide usage based on distance and location of implementation, the current study provides the following:

Punctually
Timely fumigation processes are crucial to ensure that products remain safe and free from pests before being exported. Based on the field analysis results presented in Table 4, the average effectiveness score of the fumigation treatment process on the timeliness indicator, measured according to the technical standards of methyl bromide fumigation treatment by the Indonesian Quarantine Agency Number 225 of 2025, is an average of 2.7 with an effectiveness level of 54%, which falls into the less effective category. Issues remain, including the fumigation process being conducted close to the ship's departure and the delayed issuance of the record sheet, which leads to pest risks and export delays.

The fumigation carried out at the Tanjung Emas Port has been conducted according to the procedure, namely, at night or when there is no excessive human activity. This is performed to anticipate gas leaks that could endanger human health. The fumigator also seals the gaps to prevent gas leaks. This action, Formato et al. (2012), reduced the fumigation time to 2 days by improving the fumigation techniques in a closed chamber while maintaining high efficiency and leaving no harmful residues. The implementation of fumigation is sometimes carried out close to the ship's departure, causing a bottleneck in the export logistics chain. Fumigation requires a certain amount of time for the application process, exposure period, and aeration to reduce gas residues according to safety standards. Based on the technical standards for methyl bromide fumigation treatment by the Indonesian Quarantine Agency Number 225 of 2025, the ideal duration for container fumigation ranges from 24 to 48 hours, depending on the type of commodity and the regulations of the destination country. If the fumigation process is performed without considering a sufficient time interval, the risk of re-contamination and health impacts will increase. Residual exposure to fumigants and hazardous compounds in containers is common and can disrupt product safety and quality (Svedberg & Johanson, 2017). This causes exporters to be forced to delay the ship's departure to perform effective fumigation.

After the fumigation process, the fumigator completes the record sheet. The record sheet is a document that records the fumigation results, including the dosage and execution timing, and must be submitted immediately for the issuance of the Plant Health Certificate (KT.1). The fumigation administration process often takes longer than the standard Service Level Agreement (SLA), which should be 5 days, but can take up to 8-12 days due to delays in the submission of the "record sheet" by the fumigator. The delay in submitting the record sheet also poses a risk of pests reappearing on the products. Therefore, the quarantine authorities discipline the fumigators to submit the record sheets on time, so there are no delays in exports or risks of pests reappearing on the products.

Appropriate Cost

Fumigation treatment is essential for creating transparency and fairness between exporters and fumigation companies. The price differences offered by various fumigation companies can have a direct impact on the quality of treatment, particularly in terms of the pest control dosage used on exported products. If the price applied is not uniform, based on the field analysis results presented in Table 4, the average effectiveness score of the fumigation treatment process for the price accuracy indicator, measured according to the technical standards for methyl bromide fumigation treatment of the Indonesian Quarantine Agency Number 225 of 2025, is 3.2 on average, with an effectiveness level of 64% or falling into the fairly effective category. There appears to be a price difference between fumigators, which affects the product dosage.

There are 15 fumigation companies in Central Java, especially Tanjung Emas Port, that offer lower prices but with less-than-optimal dosages or methods, which could reduce the effectiveness of the fumigation. Conversely, companies that implement higher prices may provide more effective treatment, but could burden exporters. This imbalance can affect the overall quality of export products and create market unfairness. To address this issue, a policy that standardizes the cost of fumigation treatment across all fumigation companies must be implemented. This policy will help ensure that every fumigation company applies fair and reasonable pricing standards based on international regulations. Standardizing costs will avoid jealousy and social conflict, both among exporters who might feel disadvantaged by price differences and among competing fumigator groups. Additionally, this policy will create healthier competition among fumigation companies based on service quality rather than varying prices. This principle contributes to building mutual trust, fostering stronger collaboration, and driving overall improvements in performance and SCS (Abushaega,2024). Consequently, the quality standards of exported products can be better maintained, and a fairer and more transparent system will benefit all parties within the supply chain.

Correct Procedures

The fumigation treatment procedure complies with the Indonesian Quarantine Agency standards and is conducted at the Central Java Animal, Fish, and Plant Quarantine Centre. The Human Resources (HR) aspect is crucial for fumigation treatment. Based on the field analysis results presented in Table 4, the average effectiveness score of the fumigation treatment process for the "correct procedure" indicator, measured according to the technical standards for methyl bromide fumigation treatment by the Indonesian Quarantine Agency Number 225 of 2025, is 3.0 on average, with an effectiveness level of 60% or falling into the "moderately effective" category. It appears that human resources are not sufficiently competent (not upgraded), personal protective equipment is not updated, and vehicles are limited. Figure 2 shows the state of the fumigation process at Tanjung Emas Port in Semarang City.

Figure 2. Implementation of fumigation at Tanjung Emas Port, Central Java Province
Source: Researcher Documentation (2025)

On the ground, there is a shortage of human resources among fumigators, and they are not upgrading their competencies. Some fumigators do not renew their competency certifications, and some were even found to have been certified 10 years ago. This condition is quite concerning because fumigation treatment determines product quality, durability, and food safety. Additionally, fumigation poses significant risks to the health and safety of fumigators if it is not performed with proper procedures. Some of the PPE that ensures the safety of the fumigator was also found to be in an unrenewed condition, even though its maintenance is crucial in the fumigation process. Additionally, operational vehicles are still limited and at risk of exposure to seawater, which causes corrosion. Given these conditions, fumigation companies must ensure that every employee performing fumigation updates their competencies, equipment is updated, and monitoring and evaluation are conducted regularly to check the implementation of the fumigation process. As explained by Bond and Monro (1984) in the FAO guidelines, providing fumigators with thorough training on all aspects, from the principles of fumigation and safety protocols to the use of equipment, is important. Fumigation officers must have the knowledge and skills to meet the requirements for carrying out fumigation following established standards and obtain a fumigator competency certificate; thus, high-quality and continuous training is required for the successful creation of competent fumigators (FAO, 2001).

Administrative precision

Proper administration within the IQA is essential to ensure a smooth export process, including managing costs related to commodity inspection and certification. Late payments by exporters in cases like those in Central Java Province indicate suboptimal financial management. Based on the field analysis results presented in Table 4, the average effectiveness score of the fumigation treatment process for the administrative accuracy indicator, measured according to the technical standards for methyl bromide fumigation treatment of the Indonesian Quarantine Agency Number 225 of 2025, is 2.5 on average, with an effectiveness level of 50% or falling into the fairly effective category. It appears that there is a delay in payment by the exporter, and no integrated administrative system has yet been established.

Poorly organized administrative processes at the Indonesian Quarantine Agency can lead to delays in issuing important documents, such as phytosanitary certificates, export permits, and other requirements needed by exporters to meet the regulations of the destination country. Late payments by exporters can also cause problems in the relationship between quarantine agencies and exporters, which impacts the overall smoothness of the export process. Furthermore, the lack of an integrated administrative innovation system within quarantine agencies is a major cause of these issues. The administrative system of the Indonesian Quarantine Agency and the Animal, Fish, and Plant Quarantine Centres of Central Java, which is still manual or separate between one process and another, often leads to recording errors, delays in data processing, and interdepartmental coordination difficulties. Without an automated system, the IQA faces difficulties in tracking payments, managing inspection schedules, and efficiently issuing documents.

Administrative innovations, such as the implementation of integrated digital systems, can help expedite processes, from issuing invoices and monitoring payments to timely releasing quarantine certification documents. Such systems can also provide exporters with convenience in accessing document status and making electronic payments, thereby reducing the likelihood of delays and improving deadline compliance. This technology integration is crucial for creating more transparent, efficient, and accountable processes (Cheong, 2025) in the Indonesian Quarantine Agency, including the Animal, Fish, and Plant Quarantine Centre in Central Java.

Super Quality

The case of pest discovery in exported coffee products, even after fumigation, such as the incident at PT. X in 2021 highlights the challenges in maintaining the "right quality" of export products. "Right quality" refers to a product's ability to meet established quality standards and specifications in terms of safety, integrity, and cleanliness. Based on the field analysis results presented in Table 4, the average effectiveness score of the fumigation treatment process for the "quality" indicator, measured against the technical standards for methyl bromide fumigation treatment of the Indonesian Quarantine Agency Number 225 of 2025, is 3.5 on average, with an effectiveness level of 70% or falling into the effective category. Pests were still found in the fumigated products (2021 coffee bean case), and some products were returned.

In the case of PT. X, the discovery of pests in exported coffee beans indicates that although fumigation was performed, the process may not have been optimally performed or pests may have reinfested the beans during transportation or storage. Products returned due to not meeting quality standards harm the exporter's reputation

and cause significant financial losses. In addition to fumigation treatment, monitoring of product quality throughout the supply chain, including storage and shipping, needs to be improved. Proper fumigation involves the use of appropriate chemicals and the implementation of appropriate control methods in a controlled environment to ensure that all potentially harmful pests are eradicated. Incidents like this indicate the need for strict quality control systems and continuous monitoring to ensure that export products remain safe and meet international standards throughout their journey to consumers. This finding is also consistent with research (Zou et al., 2025) indicating that integrating controlled environmental aspects with the use of fumigants can enhance fumigation treatment effectiveness, ensure product safety, and prevent pest resistance.

Figure 3 shows the effectiveness graph of fumigation treatment based on the 6T principles in Central Java.

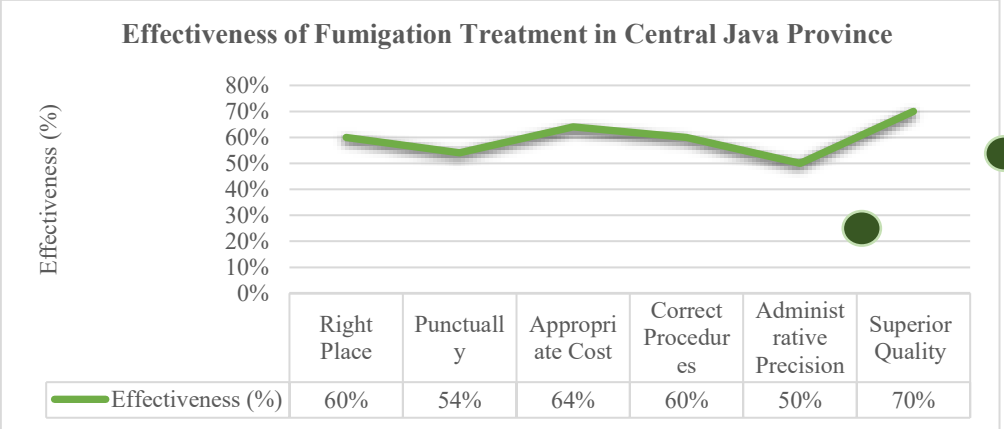

Figure 3. Graph of the Fumigation Treatment Effectiveness Level for Coffee Commodities in Central Java Province.
Source: Results of Research Data Processing (2025)

Discussion

Based on the analysis results summarized in Figure 7, "Quality Accuracy" aspect shows the highest effectiveness with a percentage of 70%. This indicates that the quality of fumigated products remains relatively stable, although some cases of plant-disturbing organisms (PTOs) were still found in certain commodities. This achievement reflects that the fumigation treatment process in Central Java has generally been able to maintain the physical and chemical quality of the products, so most commodities remain suitable for export. Success in this quality aspect is an important asset for the region's export competitiveness, as consistent product quality is one of the main factors for acceptance in international markets.

The Proper Administration aspect received the lowest effectiveness score, at 50%. This condition indicates that significant administrative management obstacles remain, such as late fee payments by exporters and the lack of an integrated administrative system between fumigators, exporters, and quarantine officers. These administrative obstacles impact the smooth flow of the export process, particularly in terms of document submission time and coordination between relevant parties. Overall, fumigation treatment in Central Java can be categorized as quite effective, but significant improvements are needed in administrative and timeliness aspects to improve export efficiency so that all process stages can run smoothly and follow international standards. The research results indicate that the non-compliance in fumigation implementation, both at the port and the exporter's warehouse, is caused by several factors, such as time inefficiency in the fumigation process, cost inconsistency, and limited human resources. Additionally, geographical challenges, such as the frequent tidal floods at Tanjung Emas Port, exacerbate the situation by disrupting the smooth fumigation process. Inefficiency in treatment time can be caused by inadequate equipment or slow procedures, while non-uniformity in cost can lead to differences in treatment quality among fumigator companies, ultimately affecting export product quality. Human resource limitations in terms of skills and workforce size also slow down the process and reduce the effectiveness of fumigation treatment. Therefore, an integrated technology innovation system is needed to overcome these various constraints and improve the implementation efficiency and effectiveness of fumigation. This system could include a digital platform that connects all stakeholders, from exporters and fumigation companies to quarantine agencies, to monitor, manage, and synchronize the fumigation process in real time. Technological innovations such as this will enable transparent cost tracking, efficient fumigation scheduling, and the use of advanced devices to ensure treatment quality. With good integration, processing time can be shortened, costs are more uniform, and geographical constraints such as tidal flooding can be effectively overcome with better planning. Exporters

will not only benefit from this innovation, but it will also boost their products' competitiveness in the global market.

Fumigation is an important method for maintaining biosecurity, especially in international trade, to prevent the spread of pests and diseases across borders. Biosecurity encompasses measures aimed at protecting ecosystems, agriculture, and human health from harmful organisms, such as insects, microbes, or other pathogens. Through fumigation, products coffee beans can be treated with chemicals that eliminate pests or organisms that might be carried in shipments. Thus, fumigation significantly contributes to the protection of local and international products while ensuring that exported commodities meet the destination country's health and safety standards and do not pose a threat to local biodiversity.

Based on the above description, it can be concluded that the implementation of fumigation for export coffee commodities at Tanjung Emas Port, Semarang City, generally runs quite effectively in meeting the 6 Right principles (Right Place, Right Time, Right Price, Right Procedure, Right Administration, and Right Quality) with an average score of 60%. The effectiveness of fumigation treatment is supported by adherence to quarantine procedures and strong cross-actor coordination among quarantine officers, fumigators, and exporting companies, as well as the availability of fumigation infrastructure and standard-compliant documentation. The fumigation treatment guidelines follow the technical standards for methyl bromide fumigation issued by the Indonesian Quarantine Agency, Deputy for Plant Quarantine, Number 225 of 2025. The fumigation process can maintain coffee quality, prevent the growth of living organisms or insects in coffee products, and meet the requirements of export destination countries.

This study also found technical and non-technical obstacles, such as potential delays in collecting record sheets, the risk of tidal flooding in the port area, limitations in exporters' warehouses, differences in costs between each fumigator affecting the dosage administered, and the lack of updated fumigator competency. These factors impact the supply chain's smooth flow and the delivery of export goods. Increased effectiveness can be achieved through improved time management, diversification of storage locations, standardized fumigation dosage and pricing policies, real-time use of monitoring technology in the fumigation process, and continuous training for fumigators to strengthen their technical capabilities. Overall, these findings confirm that the success of fumigation depends not only on adherence to technical procedures but also on synergy between actors, infrastructure readiness, and adaptation to environmental challenges. This implementation is expected to drive an effective fumigation process that is consistent with national standards and significantly contributes to improving Indonesian coffee exports' competitiveness in the global market.

Conclusion

Fumigation plays a vital role in safeguarding the quality and competitiveness of Central Java's coffee exports by preventing pest infestation and ensuring compliance with international food safety standards. The implementation at Tanjung Emas Port generally aligns with Indonesian Quarantine Agency regulations, particularly for methyl bromide treatment. The fumigation process shows moderate effectiveness in location suitability and low effectiveness in timeliness. Many exporter warehouses lack proper space and infrastructure, while Tanjung Emas Port faces contamination risks due to tidal flooding. These issues compromise product safety and highlight the need for regular site evaluations and better facility standards. Timeliness is also a concern, with fumigation often occurring too close to shipment schedules and delays in submitting record sheets, which disrupt certification and increase pest risks. To improve, fumigation should be scheduled earlier, facilities upgraded, and documentation submitted promptly to ensure safe and efficient exports. The fumigation process in Central Java, particularly at exporter warehouses and Tanjung Emas Port, is moderately effective across key indicators such as location suitability (60%), timeliness (54%), cost accuracy (64%), and procedural compliance (60%), based on standards set by the Indonesian Quarantine Agency. The findings imply that while fumigation is crucial for maintaining the quality and marketability of Central Java's coffee exports, its current implementation faces significant challenges that could undermine its effectiveness. Gaps in infrastructure, procedural delays, and inconsistent practices not only threaten product safety and compliance with international standards but also risk delaying shipments and damaging Indonesia's reputation in global markets. Without immediate improvements such as upgrading facilities, enforcing timely documentation, standardizing costs, and enhancing human resource capacity, the fumigation process may continue to hinder export efficiency and compromise food safety. Strengthening these areas is essential to ensure a resilient, competitive, and trustworthy coffee export supply chain.

Future research should focus on improving fumigation effectiveness by addressing infrastructure limitations, procedural delays, and inconsistencies in pest control outcomes. Studies should explore standardized facility designs, optimized scheduling models, and cost regulation frameworks to ensure uniform treatment quality. Enhancing human resource capacity and administrative integration will also be critical for maintaining compliance and export reliability. These efforts will support safer, more efficient fumigation practices and strengthen Indonesia's position in the global coffee market.

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