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Mineral Oil Contamination Risk in Malaysian Palm Oil Mills: The Effects of Food Safety Practices on Food Safety Performance with Hygienic Equipment Design as an Antecedent Factor

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Abstract

The health risk concerns raised by the European Rapid Alert System for Food and Feed (RASFF) from increasing mineral oil hydrocarbon (MOH) contamination in global vegetable oils and fats, such as palm oil, have gained the attention of stakeholders. The drastically rising MOH pollution incidents diminish worldwide food safety, including Malaysia, as consuming chemically contaminated food can be harmful to health. Although reports of MOH contamination risks are available, the role of food safety practices in improving the food safety performance of palm oil mills has not been attentively addressed. Therefore, this study assessed the impacts of food safety practices on food safety performance, in which hygienic equipment design as an antecedent factor in MOH contamination prevention within Malaysian palm oil mills. This study is principally based on the Human Factors and Classification System (HFACS) and Structural Contingency Theory (SCT) as an underlying theoretical underpinning. Palm oil mills that meet pre-defined criteria were subjected to a quantitative survey following selection through simple random sampling. The findings can offer detailed insights to palm oil mill management on the latent factors of and improve food safety management practices in palm oil mills to mitigate MOH risks.

Keywords: Food Safety Performance, Food Safety Practices, Hygienic Equipment Design, Malaysia, Mineral Oil Hydrocarbon; Palm Oil Mill

Introduction

Vegetable oils and fats are prone to mineral oil hydrocarbon (MOH) contamination. The MOHs do not encompass naturally occurring hydrocarbons, as they are complex mixtures of petrogenic origins derived from crude oils or synthesised from coal, natural gas, or biomass.

Migration from food contact materials and environmental contamination are among the sources of MOH contamination in food, arising from the lubricants employed in machinery, release agents, processing aids, and food or feed additives.

Based on the chemical structure, MOH comprises two classes of hydrocarbon compounds: mineral oil saturated hydrocarbons (MOSH) and mineral oil aromatic hydrocarbons (MOAH). *n*-alkanes and other straight-chain alkyl groups are categorised under MOSH. Exposure to MOSH can result in its bioaccumulation in the organs and tissues. Meanwhile, MOAH encompasses substances with three or more aromatic rings and has been associated with genotoxicity and carcinogenicity (Chain et al., 2023).

Health risk concerns from the consistently increasing MOH contamination have led the European Standing Committee on Plants, Animals, Food and Feed to recommend the withdrawal of food products exceeding the quantification limits set by the Joint Research Centre [European Commission (EC), 2022]. According to the guidelines, the allowable limit for food contains between 4% and 50% fat is 1.0 mg/kg products while 2.0 mg/kg maximum for products that consist of over 50% fat content (Bratinova et al., 2023). The recommendation has led to MOH-contaminated vegetable oils and other foods exported to the European Union (EU) countries being recalled by the EU food safety authority.

According to the European Rapid Alert System for Food and Feed (RASFF), a drastic 900% increment in worldwide MOH occurrence in various foods has been documented within five years since 2020 (EC, n.d). Vegetable oils and fats were impacted the most by MOH contamination, leading them being recalled. The phenomenon has also heightened concerns among the food industries regarding the safety of oils and fats.

Approximately one-third of global palm oil production is dominated by Malaysia, making the nation the second-largest palm oil manufacturer. Palm oil export in 2022 has also earned Malaysia RM82.49 billion, which is a 27.7% rise compared to the previous year of RM64.61 billion [Malaysia Palm Oil Board (MPOB), n.d.]. The industry is also a primary agricultural commodity within manufacturing industries in the country, where upstream, midstream, and downstream sectors contributed 35.2% to the GDP of the nation in 2021 [Department of Statistics Malaysia (DOSM), 2022].

The European Food Safety Authority (EFSA) classified MOH as an industrial chemical pollutant. Specifically, numerous contamination issues, including MOH, have been plaguing the Malaysian palm oil milling sector [Naidu & Moorthy, 2021; Federation for European Oil and Proteinmeal Industry (Fediol), 2022]. Ahmad et al. (2019) and Maznah et al. (2023) reported that various processing steps contributed to the contamination of the crude palm oil produced in several palm oil mills (POMs) in Malaysia, which supported the palm oil MOH risk highlighted in previous reports (Ahmad et al., 2019; Stauff et al., 2020). The EU also reported that 36% of MOH cases were contributed by vegetable oils and fats, with 31% contributed by palm oil, including two incidents from Malaysia.

Palm oil has been utilised as a primary ingredient in various food production, potentially yielding MOH-tainted food products, and Grob (2018) revealed that vegetable oils, including palm oil, were substantially impacted by MOH (Ahmad et al., 2019; Stauff et al., 2020). One in 10 individuals falls sick and dies from consuming chemically and biologically contaminated food [World Health Organization (WHO), 2022]. Therefore, significant concerns have been raised by international palm oil players regarding food safety, as MOH cases has led to an elevated number of global food safety incidents.

The value of the Malaysian palm oil industry and public health have been impacted by MOH contamination issues, while global food safety performance, which is measured based on the global food security index, has decreased. Significantly diminished food safety performance and quality were also documented in 2022, where Malaysia was scored 69.9, a drop from 70.1 in 2021 (The Economist Group, 2022). As a consequence, nations agricultural sector performance, specifically agri-food subsector has been negatively impacted (Rozhan, 2025). This is evidenced based on observable market pattern whereby Malaysia's palm oil export volume to EU have drastically declined by 34% from 2020 to 2024 (Parveez, n.d.-a; Parveez, n.d.-b; Parveez, n.d.-c; Parveez, n.d.-d) that corroborates with time ever since EU heightened food safety and sustainability standards. Such an impact explicitly associates with trade performance and market access risk. Hence, managing the palm oil milling process is vital to address current food safety issues, considering the heightened potential of introducing MOH during each stage (Chandran, 2023; Parveez, 2023). Millers should also remain vigilant and proactive in identifying effective control measures that can improve the food safety performance of POMs.

Within the past two decades, research on MOH contamination has shifted from assessing food samples to determining potential migration from packaging materials. Studies have also improved MOH analytical methodologies, food safety risk, toxicological, and knowledge gaps analyses, and determined the consequences of legislation enforcement actions and processing on human health. Nonetheless, previous reports have failed to address the underlying factor of MOH contamination.

Knowledge on various scopes of studies is necessary to mitigate the MOH contamination risk. Nevertheless, the focus might have diverted researchers' attention from the human variables (Griffith & Motarjemi, 2023). Food safety issues are predominantly attributed to human factors (Liu et al., 2015; Walsh & Leva, 2019). Accordingly, food business owners aiming to enhance food safety performance should consider identifying and assessing the potential role of human parameters within the food processing environment (Walsh & Leva, 2019). Despite significant number of studies on food safety performance, there are several gaps in existing literature identified.

The research on food safety performance is investigated from the perspective of food safety programs influence (Jeffer et al., 2021; Njage et al., 2018), types of food services (Cunha et al., 2018), food safety culture (Jhuang & Chen, 2019), effect of institutional pressure (Abebe, 2020), effect of management practices (Taha et al., 2020), hygiene behaviour (Nyarugwe et al., 2020) and product quality (Hoyos Vallejo & Chinelato, 2024). Only Zhang et al. (2021) assessed the impact of contamination on food safety performance in China. A parallel study is unavailable in Malaysia.

Besides, past food safety performance research has been centred on the food service (Abdul Rashid et al. 2022; Fathurrahman et al., 2021) and meat processing sectors (Ollinger & Houser, 2020; Jeffer et al., 2021). Furthermore, very few studies have evaluated the food safety performance of palm oil milling sector in the Malaysian context, specifically concerning MOH. Accordingly, in this study, the occurrences of MOH contamination incidents were not restricted to food safety performance due to the harmful chemical hazards risk to human health, but also depicted weakness in food safety systems and the elevated risk of regulatory violation that leads to product recall. Therefore, an exceptional system could detect and manage MOH contamination at an early stage to ensure food safety compliance and sustainable performance.

Subsequently, studies have acknowledged issues regarding vegetable oil production operational activities since the 1990s (Moret et al., 1997; Moret et al., 2003; EFSA, 2008; Gómez-Cola et al., 2016; Gharbi et al., 2017). Nevertheless, available articles on MOH risk mitigation to improve food safety performance within the palm oil milling process are limited and do not adopt a step-by-step approach, despite recognising operational activities as possible MOH contamination sources, including processing and transporting (Fediol, 2018). Available reports also outlined the influence of operational activities, specifically food safety practices, on food safety performance, however it focused on personnel hygiene practices. Nonetheless, limited studies emphasised other operational activity aspects that are more relevant in a vegetable oil processing environment, such as vehicle hygiene, lubrication practices, and machinery cleaning practices.

Prior studies have demonstrated inadequate food safety practices contribute to contamination during food processing. According to Chapman et al. (2021), subpar hygiene protocols resulted in microbiological contamination exposure risk in food products. Girmay et al. (2022) also highlighted that microbial contamination in the drinking water is caused by workers' poor hygiene practices. However, these past studies emphasized food safety practices that leads to microbiological contamination instead of chemical hazards. Food safety practices have also been underscored as vital in preventing chemical contamination by Onyeaka et al. (2024), Grover (2023) and Salamandane et al. (2020). Nonetheless, practices that are specifically relevant to MOH contamination during palm oil milling are scarce.

Generally, the operational activities involved during palm oil mill processing are transporting palm fruits to the mill, receiving fresh fruit bunches (FFB), processing the FFB, and storing and delivering the extracted CPO to food processing facilities. The MOH contamination can occur at any of the palm oil production steps illustrated in Figure 1. Subpar food transportation protocols are the primary contributors to MOH contamination in vegetable oil (Bevan et al., 2020), while inadequate processing machinery cleanliness (Ahmad et al., 2019; Maznah, 2023) and lubricant handling (Menegoz Ursol et al., 2023) have also caused MOH contamination. Substantial MOH levels were also recorded by the CPO sampled from various processing machineries at POMs, such as the clarifier, vibrating screen (Ahmad et al., 2019), steriliser, digester, and storage tanks (Maznah, 2023), necessitating good milling practices (GMP) to avoid MOH risk.

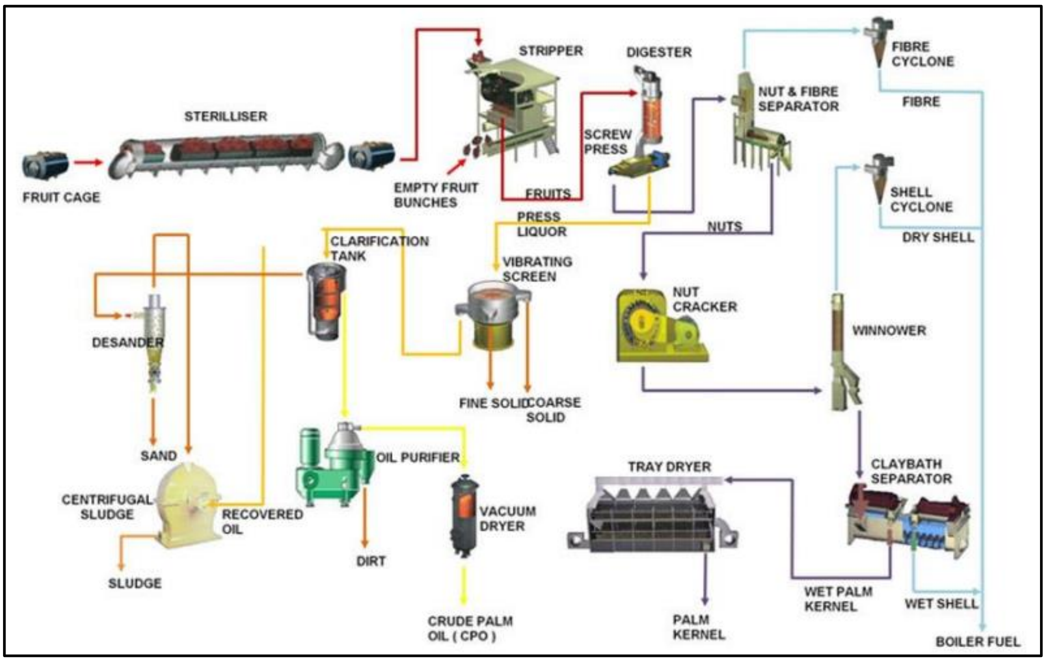

Figure 1 General palm oil milling process (Ahmad et al., 2019)

The risk of MOH contamination in palm oil is well established. Nonetheless, further assessments of the influence of food safety practices during routine palm oil milling work are essential, such as possible practices that can result in MOH risk during vegetable oil processing (EFSA, 2008). Therefore, this study evaluated other dimensions of food safety practices, including vehicle hygiene, lubrication practices, and machinery cleaning practices in POMs to enable better comprehension of the issue. Primary contributing factors also need to be determined, particularly food safety practices that depend upon equipment with a hygienic design.

Hygienic machinery design is critical in preventing cross-contamination risk and facilitate adequate cleaning (Menegoz Ursol et al., 2023). The parameter has also been highlighted as a latent organisational factor that influences unsafe food practices relevant to MOH risk in palm oil milling activities. Nevertheless, latent factors are frequently neglected and less attentively emphasised by organisations. Therefore, this study placed understanding the prevalent role of hygienic equipment design in ensuring safe food practices as a fundamental objective.

Food machinery produced with hygienic designs are easy to clean and possess features that avoid cross-contamination and sustain the safety of the food being processed (Waldhans et al., 2023). A well-hygienically designed food processing equipment also ensures fit for its intended employment by eliminating potential hazards that can be directly impacted by the equipment, such as construction materials, lubricant leakages, and damaged seals. Poor equipment design has also been associated with affecting the safety practices adhered by food handlers (Duong et al., 2023), such as an inability to perform a thorough cleaning.

The risks of MOH contamination associated with oil mill equipment commonly arise from lubricant contamination due to machinery design. Several units of processing equipment in palm oil milling activities are also linked to cross-contamination risk, such as the palm fruit elevators (Mohd Shukri, 2020). Similar to the observations reported by Menegoz Ursol et al. (2023), who revealed that the grease on mechanical parts in olive processing machineries is exposed to contact with olives, the conveyor chains in palm oil processing are also sources of MOH contamination.

Maznah et al. (2023) documented considerable MOSH levels in sterilised palm fruit and crude palm oil. The findings might be due to the placement of motorised rotating pumps on palm fruit digesters and vacuum dryers at POMs, which presents a hygienic design concern due to the possibility of MOH contamination risk from lubrication oil leakages. Consequently, Moerman et al. (2023) suggested installing rotary pump motor drives outside the product zone with self-draining protection to prevent lubricant from being introduced into the products.

Unavoidable contact between mechanical parts and food matrix and insufficient accessibility for cleaning lead to machinery contamination, necessitating designs that minimise cross-contamination risks. Digesters, press gear drives, and screw press cones have surfaces that are directly in contact with products, presenting potential mineral oil pollution from leakages. Layouts that permit easy access for maintenance of lubrication points are also essential. Nevertheless, most hygienic design literature was centred on potential microbiological contamination, while some empirical studies assessed how specific hygienic designs affect MOH transfer to crude palm oil. Consequently, equipment cleanability and design were evaluated in this study.

Addressing research gaps is vital to mitigate MOH, thereby alleviating the declining food safety performance in Malaysia. This study predominantly established the effects of food safety practices that are relevant to MOH contamination on food safety performance in Malaysian POMs. Hygienic POM equipment design as an antecedent factor in influencing safe food practices was also evaluated. The data obtained can facilitate a better understanding of contamination pathways through routine operational activities and improve control measures throughout the palm oil milling process in the country.

Literature Review

Theoretical Underpinning

The interconnected associations among variables in a study are explained by a theory. Theories also justify why the correlations might influence problems of a study and shape propositions that indicate the connection between the parameters assessed (Bougie & Sekaran, 2020). This study was based on two underpinning theories: human factors analysis and classification system (HFACS) and structural contingency theory (SCT). Organisational latent factors influencing food safety practices implementation were explained according to HFACS (Wiegmann & Shappell, 2003), while the effects of food safety performance contingent upon internal contingencies of an organisation were determined based on SCT (Thompson, 1967).

According to the HFACS model, the human variable error encompasses four levels in a sociotechnical system: organisational influence, unsafe supervision, and preconditions for unsafe and unsafe acts (Wiegmann & Shappell, 2003). The model was developed based on Reason’s theory and enables organisations to structurally investigate underlying active failure factors or internal deficiencies stemming from human error. Latent conditions leading to incidents are also considered to allow organisations to devise strategies that mitigate the contributory factors.

This study postulated that MOH contamination risk during palm oil milling arises from improper food safety practices are due to human error. The human error aspect is classified as skill-based error at the unsafe act level in HFACS. Meanwhile, the determinants of food safety practices were focused on hygienic equipment design, that are classified as technological environment, in which this study theorised at preconditions of unsafe act level being as a latent failure factor within the organisation.

Based on SCT, the relationship between organisational characteristics and effectiveness is contingent upon certain parameters. The theory suggested that various contingency factors influence the attainment of intended performance, instead of depending upon a sole determinant. Moreover, SCT does not recognise one optimal fit model for appropriateness and efficiency of risk mitigation strategies (Kumar et al., 2021). Therefore, this study conceptualised the effectiveness of food safety performance in POMs as influenced by the extent of the food safety practices implemented by a company, are contingent upon technological variables, which in this study refers to hygienic equipment design.

Hygienic Equipment Design and Food Safety Practices
Studies across different food business settings have acknowledged the role of hygienic equipment design for sustainable, safe food practices. Minimising biological, chemical, and physical contamination of food products necessitates equipment with better hygienic designs, including tools that are easy to clean and maintain (Rodrigo et al., 2021). Designing hygienic equipment is also essential for maintaining food safety practices, as food processing equipment with surfaces that are directly in contact with food imposes risks of cross-contamination when safe food handling activities are not executed properly.

The effects of hygienic equipment design on food safety practices have been highlighted in numerous reports. For instance, Reichler et al. (2020) documented unsatisfactory bacterial reduction when performing random sampling in post-pasteurisation milk processing facility despite the implementation of a modified cleaning system. The study highlighted the importance of hygienic design to support adequate cleaning outcomes.

The EFSA has also listed hygienic equipment design as critical in hindering exposure to microbes in the frozen fruits and vegetables processing industry (Hazards et al., 2020). Schnabel et al. (2021) also stressed that the hygienic design of the production line leads to an effective non-thermal sanitation in mitigating microbial contamination on fresh-cut lettuce. In another study, Stessl et al. (2022) revealed that microbial contamination in a meat processing plant was due to inadequate conveyor belt and crate washing line. A hygienically designed apple packing machine surface has also enabled the effective cleaning and sanitation practice, minimising microbial load by threefold (Ruiz-Llacsahuanga et al., 2022). The influence of hygienic equipment design on food safety practices has also been evaluated based on microbiological hazards in a cheese-making facility (Piras et al., 2023), on plastic and metal surfaces in the meat processing industry (Waldhans et al., 2023), and in food and feed processing environments (Hazards et al., 2024).

Reports on the effects of hygienic design on food safety practices are primarily based on experimental designs. Therefore, the studies assessed the influence of the designs on food safety practices based on cleaning efficiency, which was determined according to microbiological contamination risk. Studies focusing on chemical hazard contamination risk based on the feedback provided by respondents in a survey are limited.

Survey studies are necessary, as they encompass the psychological effects and visual clues that equipment design has on engaging personnel to perform safe food handling procedures. The data from such studies also offers insights into the level of awareness and understanding of the personnel. Moreover, analysing hygienic design influence through survey research enables respondents to provide feedback on design-related challenges they face when cleaning the equipment. The information can then be manipulated to make informed decisions and manage investment costs to achieve further improvements (Aarnisalo et al., 2006).

Conclusively, employing hygienically-designed food equipment can lead to significant savings during cleaning operations and cost-effectiveness and sustainability in the long-term perspective, despite a substantial initial investment (Moerman et al., 2023). Consequently, this study hypothesised that hygienic equipment design and food safety practices are correlated. The effects of both variables were assessed in the POM context.

Food Safety Practices and Food Safety Performance

For decades, the performance of food business organisations has been implicated in various food safety issues. Several measures have been implemented to address the matter, including a plethora of food safety management systems to govern food safety in the supply chain. Nonetheless, differences in food safety practices across business organisation, even within the same business nature, present obstacles to achieving the desired food safety output. The discrepancies could be due to the variations in production and distribution in food supply chains.

Based on the literature reviewed in this study, the implementation of food safety practices in food manufacturing facilities is linked to food safety performance. Abebe (2020) underscored the positive correlation between food safety practices implementation and food safety performance through a study conducted among Lebanese food processors, who produced baked goods, meat, dairy, fruits and vegetables, confectionery, cereals, and oils. Based on the outcomes, food safety performance among the Lebanese food processors was poor despite a positive association, as evidenced by food safety complaints and hygiene non-conformities. Therefore, food manufacturers should improve their safe food handling practices. Meat-related disease outbreaks in Uganda beef slaughterhouses were also the consequences of food safety practices that lacked inclusiveness and did not assert seriousness in food safety system evaluation. Moreover, food safety and hygiene-related complaint system deficiencies also contributed to the issue (Jeffer et al., 2021). Conclusively, notably poor food safety performance was predominantly due to poor sanitation, hygiene and handling practices.

According to Nguyen (2022), food safety practices adopted by the Vietnamese food industries had statistically significant positive effects on the food performance in the nation. The positive relationship between food safety practices and food safety performance was also affirmed by Woreta et al. (2024) based on cross-contamination prevention procedures implemented by the water bottling industries in Northwest Ethiopia. Inadequate hygiene practices during the water bottling process, marked by food safety protocol discrepancies, led to microbiological contamination, thereby causing subpar food performance.

Significantly different food handling practices led to notably moderate performance variations among vendors of street food stands in China (Wu et al., 2024). Conversely, Abdul-Rashid et al. (2022) contended that the safe handling practices of government hospital kitchen personnel did not influence food safety performance when evaluated based on microbial indicators. Nevertheless, most studies indicated the positive effects of safe handling practices on performance, considering that each strategy implemented to improve food safety practices enhanced food safety performance by 40% (Abebe, 2020). Therefore, this study assessed the effects of food safety practices on food safety performance in the POM context.

Research Gap

Several research gaps relevant to the context of this research identified based on review of prior literatures. Firstly, is contextual gap whereby prior research on MOH contamination and mitigation action was emphasized based on source of contamination. Researches addressing food safety incidents specifically in MOH contamination perspective that are based on human causal contributing factor from the perspective of active and latent failure factors lacks of examination, specifically in Malaysia palm oil milling context. More specifically, the linkage of human causal factors towards food safety performance context is lacking. Aside this, past researches underexplored the influence of food safety practices on performance from the perspective of operational activities such as vehicle hygiene, lubrication and cleaning practices which are relevant in MOH incidents within palm oil processes. Thus, practical and feasible intervention that provide cost-effective remedial based on day-to-day operational activities lacks of investigation. Moreover, the past studies that investigates food safety practices less focused on chemical contamination context and the antecedents of inadequate practices relevant to MOH incidents unaddressed within Malaysia palm oil mills.

Secondly, is empirical gap, in which most of the MOH previous studies much prioritize on harmonization of MOH analytical methodology. Limited studies have focused on investigating human causal route in relation to MOH contamination since this is an emerging food safety issue and nothing much is known on the mitigation based on human factors within Malaysian palm oil mill context. Hence the existing literatures lacks in empirical evidence based on human factors being as primary data to address the mentioned gap.

Thirdly, is theoretical gap based on the two main underpinning theories, HFACS and SCT. The HFACS model analyze human causal factors in accidents incidents investigation based on internal organization environment, lacks exploration on the impact towards organisations performance. On the other hand, past researches based on SCT that posits organizational performance contingent upon system and the context it operates, merely considered the effect of technological environment factor, especially hygienic equipment design towards food safety performance. Prior research using SCT as theoretical framework emphasized on supply chain performance management (Yadav et al., 2023; Amhalhal et al., 2021) and management accounting practices (Nguyen et al., 2023; Najera Ruiz & Collazzo, 2021; Hadid & Al-Sayed, 2021). Therefore, this research undertakes the gaps identified in literature and a new framework will be established by integrating HFACS model and SCT, the two separate strands theories focus on Malaysia palm oil milling sector.

Conceptual Framework

Figure 2 illustrates the conceptual framework adopted in this study. The framework provides a way to comprehend the research objective set in this study.

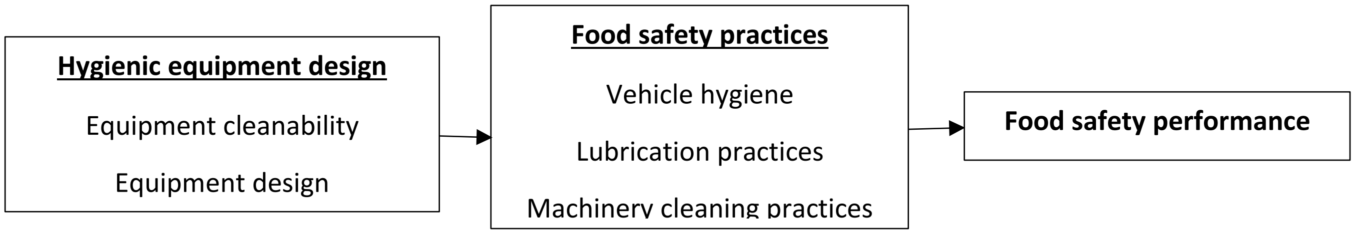

Figure 2: Conceptual framework

Methodology

The target population in this study was selected from a list of POMs operating in Malaysia. According to the list, which was obtained from the MPOB Directory of Malaysian Palm Oil Processing Sector (2021), 465 POMs were registered in the country. The directory also provided the names, addresses, and contact details of the POMs in each state in Malaysia without offering information on mill characteristics. The POMs in Malaysia have contributed substantially to the economy of the nations, hence they were all considered as possible candidates.

During respondent selection, random numbers between 1 and 465 were first generated utilising an online randomiser tool from Research Randomizer. The simple random sampling strategy was employed to select the respondents that met specific pre-defined criteria relevant to the variables of interest in this study. The numbers were then assigned to the target population based on the list procured from the MPOB Directory, allowing this study to choose representative samples, prevent bias, and allow outcome generalisability (Saunders et al., 2019). The method also yielded a uniformed core processes and similar regulatory requirements depicting standardised operational processes and regulatory compliance regardless of operating conditions across different POMs, per the benefits recorded by, Cunha et al. (2018) and Wang et al. (2022). Consequently, this study obtained a homogenous sample of mills with similar attributes.

The respondents in this study were personnel employed in the POM sector who were responsible for overseeing and implementing food safety. Nevertheless, only individuals with a minimum of two years of working experience with responsibilities in food safety implementation tasks were involved to guarantee that their perceptions were directly relevant to the focus of this study, which was the underlying human factors contributing to MOH contamination and food safety performance in POMs. Similar strategies were adopted by Njage et al. (2018), Abebe (2020), Nyarugwe et al. (2020) and Durme et al. (2024), who tailored their respondents' criteria to align with the quantitative goals of their investigations.

A survey questionnaire generated with Google Forms was the primary data collection approach employed in this study, which was only provided to consenting respondents after obtaining written permission from the management of each selected POM. Before agreeing or disagreeing to participate in this study, each respondent was asked to read and acknowledge the consent form, and all information procured was anonymous and confidential. The administration department of each POM was emailed the structured survey questionnaire, an explanation of the objectives of this study, the inclusion criteria, and instructions for participation. Outliers were then screened before conducting data analysis with a descriptive evaluation and partial-least square structural equation modeling (PLS-SEM).

Conclusion

The economic performance of Malaysia significantly relies upon its palm oil production, which is being threatened by persistent MOH contamination incidents. Nonetheless, MOH-polluted oil palm cases in the nation present public health risks and subject the integrity of the industry, trade competitiveness, and national food safety performance to potential damage. Enhancing the food safety systems in Malaysian POMs is also urgently required due to the stringent regulatory expectations, increasing product recalls, and rising international concerns over MOH contamination. Consequently, palm oil milling operations should implement targeted interventions, especially food safety practices that directly prevent contamination.

Available data are insufficient to address the operational and human-driven factors contributing to contamination within processing environments, despite substantially advanced scientific understanding of MOH detection, migration behaviour, and toxicological risks. Inadequate empirical reports linking operational practices and hygienic equipment design to MOH contamination in POMs also present limitations. This study fills the critical knowledge gaps by assessing the influence of design-related latent factors on routine food safety practices, which affects food safety performance.

Hygienic equipment design, which is a commonly overlooked factor, is critical in chemical contamination. The design of equipment exerts a fundamental effect on cleanability, lubricant management, and the feasibility of safe work protocols. This study established the correlations between routine operational activities, such as vehicle hygiene, lubrication handling, and machinery cleaning, and equipment design. Therefore, the information obtained offered meaningful insights into the organisational and technical conditions that enable or prevent MOH contamination. This study also provided an evidence-based pathway for improving preventive measures, mitigating MOH risks, and supporting a sustainable food safety performance within the Malaysian POM sector.

References

Aarnisalo, K., Tallavaara, K., Wirtanen, G., Maijala, R., & Raaska, L. (2006). The hygienic working practices of maintenance personnel and equipment hygiene in the Finnish food industry. *Food Control*, *17*(12), 1001-1011. doi:10.1016/j.foodcont.2005.07.006

Abebe, G. K. (2020). Effects of institutional pressures on the governance of food safety in emerging food supply chains: a case of Lebanese food processors. *Agriculture and Human Values, 37*(4), 1125-1138. https://doi.org/10.1007/s10460-020-10071-3

Abdul-Rashid, S., Ungku Fatimah, U. Z. A., Abdul-Mutalib, N. A., Omar, S., Jinap, S., & Sanny, M. (2022). Relating food handlers' knowledge, attitude, and self-reported practices on food safety and hygiene to the performance of food safety assurance system: A multiple case study in government hospital kitchens. *Pertanika Journal of Tropical Agricultural Science, 45*(3), 731-745. https://doi.org/10.47836/pjtas.45.3.12

Ahmad, H., Noor, A. M., Sabri, M. P. A., Ngteni, R., & Hilmi, S. M. H. S. (2019). Mineral oil saturated hydrocarbon in crude palm oil-current status in Sime Darby Palm Oil Mills. *Journal of Advanced Agricultural Technologies, 6*(4), 299-303. https://doi.org/10.18178/joaat.6.4.299-303

Amhalhal, A., Anchor, J., Tipi, N. S., & Elgazzar, S. (2021). The impact of contingency fit on organisational performance: An empirical study. *International Journal of Productivity and Performance Management, 71*(6), 2214-2234. https://doi.org/10.1108/ijppm-01-2021-0016

Bevan, R., Harrison, P. T. C., Jeffery, B., & Mitchell, D. (2020). Evaluating the risk to humans from mineral oils in foods: Current state of the evidence. *Food and Chemical Toxicology*, *136*, 110966. https://doi.org/10.1016/j.fct.2019.110966

Bougie, R., & Sekaran, U. (2020). *Research methods for business: A skill building approach* (8th ed.). John Wiley & Sons.

Bratinova, S., Roubouch, P., & Hoekstra, E. (2023). Guidance on sampling, analysis and data reporting for the monitoring of mineral oil hydrocarbons in food and food contact materials : in the frame of Commission Recommendation (EU) 2017/84. Publications Office of the European Union. https://data.europa.eu/doi/10.2760/963728.

Chain, E. P. o. C. i. t. F., Schrenk, D., Bignami, M., Bodin, L., Del Mazo, J., Grasl-Kraupp, B., Hogstrand, C., Hoogenboom, L. R., Leblanc, J. C., Nebbia, C. S., Nielsen, E., Ntzani, E., Petersen, A., Sand, S., Schwerdtle, T., Vleminckx, C., Wallace, H., Alexander, J., Goldbeck, C., Grob, K., Gomez Ruiz, J. A., Mosbach-Schulz, O., Binaglia, M., & Chipman, J. K. (2023, Sep). Update of the risk assessment of mineral oil hydrocarbons in food. *EFSA Journal, 21*(9), e08215. https://doi.org/10.2903/j.efsa.2023.8215

Chandran, M. R. (2023, November 7-9). *Making palm oil safe for the planet and your plate: The need to embrace change* [Paper presentation]. MPOB International Palm Oil Congress and Exhibition, Kuala Lumpur, Malaysia

Chapman, B. J., Linton, R. H., & McSwane, D. Z. (2021). Food safety postprocessing: Transportation, supermarkets, and restaurants. In *Foodborne Infections and Intoxications* (pp. 523-544). https://doi.org/10.1016/b978-0-12-819519-2.00029-3

Cunha, D. T. D., Rosso, V. V., & Stedefeldt, E. (2018). Food safety performance and risk of food services from different natures and the role of nutritionist as food safety leader. *Cien Saude Colet, 23*(12), 4033-4042. https://doi.org/10.1590/1413-812320182312.21042016

Department of Statistics Malaysia. (2022, October 25). *Selected agricultural indicators, Malaysia, 2022*. https://www.dosm.gov.my/portal-main/release-content/selected-agricultural-indicators-malaysia-2022

Duong, A. T. B., Nguyen, T. T. B., Li, D., & Quang, H. T. (2023). Unleashing food business's potential: the mediating role of food safety management on the relationship between critical success factors and business performance. *Operations Management Research, 16*(4), 2064-2080. https://doi.org/10.1007/s12063-023-00389-6

Durme, J. V., Spagnoli, P., Doan Duy, L. N., Lan Nhi, D. T., & Jacxsens, L. (2024). Maturity of food safety management systems in the Vietnamese seafood processing industry. *Journal of Food Protection, 87*(4), 100240. https://doi.org/10.1016/j.jfp.2024.100240

European Food Safety Authority. (2008). EFSA statement on the contamination of sunflower oil with mineral oil exported from Ukraine. *EFSA Journal, 6*(5), 1-3. https://doi.org/10.2903/j.efsa.2008.1049

European Commission. (2022, April 21). *Standing committee on plants, animals, food and feed section novel food and toxicological safety of the food chain*. https://www.actu-environnement.com/media/pdf/news-39833-reg-com-toxic-20220421-summary.pdf

European Commission. (n.d.). *RASFF window*. https://webgate.ec.europa.eu/rasff-window/screen/search?searchQueries=eyJkYXRlIjp7InN0YXJ0UmFuZ2UiOiIiLCJlbmRSYW5nZSI6IiJ9LCJjb3VudHJpZXMiOnt9LCJ0eXBlIjp7fSwibm90aWZpY2F0aW9uU3RhdHVzIjp7Im5vdGlmaWNhdGlvblN0YXR1cyI6W1sxXV19LCJwcm9kdWN0Ijp7fSwicmlzayI6e30sInJlZmVyZW5jZSI6IiIsInN1YmplY3QiOiJNT0FIIn0%3D

Fathurrahman, R. N., Rukayadi, Y., Ungku Fatimah, U. Z. A., Jinap, S., Abdul-Mutalib, N. A., & Sanny, M. (2021). The performance of food safety management system in relation to the microbiological safety of salmon nigiri sushi: A multiple case study in a Japanese chain restaurant. *Food Control, 127*. https://doi.org/10.1016/j.foodcont.2021.108111

Federation for European Oil and Proteinmeal Industry. (2022, May). *Flow chart of the production chain of palm oil and palm kernel oil products for food application in the EU: Risk assessment of the chain of palm and palm kernel oil products.* https://www.fediol.eu/data/Risk%20Assessment%20Palm%20Food%20FEDIOL%20Final%20160522.pdf

Federation for European Oil and Proteinmeal Industry. (2018, February 14). *Fediol code of practice for the management of mineral oil hydrocarbons presence in vegetable oils and fats intended for food uses*. https://www.fediol.eu/data/14COD341Rev1%20CoP%20MOH%2014Feb2018%20FINAL.pdf

Gharbi, I., Moret, S., Chaari, O., Issaoui, M., Conte, L. S., Lucci, P., & Hammami, M. (2017). Evaluation of hydrocarbon contaminants in olives and virgin olive oils from Tunisia. *Food Control, 75*, 160-166. https://doi.org/10.1016/j.foodcont.2016.12.003

Girmay, A. M., Mengesha, S. D., Weldetinsae, A., Alemu, Z. A., Dinssa, D. A., Wagari, B., Weldegebriel, M. G., Serte, M. G., Alemayehu, T. A., Kenea, M. A., Teklu, K. T., Adugna, E. A., Gobena, W., Fikresilassie, G., Wube, W., Melese, A. W., Redwan, E., Tessema, M., & Tollera, G. (2022). Factors associated with food safety practice and drinking-water quality of food establishments in Bishoftu Town, Ethiopia. *Discover Food, 2*(1). https://doi.org/10.1007/s44187-022-00037-1

Gómez-Coca, R. B., Perez-Camino, M. D. C., & Moreda, W. (2016). Saturated hydrocarbon content in olive fruits and crude olive pomace oils. *Food Additives & Contaminants: Part A*, *33*(3), 391-402. DOI: 10.1080/19440049.2015.1133934

Griffith, C.J., & Motarjemi, Y. (2023). Human factors in food safety management. In V. Andersen, H. Lelieveld & Y. Motarjemi (Eds.), Food safety management: A practical guide for food industry (pp. 935-937). Academic Press.

Grob, K. (2018). Mineral oil hydrocarbons in food: A review. *Food Additives Contaminants-Part A Chemical Analysis Control Exposure Risk Assessment, 35*(9), 1845-1860. doi:10.1080/19440049.2018.1488185

Grover, A. K. (2023). Out of the frying pan and into the fire? Uncovering the impact of FSMA's sanitary food transportation rule on the food logistics industry. *Business Horizons, 66*(2), 203-214. https://doi.org/10.1016/j.bushor.2022.06.003

Hadid, W., & Al-Sayed, M. (2021). Management accountants and strategic management accounting: The role of organizational culture and information systems. *Management Accounting Research, 50*. https://doi.org/10.1016/j.mar.2020.100725

Hazards, E. P. o. B., Koutsoumanis, K., Allende, A., Bolton, D., Bover-Cid, S., Chemaly, M., De Cesare, A., Herman, L., Hilbert, F., Lindqvist, R., Nauta, M., Nonno, R., Peixe, L., Ru, G., Simmons, M., Skandamis, P., Suffredini, E., Fox, E., Gosling, R. B., Gil, B. M., Moretro, T., Stessl, B., da Silva Felicio, M. T., Messens, W., Simon, A. C., & Alvarez-Ordonez, A. (2024). Persistence of microbiological hazards in food and feed production and processing environments. *EFSA Journal, 22*(1), e8521. https://doi.org/10.2903/j.efsa.2024.8521

Hazards, E. P. o. B., Koutsoumanis, K., Alvarez-Ordonez, A., Bolton, D., Bover-Cid, S., Chemaly, M., Davies, R., De Cesare, A., Herman, L., Hilbert, F., Lindqvist, R., Nauta, M., Peixe, L., Ru, G., Simmons, M., Skandamis, P., Suffredini, E., Jordan, K., Sampers, I., Wagner, M., Da Silva Felicio, M. T., Georgiadis, M., Messens, W., Mosbach-Schulz, O., & Allende, A. (2020). The public health risk posed by Listeria monocytogenes in frozen fruit and vegetables including herbs, blanched during processing. *EFSA Journal, 18*(4), e06092. https://doi.org/10.2903/j.efsa.2020.6092

Hoyos Vallejo, C. A., & Chinelato, F. B. (2024). Delivering trust: How food safety performance drives loyalty across the online ordering journey. *International Journal of Quality & Reliability Management*. https://doi.org/10.1108/ijqrm-12-2023-0399

Jeffer, S. B., Kassem, I. I., Kharroubi, S. A., & Abebe, G. K. (2021). Analysis of food safety management systems in the beef meat processing and distribution chain in Uganda. *Foods, 10*(10). https://doi.org/10.3390/foods10102244

Jhuang, C.-Y., & Chen, Y.-L. (2019). Empirical study on the relationship between food safety culture and food safety performance. *Taiwanese Journal of Agricultural Chemistry & Food Science, 57*(2).

Kumar, A., Mangla, S. K., Kumar, P., & Song, M. (2021). Mitigate risks in perishable food supply chains: Learning from COVID-19. *Technological Forecasting and Social Change, 166*. https://doi.org/10.1016/j.techfore.2021.120643

Liu, Y., Liu, F., Zhang, J., & Gao, J. (2015). Insights into the nature of food safety issues in Beijing through content analysis of an Internet database of food safety incidents in China. *Food Control, 51*, 206-211. https://doi.org/10.1016/j.foodcont.2014.11.017

Moerman, F., Kastelein, J., & Rugh, T. (2023). Hygienic design of food processing equipment. In V. Andersen, H. Lelieveld & Y. Motarjemi (Eds.), *Food safety management: A practical guide for the food industry (*pp. 623-678). Academic Press.

Malaysian Palm Oil Board. (2021). *Directory of Malaysian palm oil processing sectors 8th edition*. Malaysian Palm Oil Board

Malaysian Palm Oil Board. (n.d.). *Production of crude palm oil 2023*. https://bepi.mpob.gov.my/index.php/production/301-production-2023/1138-production-of-crude-oil-palm-2023

Malaysian Palm Oil Board. (n.d.). *Production of crude palm oil 2022*. https://bepi.mpob.gov.my/index.php/production/286-production-2022/1092-production-of-crude-oil-palm-2022

Maznah, Z., Tarmizi, A. H. A., Ramli, M. R., Halim, R. M., Che Mat, C. R., Hammid, A. N. A. (2023, November 7-9). *Evaluation of mineral oil saturated hydrocarbon (MOSH) concentration levels at critical control point (CCP) in the palm oil processing chain* [Paper presentation]. MPOB International Palm Oil Congress and Exhibition, Kuala Lumpur, Malaysia

Menegoz Ursol, L., Conchione, C., Peroni, D., Carretta, A., & Moret, S. (2023). A study on the impact of harvesting operations on the mineral oil contamination of olive oils. *Food Chemistry, 406*, 135032. https://doi.org/10.1016/j.foodchem.2022.135032

Mohd Shukri, N. F. (2020). Code of good milling practice in enhancing sustainable palm oil production. *Journal of Oil Palm Research*. https://doi.org/10.21894/jopr.2020.0055

Moret, S., Populin, T., Conte, L. S., Grob, K., & Neukom, H. P. (2003). Occurrence of C15-C45 mineral paraffins in olives and olive oils. *Food Additives & Contaminants*, *20*(5), 417-426. DOI:10.1080/0265203031000098687

Moret, S., Grob, K., & Conte, L. S. (1997). Mineral oil polyaromatic hydrocarbons in foods, eg from jute bags, by on-line LC-solvent evaporation (SE)-LC-GC-FID. *International Journal of Food Research and Technology*, *204*, 241-246. https://doi.org/10.1007/s002170050071

Naidu, L., & Moorthy, R. (2021). A review of key sustainability issues in Malaysian palm oil industry. *Sustainability, 13*(19), 1-13. https://doi.org/10.3390/su131910839

Najera Ruiz, T., & Collazzo, P. (2021). Determinants of the use of accounting systems in microenterprises: evidence from Chile. *Journal of Accounting in Emerging Economies, 11*(4), 632-650. https://doi.org/10.1108/jaee-07-2020-0173

Nguyen, T. H., Nguyen, D. T., Nguyen, T. A., & Nguyen, C. D. (2023). Impacts of contingency factors on the application of strategic management accounting in Vietnamese manufacturing enterprises. *Cogent Business & Management, 10*(2). https://doi.org/10.1080/23311975.2023.2218173

Nguyen, B. A. (2022). The effects of laws and regulations on the implementation of food safety practices through supply chain integration and dynamic supply chain capabilities. *Uncertain Supply Chain Management, 10*(1), 137-154. https://doi.org/10.5267/j.uscm.2021.10.002

Njage, P. M. K., Opiyo, B., Wangoh, J., & Wambui, J. (2018). Scale of production and implementation of food safety programs influence the performance of current food safety management systems: Case of dairy processors. *Food Control, 85*, 85-97. https://doi.org/10.1016/j.foodcont.2017.09.015

Nyarugwe, S. P., Linnemann, A. R., Ren, Y., Bakker, E.-J., Kussaga, J. B., Watson, D., Fogliano, V., & Luning, P. A. (2020). An intercontinental analysis of food safety culture in view of food safety governance and national values. *Food Control, 111*. https://doi.org/10.1016/j.foodcont.2019.107075

Ollinger, M., & Houser, M. (2020). Ground beef recalls and subsequent food safety performance. *Food Policy, 97*. https://doi.org/10.1016/j.foodpol.2020.101971

Onyeaka, H., Ghosh, S., Obileke, K., Miri, T., Odeyemi, O. A., Nwaiwu, O., & Tamasiga, P. (2024). Preventing chemical contaminants in food: Challenges and prospects for safe and sustainable food production. *Food Control, 155*. https://doi.org/10.1016/j.foodcont.2023.110040

Parveez, G. K. A. (2023, November 7-9). *Addressing challenges in the palm oil industry.* [Paper presentation]. MPOB International Palm Oil Congress and Exhibition, Kuala Lumpur, Malaysia.

Parveez, G. K. A. (n.d.- a). *Overview of the Malaysian oil palm industry 2024.* https://bepi.mpob.gov.my/images/overview/Overview2024.pdf

Parveez, G. K. A. (n.d.- b). *Overview of the Malaysian oil palm industry 2023.* https://bepi.mpob.gov.my/images/overview/Overview2023.pdf

Parveez, G. K. A. (n.d.- c). *Overview of the Malaysian oil palm industry 2022.* https://bepi.mpob.gov.my/images/overview/Overview2022.pdf

Parveez, G. K. A. (n.d.- d). *Overview of the Malaysian oil palm industry 2021.* https://bepi.mpob.gov.my/images/overview/Overview2021.pdf

Piras, F., Siddi, G., Le Guern, A. S., Bremont, S., Fredriksson-Ahomaa, M., Sanna, R., Meloni, M. P., De Santis, E. P. L., & Scarano, C. (2023). Traceability, virulence and antimicrobial resistance of Yersinia enterocolitica in two industrial cheese-making plants. *International Journal of Food Microbiology, 398*, 110225. https://doi.org/10.1016/j.ijfoodmicro.2023.110225

Reichler, S. J., Murphy, S. I., Erickson, A. W., Martin, N. H., Snyder, A. B., & Wiedmann, M. (2020). Interventions designed to control postpasteurization contamination in high-temperature, short-time-pasteurized fluid milk processing facilities: A case study on the effect of employee training, clean-in-place chemical modification, and preventive maintenance programs. *Journal of Dairy Science, 103*(8), 7569-7584. https://doi.org/10.3168/jds.2020-18186

Rodrigo, D., Rosell, C. M., & Martinez, A. (2021). Risk of bacillus cereus in relation to rice and derivatives. *Foods, 10*(2). https://doi.org/10.3390/foods10020302

Rozhan, A. D. (2025). Food security dilemma in Malaysia. *Food and Fertilizer Technology Center for the Asian and Pacific Region Policy Platform*. https://ap.fftc.org.tw/article/3745

Ruiz-Llacsahuanga, B., Hamilton, A. M., Anderson, K., & Critzer, F. (2022). Efficacy of cleaning and sanitation methods against Listeria innocua on apple packing equipment surfaces. *Food Microbiology, 107*, 104061. https://doi.org/10.1016/j.fm.2022.104061

Salamandane, C., Fonseca, F., Afonso, S., Lobo, M. L., Antunes, F., & Matos, O. (2020). Handling of fresh vegetables: Knowledge, hygienic behavior of vendors, public health in Maputo Markets, Mozambique. *International Journal of Environmental Research and Public Health, 17*(17). https://doi.org/10.3390/ijerph17176302

Schnabel, U., Balazinski, M., Wagner, R., Stachowiak, J., Boehm, D., Andrasch, M., Bourke, P., & Ehlbeck, J. (2021). Optimizing the application of plasma functionalised water (PFW) for microbial safety in fresh-cut endive processing. *Innovative Food Science & Emerging Technologies, 72*. https://doi.org/10.1016/j.ifset.2021.102745

Stauff, A., Schnapka, J., Heckel, F., & Matissek, R. (2020). Mineral Oil Hydrocarbons (MOSH/MOAH) in Edible Oils and Possible Minimization by Deodorization Through the Example of Cocoa Butter. *European Journal of Lipid Science and Technology, 122*(7). https://doi.org/10.1002/ejlt.201900383

Stessl, B., Ruppitsch, W., & Wagner, M. (2022). Listeria monocytogenes post-outbreak management - When could a food production be considered under control again? *International Journal of Food Microbiology, 379*, 109844. https://doi.org/10.1016/j.ijfoodmicro.2022.109844

Taha, S., Wilkins, S., Juusola, K., & Osaili, T. M. (2020). Food safety performance in food manufacturing facilities: The influence of management practices on food handler commitment. *Journal of Food Protection, 83*(1), 60-67. https://doi.org/10.4315/0362-028X.JFP-19-126

The Economist Group. (2022). *Global food security index 2022*. https://impact.economist.com/sustainability/project/food-security-index/reports/Economist_Impact_GFSI_2022_Global_Report_Sep_2022.pdf

Thompson, J. D. (1967). *Organizations in actions*. McGraw-Hill

Waldhans, C., Hebel, M., Herbert, U., Spoelstra, P., Barbut, S., & Kreyenschmidt, J. (2023). Microbial investigation of cleanability of different plastic and metal surfaces used by the food industry. *Journal of Food Science & Technology, 60*(10), 2581-2590. https://doi.org/10.1007/s13197-023-05778-0

Walsh, C., & Leva, M. C. (2019). A review of human factors and food safety in Ireland. *Safety Science, 119*, 399-411. https://doi.org/10.1016/j.ssci.2018.07.022

Wang, Y., Li, D., & Zhou, J. (2022). Interregional collaboration for food safety governance: the scheme design and performance evaluation with cases in China. *Journal of Chinese Governance, 8*(2), 234-255. https://doi.org/10.1080/23812346.2022.2134625

Wiegmann, D. A., & Shappell, S. A. (2003). *A human error approach to aviation accident analysis*. Ashgate Publishing Limited

Woreta, T. M., Worku, A. F., Tenagashaw, M. W., Yemata, T. A., Mamo, F. T., & Damtie, D. G. (2024). Performance assessment of food safety systems (FSMSs and FSC) in water bottling factories in view of their contextual characteristics. *Discover Applied Sciences, 6*(10). https://doi.org/10.1007/s42452-024-06246-w

World Health Organization. (2022). WHO global strategy for food safety 2022-2030: Towards stronger food safety systems and global cooperation. https://www.who.int/publications/i/item/9789240057685

Wu, J., Gong, S., Guo, Z., & Bai, L. (2024). Street food vendors' hygienic and handling practices in China: Checklist development and observational assessment. *Food Control, 166*. https://doi.org/10.1016/j.foodcont.2024.110765

Yadav, S., Luthra, S., Kumar, A., Agrawal, R., & Frederico, G. F. (2023). Exploring the relationship between digitalization, resilient agri-food supply chain management practices and firm performance. *Journal of Enterprise Information Management*. https://doi.org/10.1108/jeim-03-2022-0095

Zhang, H., Sun, C., Huang, L., & Si, H. (2021). Does government intervention ensure food safety? Evidence from China. *International Journal of Environmental Research and Public Health, 18*(7). https://doi.org/10.3390/ijerph18073645