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Strengthening Food Safety in Guyana's Rice Industry: A Supply Chain Review of the Physical Hazards of Rice

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ABSTRACT

Rice contributes significantly to Guyana's economy and plays an important role in ensuring food security. However, within the rice sector, food safety receives less attention compared to productivity and grain quality. This review examines the physical hazards that have the potential to contaminate rice. It focuses on the types, sources, risks and mitigations strategies for the physical hazards identified. Physical hazards are characterized as any unintended foreign or extraneous materials found in food, which may cause harm, illness, injury or psychological trauma to consumers, and can enter rice at multiple points from farm to fork. Inadequate infrastructure, poor hygienic practices, lack of stakeholders' commitment and weak compliance with food safety measures contribute to an elevated risk of contamination. The paper identifies critical weaknesses in Guyana's legal framework by analyzing the Rice Factories Act and the Guyana Rice Development Board Act, which together govern key aspects of the rice sector, with minimal focus on food safety. These legal gaps exacerbate poor stakeholder compliance and accountability. Recommendations to effectively prevent and control physical hazards in rice include the implementation of prerequisites programs and food safety systems such as Hazard Analysis Critical Control Points (HACCP). This paper is the first to address the issue of physical hazards in rice in Guyana, it provides a better understanding of the risks of contamination and proposes a foundation for future policy and research efforts tailored to the country's rice supply chain.

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Keywords: Physical hazards, food safety, rice supply chain, control measures; sources of contamination.

INTRODUCTION

Rice is a herbaceous plant belonging to the genus *Oryza,* which has four species. The species *Oryza sativa,* commonly known as the Asian rice, is distributed worldwide [1] and cultivated in Guyana. Rice provides one-fifth of the global dietary energy and is considered a staple crop for over half of the total population [2,3]. It significantly contributes to improving food security and plays a leading role in the fight against global hunger and poverty [2,3]. Rice production in Guyana mirrors the global trend, with rice grain production expanding approximately fivefold from 1970 to 2024 and yield increasing from 1.8 to 6.6 tons per hectare during the same period. Rice is the largest agricultural sector in the country [4,5], with exports exceeding US $254 million dollars in 2024.

Since rice and rice products generally have low moisture content, they are considered low-risk foods [6]. However, contaminants can enter the rice at various stages of the supply chain. Grains, including rice, go through a complex journey from farm to plate [6,7]. In Guyana, after harvesting, rice is transported to mills for mechanical drying or sun-dried on drying floors or at the roadside, depending on available infrastructure and weather conditions. The paddy may be stored by farmers or held by millers for later use. At rice mills, various processing operations take place, including cleaning, dehusking, polishing, parboiling, and packaging. From mills, the majority of grains are exported, and less than 10% is utilized for domestic use and consumption [8]. Hazards that pose a threat to health can occur at one or multiple stages of this supply chain [7]. The complexity of the rice supply chain, combined with the heavy dietary reliance on rice, particularly in developing and underdeveloped countries, its nutritional composition, how it is usually grown and processed, and its near-neutral pH when boiled, makes rice highly susceptible to contamination by food hazards.

The Codex Alimentarius Commission defines a hazard as any biological, chemical, or physical agent present in a food or a condition of the food that may lead to an adverse health effect [9]. Food contaminated by the three types of hazards can cause over 200 different diseases. The World Health Organization (WHO) estimates that each year, over 600 million people, i.e., 1 in 10 people, fall ill from consuming contaminated food. Contaminated food directly reduces food security, limits trade and tourism, affects food businesses, hinders the growth of national economies, and pressures healthcare systems especially in low and middle-income countries [10–12]. As the population is expected to increase significantly in the future, the need for sufficient, safe and nutritious food will become even more crucial, especially in staple crops like rice.

Throughout history and to the present day, there have been numerous cases and outbreaks of grain products being contaminated with various types of food hazards, with effects ranging from minor to severe [6]. Physical contamination of rice mostly occurs after harvesting during drying and other processing operations (see figure 1 for sources of contamination). Physical contaminants such as soil, weeds, dockage and other grains can be removed during cleaning, and these are more related to the quality rather than the safety of the rice. However, glass pieces, stones and metal fragments are considered physical hazards that can enter the chain during harvesting, handling and transportation [7]. While much of the global focus has been on microbial and chemical contaminants, physical hazards are often underestimated and remain a critical food safety concern, especially in staple grains like rice. This review examines the physical hazards associated with rice, assessing risks to consumer safety and recommending strategies for mitigation and prevention.

WHAT ARE THE PHYSICAL HAZARDS OF RICE?

Physical hazards are any foreign or extraneous materials or objects that are not normally found in food which may harm, cause an illness, or psychological trauma to consumers [13–17]. They are often the most frequently reported type of hazard because they produce physical evidence of contamination or processing failure [16]. In 2024, the US Department of Agriculture (USDA) reported that of the 55 recalls and public health alerts issued, four were due to the presence of foreign materials (FM) in food and beverages [18].

Physical hazards cause injury or harm due to their size, shape, and hardness and include jewelry, glass, stones, wood and metal fragments, plastic materials, building materials, other personal effects of employees, pests and microplastics [10,13,16,17,19–21]. The severity of injury also depends on the nature of the food and the vulnerability of the consumer. For example, a physical hazard found in baby cereal is likely to cause more harm than the same hazard found in food consumed by healthy adults. Children, infants, elderly and visually impaired persons are more likely to consume physical hazards and are also likely to suffer more severe trauma than healthy adults [15]. The extent of injury caused by physical hazards varies from case to case and can result in cuts, lacerations, choking or internal bleeding [15]. The most common injuries reported include cuts, choking and dental damage [22]. Some of these injuries can also lead to secondary infections of the mouth (teeth, tongue, gum), esophagus, and digestive organs. About 80 to 90% of foreign materials consumed can exit the digestive system naturally, while the remaining 10 to 20% require removal via surgery or endoscopy [15]. See table 1 for the injury potential of physical hazards of rice [23]. Other physical contaminants or foreign materials such as hairs, small insect parts, and pest droppings are sometimes grouped under this category of food hazard [21]; while these are not hazardous due to their physical characteristics [20], they may be sources of biological hazards which causes foodborne diseases or an indication of poor hygienic and sanitation practices [15,22]. Nevertheless, food establishments in some countries like the United Kingdom could be prosecuted for the presence of any foreign material in a product, regardless of whether it can cause injury [20]. For the purpose of this review, all foreign materials will be considered as physical hazards. The major categories of physical hazards include metals, stones, plastic, glass and wood [14], and like biological and chemical hazards, they can be introduced into the rice supply chain at any stage [10,17,21]. See figure 1 for sources of physical hazards. However, it is important to note that the type of physical hazard that can contaminate a product is directly related to its origin and its movement through the supply chain [14].

Traditional or Mechanical Hazards

These hazards can enter the supply chain at multiple stages [10,15]. Sources of traditional hazards include raw materials, facilities, faulty equipment, water, grounds, employees' practices and their personal effects, and building materials [14,16]. They include stones, soil particles, metal fragments, nuts, bolts, and screws from equipment, plastic pieces, wood chippings and splinters, glass, plant straws, other plant remnants, and insects. In 2024, recalls, public alerts, and market withdrawals of food and beverages contaminated with foreign materials in the United States were primarily due to metal fragments, hard plastic, rocks and rubber [18,23]. Some of these foreign materials like hair, dust, small parts of insects and rodent droppings, do not cause injury but are associated with poor hygiene and unsanitary conditions during production, processing, storage and distribution [21]. It should be noted that all traditional hazards also have the potential to transfer microbiological hazards to the product, especially if they enter the product after the control steps for these hazards have been implemented [20]. Physical hazards can be categorized into three types: those that are sharp and can cause injury, items that are hard and can result in dental damage, and those that are capable of causing choking due to blocked airways. Based on these categories, almost any foreign material in food can be considered a physical hazard especially, when consumed by children below the age of five [20]. See figure 1 for sources of physical hazards in Guyana's rice supply chain.

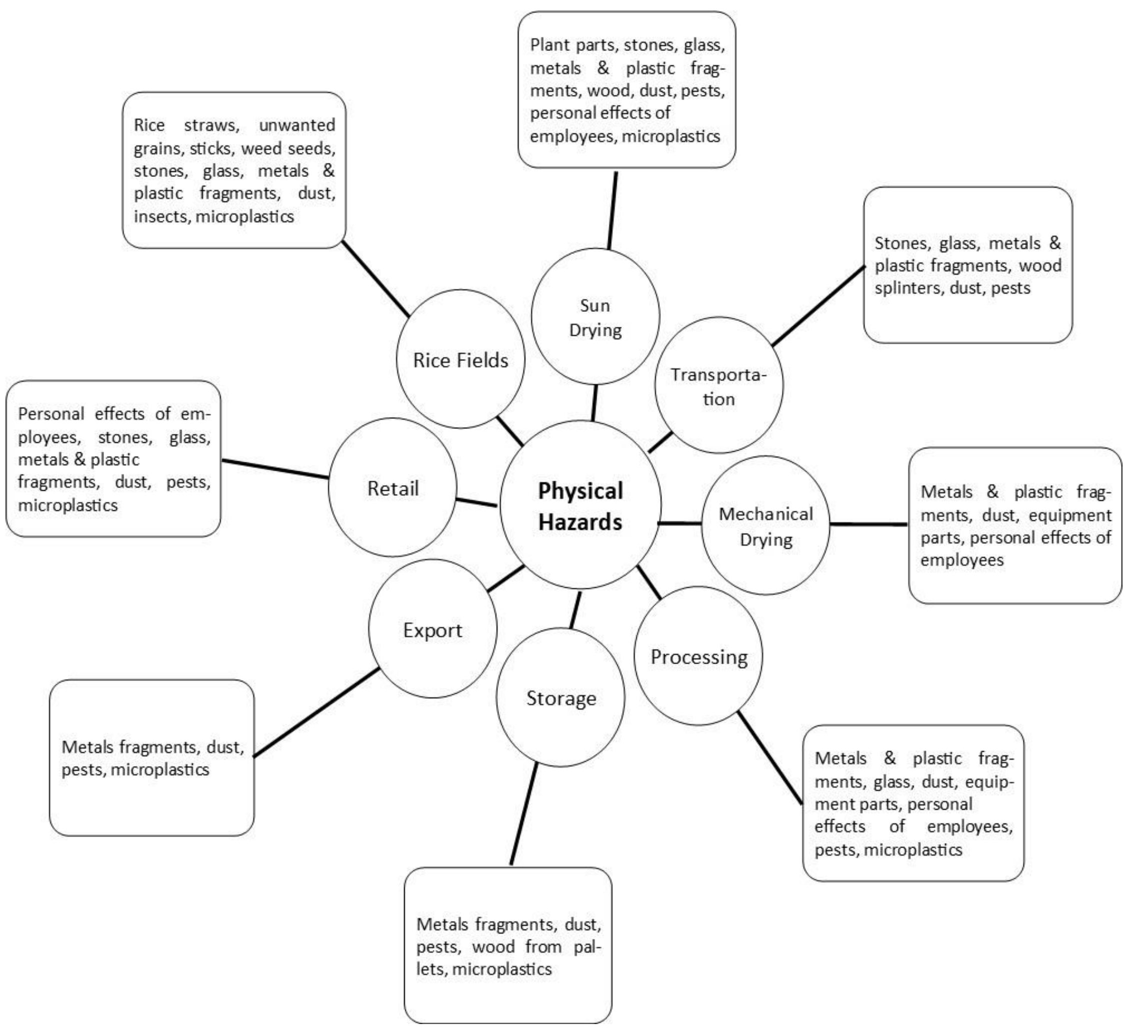

Figure 1: Sources of Physical Hazards in Guyana's Rice Supply Chain

ROUTES OF CONTAMINATION

Harvesting and Drying

Contamination of rice can occur as early as the harvesting process. In Guyana, rice harvesting is done mechanically by combine harvesters. During harvesting, it is possible for the combines to pick up foreign materials that occur naturally in the field (plant remnants, unwanted grains from other species, weeds growing among the rice plants or at the corner of the field, insects and other animals feeding among the rice, soil, girt, wood and stones) or were left by humans (glass and metals) [14,24,25]. From this stage, there is no control in place until the grain reaches the mill. At transportation and drying, there are even more opportunities for the grain to become contaminated. Drying of grains is done to reduce their moisture content, which increases shelf life and prevents postharvest losses during storage [26]. Paddy is usually transported from the fields to the mills or drying floors for drying; this is done using trailers or trucks with wooden or metal attachments, which are sometimes owned or rented by the farmers. There is no requirement for maintenance or inspection of vehicles; therefore, hazards like paint or metal chippings, pests, and wood fragments can easily contaminate the paddy at this stage.

Conventional drying also known as sun drying, is practiced by the majority of farmers throughout Guyana, with only a few having access to mechanical dryers. Sun drying is a low-cost method that utilizes solar energy to reduce moisture content. It is done openly on the ground, tarpaulins or roadside pavements. This type of drying is labour-intensive and time-consuming, and the grains are exposed to unfavourable weather conditions, dust, and intrusion by animals, insects, pests, rodents, and birds. Moreover, farmers and labourers use their feet to mix or turn over the layers of the grains, which is not only unsanitary but their personal effects can contribute to the contamination of the grains [26,27]. Other physical hazards that can be introduced at this stage are stones, dust, insect fragments, and rodent and bird droppings. There are several types of mechanical dryers used in Guyana, including column dryers, inclined bed dryers, fluidized bed dryers, and combinations of two or more types. Some of these mechanical dryers have been in operation for over 55 years, highlighting the need for frequent maintenance and repairs [27]. Wear and tear of this equipment, especially the older dryers, can result in metal pieces and loose screws entering the grains [28]. Industrial-scale mechanical dryers are almost fully automated, which significantly reduces contamination and improves drying conditions, including temperature, moisture removal, and airflow. Small-scale mechanical dryers, on the other hand, are locally made, and the potential for contamination with physical hazards such as metal fragments, pests, and employees' personal effects, is high [27].

Processing at the Rice Mills

It is only until the paddy arrives at the mill that an inspection is carried out. However, this is more for quality purposes than for safety. During the inspection, samples of paddy are collected by a trained grading officer, and the quality is determined based on factors such as moisture content, debris, weed seeds, and damaged grains, among others. The dockage is then calculated. Farmers are usually paid based on the grade they receive. The next step is cleaning where the paddy passes through an aspirator to remove dust and other light materials such as plant straws and debris; a destoner or vibrating sieves to remove stones, sticks, and other larger and heavier foreign materials; and, less frequently a magnet separator which remove metals [14,24]. After the cleaning process, the paddy may be stored, exported in bulk, shelled or dehusked, parboiled or polished, and then packaged.

Even though the processing steps remove physical hazards from the grains, these stages can also contribute to foreign materials contamination. In many cases, foreign bodies in food can be traced back to processing machinery [25]. Physical hazards at these stages include glass, dust, insects, pests, metal fragments from worn machinery, bolts and nuts from equipment, plastics, and personal effects on employees. Besides the equipment used in processing and storage, it is essential that the processing facilities or mills are well-designed and maintained to prevent the entry of these hazards into the rice [14,15]. The structural features of the facilities, such as the ceilings, walls and floors, can be a source of various physical hazards depending on the type of material they are made of. For example, wooden ceilings, if not properly maintained, can be a source of dust, wood chippings or splinters. If painted, they can result in paint flakes falling into the grains in the various processing areas. Moreover, since processing areas require adequate lighting, unprotected bulbs and skylights can be significant sources of glass contamination in the event of breakage [14].

Unsanitary environments in rice mills can be a source of dust, stones, insects and other pests. However, this is primarily due to the negligence of workers [26]. Additionally, the employees themselves can inadvertently introduce physical hazards into the product [25]. Depending on the scale of operation and level of automation, the number of employees in processing areas may vary, which in turn influences the potential for contamination. Operatives working in factories are a major source of foreign materials found in food [25]. Personal items such as jewelry, pins, hair, watches, body piercings, buttons, pens, broken fingernails, and other foreign objects can contaminate rice during handling or packaging [14,17]. Contamination of food by factory operatives can occur accidentally or intentionally through sabotage. Sabotage by employees can be challenging to control, as it can occur at any stage during processing at factories, including after detection and removal processes [26].

Storage

After processing and packaging, the grains are stored at the mills, exported, or sold for local consumption. In Guyana, storage is done in warehouses or bins/silos. In warehouses, grains are commonly stored in jute sacks, although polypropylene bags are also frequently used for this purpose. Grains stored in warehouses cannot be kept for long periods due to interactions with the environment, where they are exposed to oxygen and pests [27]. Storage bags are very susceptible to damage and infestation by rodents and insects. In addition to transmitting diseases, rodents contribute significantly to postharvest losses, accounting for an estimated 17% globally [28]. They contaminate rice with urine, droppings, and hair [27]. Similarly, insect pests contaminate stored rice with excreta, eggs, scales, dead bodies, and insect parts. There are approximately seventeen species of insect pests that can infest stored rice [29]; in Guyana, the *Sitotroga cerealella* (Angoumois grain moth) and *Sitophilus oryzae* (rice weevils) are the most common. Infestations of rice grains can originate from the field, migrate from contaminated areas, or result from residual insect populations in poorly managed facilities [30]. Alternatively, storage bins or silos are used for bulk storage for long durations. This method has several advantages when compared to storage in warehouses; it uses less space, decreases handling and the use of bags, and allows for temperature control, moisture reduction and continuous aeration of the grains. Despite the benefits, silos or storage bins are prone to system failure and environmental wear, which can lead to a build-up of temperature and moisture, water ingress, and vulnerability to storage pests [27]. Additionally, they can also lead to contamination with foreign bodies if maintenance, repairs, or modifications are not preformed thoroughly or when required [25].

Export and Local Retail

Grains leaving the mills are destined for export or local sale. In 2024, Guyana's rice exports increased for the third consecutive year, with 425,490 tonnes of rice and rice products being exported to thirty countries worldwide [33,34]. The World Trade Organization (WTO) has implemented agreements, such as the Technical Barriers to Trade and the Sanitary and Phytosanitary Measures (SPS) Agreement, which ensure food safety. The agreements allow countries to acknowledge the 'conformity assessment' systems of other member states. The conformity assessment systems are based on international standards and include inspections, testing and certification of products which cannot be achieved without a good Quality Management System [35]. The export of rice in Guyana is partially controlled by the millers and the Guyana Rice Development Board (GRDB). GRDB is a governmental organization that conducts inspections and certifications, playing a major role in ensuring that rules, standards, regulations, and practices are met when exporting rice and rice products globally. However, this aspect of the organization is primarily focused on meeting the quality criteria of importing countries, and less attention is given to food safety issues, such as contamination with food hazards. The rice and rice products exported are usually inspected for insect pests and rodents, and shipment containers are inspected and fumigated; however, there have been several reports of rice shipments being condemned due to infestations with insects [36].

The local retail sector faces its own challenges in addressing food safety due to its size and variation, and it is the last stage in the supply chain before the rice reaches the consumers. Guyana's rice retail sector encompasses traditional groceries, modern supermarkets and retail outlets, as well as food service establishments such as restaurants and street food vendors; each with its unique food safety concerns. For example, modern supermarkets would need to address food safety issues involved in procurement, processing, packaging, storage, warehousing, and the point of sale [37]. Physical hazards likely to contaminate packaged rice sold by supermarkets include mechanical hazards such as metal, glass and plastic fragments, as well as storage pests and personal effects of employees. On the other hand, in establishments like restaurants, cafeterias and street food vending where cooked rice and rice products are sold, common physical hazards include personal effects of personnel such as jewelry, hair, buttons, pins, and pests like rodents, cockroaches, and flies.

MICROPLASTICS: AN EMERGING HAZARD

One of the first physical hazards to enter the rice supply chain is microplastics [19]. Microplastics are very small pieces of plastics with dimensions ranging from 0.1 to 5,000 μm [38,39]. This hazard is considered an emerging issue for both environmental health and food safety [10,19]. Even though they are recognized as physical hazards, concerns about their negative impact on health are partly due to their chemical components [40]. Microplastics vary in shape and sharp particles can cause physical stimulation of the body leading to toxicity. There are five groups of microplastics: micro-pellets, which are hard, rounded particles; fragments, which are hard, jagged-edged particles; films, which are thin, two-dimensional plastic films; fibers, which are fibrous, thin plastic strands; and foam, which are styrofoam-type materials [41]. They can also be categorized as polyethylene, polyamide, polyvinyl chloride, polypropylene, polyethylene terephthalate, and polyurethane [41]. Some of the chemicals used for making the plastic polymers are endocrine disruptors. Some microplastics can also absorb heavy metals and other pollutants, which can have a negative impact on the body [42]. Other adverse health effects include cardiovascular disease, oxidative stress, and cell injury [43], obesity, infertility, chromosomal alterations, neurotoxicity, embryotoxicity, negative immune response, and intestinal obstruction [10].

They are known to be ubiquitous and can be found in freshwater, marine, and terrestrial ecosystems. Humans can be exposed through direct contact, inhalation but mostly through ingestion of food and water [38,39,42]. Food and beverages contaminated with microplastics are poorly documented, and for rice, there are even fewer studies. Sources of microplastic contamination occur at multiple stages of the chain starting from the agroecosystem [19]. Several studies have confirmed the accumulation of microplastics in various parts of plants [38]. Contamination can occur through irrigation waters, the application of organic fertilizers and biosolids, the degradation of plastic-made farming equipment, airborne contamination, and rain deposition [19]. Microplastics can also enter the supply chain when rice and rice products are packaged in plastics, through microplastic contaminated water used to wash and cook rice, by microwaving rice in plastic containers, and through various industrial processing steps that could lead to the possible contamination of rice and rice products [19]. A study carried out in Australia investigated microplastic contamination in 52 rice samples packaged in assorted plastics and found polyethylene in 100% of the samples with instant rice recording significantly higher concentrations when compared to uncooked packaged rice ($p<0.01$). The study estimated that the annual consumption of microplastics by Australians through the consumption of rice and rice products was 1 gram per person [19].

Table 1: Sources and injury potential of physical hazards.

Physical Hazards	Sources	Injury Potential
Glass	Fields, bulbs, gauge covers, and skylights	Cuts, choking, bleeding, and gastrointestinal perforations, and may require surgery [13–16,20,21,31].
Stones	Fields, drying floors, and buildings	Broken teeth and choking [13,14,16,20,21,31].
Plastic	Fields, drying floors, equipment parts, packaging materials, and employees	Cuts, choking, intestinal damage, infection, and may require surgery [13,15,16,20,21,31].
Pests	Fields, drying floors, transportation vehicles,	Psychological trauma, foodborne illness, and choking [13,15,16,20,21,24,31].

	processing environment, equipment, and storage	
Metal	Fields, machines, wires, equipment, employees, transportation vehicles, and storage bins	Cuts, oral and throat lacerations, choking, infection, and may require surgery [14–16,20,21,31,32].
Wood	Fields, building structures, and pallets	Cuts, choking, infection, and may require surgery [16,20,21,31].
Dust, plant straws, other foreign particles	Field, drying floors, and mills	Carry microorganisms, trauma, indicate unsanitary conditions [24].
Employees' personal effects (e.g. jewelry, hair, pens, watches, etc.)	Employees	Cuts, choking, broken teeth, and may require surgery [13,14,16,20,21].
Microplastics	Field, organic fertilizers, irrigation, equipment, packaging materials, atmospheric deposition, floods and run-off, and human activities	Oxidative stress, cell injury, inflammation, DNA damage, neurotoxicity, metabolic implications, lung and gut injury, immunological reaction. Chemicals are sometimes endocrine disruptors, and can cause cancer [10,33–35].

DETECTION AND REMOVAL

The presence of physical foreign materials (FM) or physical hazards in food and beverages has resulted in several recalls and safety alerts each year [31]. In 2024, there were four instances where food in the United States was contaminated with physical hazards; these ranged from Class I (high risk), where products were recalled, to Class III (low risk), where safety alerts were issued [18,36]. FM can be classified into two types: intrinsic and extrinsic. Intrinsic materials include the raw materials used in the manufacture of the food, the packaging materials of the food, or those that are related to the food itself [25,26,31]. In rice, intrinsic materials would include the paddy hull, straws, panicle stalk, and rice packaging materials. Extrinsic materials are those that enter the food from an external source and are not directly related to the product, for example, metals, glass, rubber, stones, etc. [25,26,31]. Early detection of both extrinsic and intrinsic materials in rice is crucial for ensuring the safety and quality of rice and rice products.

There are several methods for detecting FM once they have entered the supply chain. Most detection methods are specific to the application and what may work for one product may not work for another [14,31,37]. Graves et al. placed detection systems into three categories: those that detect foreign objects based on size or weight differences between the loose product and the FM; those that use optical techniques such as shape or colour to find FM mixed in a loose product; and techniques that find FM inside a product using the electromagnet spectrum such as X-rays and metal detection [37]. Edwards classified these methods into two systems: detection and removal systems and separation systems [25]. The detection and removal systems use advanced electronic technology to detect and remove FM, while the separation systems separate FM present in the food by using the physical differences between the FM and food [25].

Conventional methods, such as metal detectors, magnets, sieving, electrical impedance, and surface-penetrating radars, are simple and reliable; however, they have limitations in their applications. For example, metal and magnet detection systems are not suitable for non-conductive materials such as glass and plastic [26]. To address these limitations, noninvasive techniques such as x-rays, thermal imaging, near-infrared spectroscopy and hyperspectral imaging, ultrasonic, and terahertz have been implemented to detect FM without altering the original characteristics of the food [26]. See table 2 for methods of detection and removal of physical hazards in rice.

Table 2: Methods of detection and removal of physical hazards in rice.

Methods	Physical Hazards	Principle and Characteristics of Method
Metal Detectors	Metal fragments	• Used in raw material to final product processing; • Two types: coil-based systems and magnetic field systems; • The coil-based system is more common and uses a high-frequency system with three coils to detect metal fragments. The system detects a change in frequency and voltage when metal passes through and signals its presence; • Unreliable in the detection of non-conductive and non-magnetic materials e.g. stainless steel, glass and plastic; and • May not be able to detect metals below a specific size [14,25,31,32,37].
Terahertz spectroscopy	Glass, plastics, stones, metals, wood and rubber fragments.	• Overcomes the limitations of metal detectors; can detect the presence of non-conductive and non-magnetic materials using electromagnetic radiation; and • Non-destructive, can penetrate various materials, and has low spatial resolution [14,26].
Near-infrared spectroscopy	Plastic, cardboard, metals, coins, jewelry, Different cultivars/ varieties of rice.	• Detect and remove physical hazards from both raw materials and finished products using optical absorption and reflection; • Uses light in the 750 to 2500 nm wavelength range that interacts with the FM. This interaction causes changes in energy based on how the atoms vibrate. These changes help identify and remove the hazards from the product; • Uses a non-ionizing technique, able to penetrate air gaps in the grains, and can capture FM of small particle sizes; and • One limitation is that NIR relies on reference methods for accurate calibration [14,26,31,37,38].
X-ray imaging	Wood chips, soft plastics, metal, glass, steel, stones, aluminum	• Uses electromagnetic radiation of short wavelengths to detect and remove FM. Can identify FM based on density characteristics and offers a high imaging resolution; • Relatively expensive but can be designed to detect FM that are difficult to find using other methods;

	foil, and insect pests.	• Require high-voltage power supplies and there is a negative consumers' perception on the effect of radiation on food; • More effective than NIR detection except for identifying varietal differences; • Have limitations when it comes to the high-speed inspection demands of bulk grain processing; and • May be unable to detect insect larvae in early stages [14,25,26,31,37,39].
Thermal imaging	Paper, stones, plastic, wood, textile fibers, glass.	• Uses infrared radiation produced by the FM. Creates images of the FM based on thermal energy released; • Detects FM of varying sizes in both raw material and finished product; • Sensitive to temperature interferences; and • Non-contact detector, operate in real-time, and does not emit harmful radiation [14,31].
Hyperspectral imaging	rubber fragments, pieces of plastic, glass beads.	• Similar to thermal imaging; • Relies on spectral and reflectance properties of physical hazards to identify and remove them; and • High cost, slow imaging speed, data generated may be difficult to interpret by employees [14,26,31].
Humans	Most physical hazards visible to the human eyes.	• More flexible than machines; • Use five senses to observe and make decisions; and • Cannot work for long, uninterrupted periods [25].
Air separation (e.g. Aspirators)	Husk, dust, plant straws and other plant materials, insect fragments.	• Usually combined with other removal methods; • Cheap and convenient; • May generate high levels of dust; and • Separate FM from grains based on differences in weight and densities [25].
Sieves	Stones, soil, weed seeds, other grains.	• Removes FM based on size of the grains and FM. Cannot remove FM that have the same size as the grains; • Can be simple hand-held tools or advanced systems built into processing lines; • Used earlier in grain processing when cleaning the paddy; • May require shaking to allow grains to move more freely; • Can be used to remove a wide range of FM but systems may be designed specifically for known physical hazards; • Effective, high throughput, and low cost; and • Must be maintained so that they do not become sources of FM contamination [25,31].
Magnetic separators	Metals, bolts, screws, nuts, rust scales.	• Low-intensity magnetic fields for larger metals and higher-intensity magnetic fields for smaller or particles with weaker magnetic strength; • Removes ferrous metals contaminating grains, does not remove non-magnetic metals; • Removes a wide range of particle sizes, as small as metal dusts; and

		• Low maintenance, low cost, limited product loss [25,31].

In Guyana, rice milling operations are relatively basic, with greater emphasis placed on rice quality than on safety considerations. Figure 2 shows the typical equipment found in local mills. It is important to note that this comprehensive line of equipment is generally found in more advanced, large-scale mills. Smaller mills may lack one or more of these machines; for example, most small-scale operations do not have a colour sorter due to their high cost. Colour sorters have been used in rice milling for years. These machines use digital cameras to detect FM and remove them by applying short bursts of compressed air. Initially, they were used to remove grains discoloured due to insect and fungi damage, immature kernels (green grains), and bran. Today, optical sorters are a requirement of modern mills. They are situated at the end of the rice milling process, just before packaging, to remove other contaminations such as stones, glass, and paddy [40]. The use of colour sorters before packaging is not mandated in Guyana, and so physical contaminants that are missed or enter the milling process after cleaning and destoning remain in the packaged grains. Similarly, metal detectors and magnetic separators are also not commonly used in local rice mills, which means that small metal fragments may remain in the final packaged product.

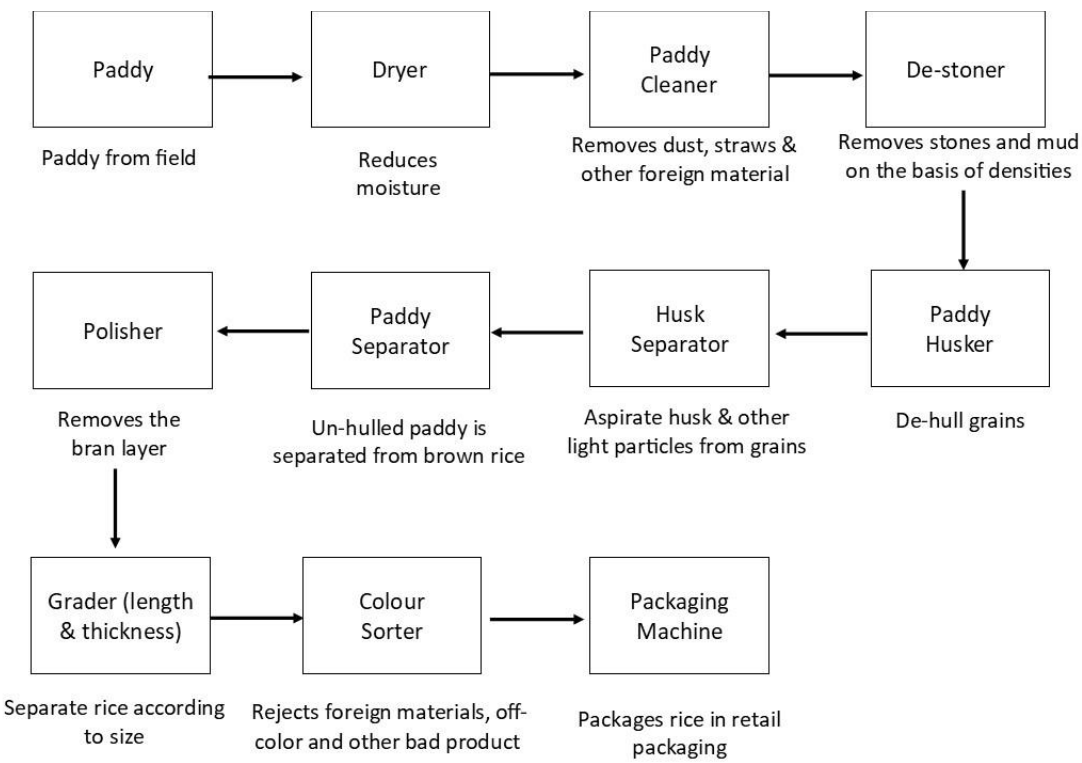

Figure 2: Common equipment used in rice mills in Guyana.

STRATEGIES FOR THE MITIGATION OF PHYSICAL HAZARDS IN RICE

Despite the importance of food safety, it remains a challenge in developing countries, including Guyana, due to the lack of knowledge of stakeholders, low incentives to invest along the food chain, weak regulatory enforcement and food safety infrastructure systems, limited knowledge on practical food safety application, subsistence production and informal distribution channels, limited consolidation within food and agricultural sectors, and low public capacity to monitor and respond to foodborne illnesses and outbreaks [41–43].

Stakeholders' Involvement

While the utilization of detection and removal technologies is important for eliminating FM, the rice sector should not only depend on equipment to ensure the safety of its rice and rice products. To control, prevent, reduce and eradicate FM from foods, safety considerations must be given to every step of the rice supply chain from primary production, harvesting, processing, storage, distribution and consumption [14,25,31]. Every stakeholder involved in the food chain must be responsible for safety at every step, from production to consumption [15,44]. This means that the responsibility for providing safe food does not fall solely to the millers. In Guyana, even millers, especially those with small to medium-scale operations, often fail to implement food safety measures. This may be due to a limited understanding and knowledge of various aspects of food safety, such as food safety and quality management systems, foodborne illnesses, etc. Additionally, some millers, particularly those serving the local market, may not have any incentive or motivation, whether legal or financial, to invest in and implement food safety measures.

The government's role in rice safety is limited in Guyana. The legal system governing safety in the rice industry is fragmented with no single comprehensive law governing the entire supply chain. The Rice Factories Act (Cap. 95:05) and the Guyana Rice Development Board Act (Cap. 72:01) regulate certain aspects of the supply chain. The Rice Factories Act (Cap. 95:05) focuses mostly on postharvest activities that occur in the mills and provides regulatory oversight for rice milling operations. The Act covers requirements for licensing, grading, quality control, and factory inspections. It does not address food safety concerns before (for example, primary production, sun-drying, etc.) or after (for example, transportation, retail, export, etc.) the milling stage of the food chain [45]. While the Guyana Rice Development Board Act (Cap. 72:01) covers aspects of primary production, grading, and management of exports, its focus is mostly developmental, with attention given to yield improvement, research, and facilitation of trade, rather than implementing food safety standards [46]. Ther is also the Food Safety Act (Act No. 19 of 2019) which is broad, robust and uses an integrated food safety system to protect consumers; however, this Act does not include the rice sector in its regulatory scope [47]. This indicates a lack of legal accountability for food safety and reinforces the notion that protecting rice from FM contamination should involve all stakeholders, with the government playing a more proactive role in ensuring rice safety throughout the supply chain.

The lack of food safety measures in the rice sector is not due solely to the shortcomings of the government but also other stakeholders such as farmers, drivers, distributors and retailers, all of whom are failing to protect rice and rice products from contamination at the respective stages. For example, farmers are mostly focused on improving production, while the implementation of good agricultural practices and other food safety considerations are often relegated to secondary status. Farmers, especially smallholders, should be supported in producing high-quality and safe grain through training and linking them to higher-value markets for increased profitability. Similarly, during the transportation of grains there is no established protocol for the cleaning and maintenance of trucks. Grains are typically transported in wooden or metal trailers, which can be a source of physical hazards such as splinters, rust, and metal fragments. Ultimately, the safety of rice and rice products requires coordinated action and accountability of all actors across the supply chain, which should be supported by targeted training, regulatory and organizational reforms, and incentive-based mechanisms tailored to stakeholders' roles and capacities.

Food Safety and Quality Management Systems (FS and QMS)

The traditional system of final product analysis and factory inspection is still practiced in Guyana with only a few modern mills implementing food safety and quality management systems (FS and QMS). FS and QMS are crucial for preventing and controlling FM in food processing, as they support the manufacture of safe foods of the required quality. These systems not only protect the manufacturers but also provide assurance and boost consumers' confidence that the milling process is continuously under control [25,48]. FS and QMS consist of practices, procedures, work instructions, and methods of a food establishment that ensure the assurance of safety, quality, and legality of its products. In some instances, the systems may be split into separate functions, the QMS which guarantees quality of the product and a Food Safety Management System (FSMS) which ensures product safety. FSMS usually consists of the Hazard Analysis Critical Control Point (HACCP) program for the food establishment, this is especially the case in countries where HACCP is a legal requirement [48]. HACCP is the preferred approach to food safety, it is science-based, preventive, structured, risk-based, logical, practical, cost-effective and can applied to any size of operation [25,49,50]. In the case of rice milling, HACCP examines every stage of operation, determines where hazards can occur, and develops controls to prevent, eliminate, or reduce hazards to acceptable levels [51]. HACCP conducts a hazard analysis, determines critical control points (CCPs) where there is a high risk of contamination, and sets up corrective actions for each CCP. Millers would set up monitoring systems for each CCP and establish verification procedures to ensure that HACCP is working efficiently [51].

Prerequisite Programs

HACCP cannot function alone in ensuring safe food [49,51); there are a number of prerequisite programs (PRPs) required for the application of its principles [49,50,52–54]. While HACCP focuses on the raw material, the manufacturing process, and the product, PRPs focus on quality assurance support and a hygienic operating environment managed by knowledgeable people dedicated to ensuring food safety [52]. PRPs are practices and conditions that are required for and during the implementation of HACCP. They reduce the likelihood of hazards occurring and include basic environmental and operating conditions that keep food safe [52,53]. Most physical hazards found in rice can be controlled successfully as part of PRPs [20] (see table 3 for the control of physical hazards in rice). Once PRPs are in place, then the HACCP system will focus on areas that pose more significant risks. PRPs ensure that each stakeholder in the rice supply chain provides conditions that protect food at the stage/s under their responsibility. Moreover, in cases where these potential physical hazards are identified, they can be "designed out". For example, changes to the building structure or equipment can be made to prevent the entry of some physical hazards; however, millers must ensure that these hazards are fully controlled before they are removed from the hazard analysis [20].

PRPs can be split into various groups: primary production which includes environmental and personal hygiene, safe production of the grains, and good handling and transportation practices; and the food chain, which includes the design and facilities of the establishment, control of operations, maintenance sanitation and person hygiene of the establishment, transportation, training, product information and consumer awareness [54]. Examples of PRPs that can be utilized in the rice food chain include good agricultural practices (GAP), which ensure safety during primary production; good manufacturing practices (GMP), which safeguard food during processing; and good hygiene practices (GHP), which are practiced throughout the food chain [55]. PRPs also include sanitation standard operating procedures (SSOPs), good handling practices, pest control, cleaning and disinfection plans, waste management, traceability and recall programs, supplier quality assurance, preventative maintenance, sampling and testing, training, staff competencies, and competence determination, water control, and documentation and record-keeping [48,50,53,56,57].

Table 3: Control measures for physical hazards in rice.

Physical Hazards	Control Measures
Glass	• Glass procedures: Reduce the use of glass and windows. Where unavoidable, protect from breakage or use non-glass materials; • Light fittings/bulbs must be covered or protected; • Good factory design, construction, and maintenance; and • Use detection and removal systems [14,25,58].
Stones	• Good factory design, construction, and maintenance; • Cleaning and sanitation of mills, storage facilities, and drying floors; and • Implement detection and removal systems [15,25].
Plastic	• Avoid loose plastic items e.g. pen covers, buttons, and jewelry in processing areas; and • Good equipment design and maintenance where hard plastic are used [58].
Pests	• Good agricultural practices to control field pests; • Pest control program at rice mills. Includes good design of mills and storage facilities, waste management, extermination procedures, screening/proofing, and routine inspection; • Keep areas surrounding facilities clean and free of weeds. Repair cracks and cervices in external walls; • Cleaning of transport vehicles, facility/mill, equipment, storage areas; • Use first in, first out (FIFO) procedures for storage facilities; • Removal of grain spillage; • Maintenance of good storage conditions e.g. temperature and moisture content; • Management of product flow to prevent infestation from raw materials to final product; and • Proper sealing of packaged grains [7,25,58].
Metal	• Ensure proper equipment design and maintenance; • Inspection of machines and equipment for wear;

	• Avoid the use of fasteners e.g. bolts, screws and rivets, especially over open products. If unavoidable, use thread locking compound or ensure they are self-locking; • Avoid loose metal items in processing areas e.g. jewelry, pins, and small tools; and • Implement metal detection and removal systems [25,58].
Wood	• Good factory design, construction, and maintenance; • Discourage the use of wood in processing areas. If unavoidable, ensure that surfaces are durable and resistant to flaking, chipping, cracking, and abrasion; • Inspection of wood pallets for integrity; and • Protect wooden parts of mills e.g. doors and frames from impact damage [25,31,58].
Dust, plant straws, other light foreign particles	• Supplier control – in this case the supplier will be the farmers. Establish quality control standards for raw materials. Inspect raw material; • Removal equipment e.g. aspirators and sieves; • Implementation of good agricultural practices by farmers; • Good factory design, construction, and maintenance; and • Cleaning and sanitation of mills, storage facilities and drying floors [15,25].
Employees' personal effects (e.g. jewelry, hair, pens, watches, etc.)	• Good hygienic and manufacturing practices; • Recruitment of employees with positive attitudes and training of staff; • Clothing rules or provision of appropriate clothing, hairnets, etc.; • Rules prohibiting employees from wearing jewelry; • Designation of eating and drinking areas and changing, toilet, and handwashing facilities; and • Regulate access to processing areas [14,15,58].
Microplastics	• Policies and regulations for the reduced use of plastics and sustainable waste management; • Sustainable agricultural production; • Shift to use bioplastic packaging material; and • Maintenance and replacement of worn plastic parts of machinery [59–61].

CONCLUSION

Physical hazards or foreign materials are one of the three major contaminants of rice and rice products, the other two being biological and chemical hazards. Like biological and chemical hazards, they originate from various sources, such as raw materials, machinery, employees, or even the processing facility, and can enter the food chain at any stage, from primary production to consumption. They may be sharp or hard objects such as glass, plastics, stones, metals. Because rice-importing countries like the United Kingdom consider any foreign objects found in food an offense, all foreign materials that can potentially contaminate rice are considered hazards, including soft plastics, hair, microplastics, and dust. From a food safety perspective, cereals like rice are not considered hazardous, high-risk food when compared to other perishable or ready-to-eat foods. This general discernment can downplay the importance of physical hazards in rice and rice products. Physical hazards can cause injuries ranging from cuts, choking, internal bleeding, psychological trauma and even death depending on their size, food they are found in, and person affected. Additionally, they can also have dire legal consequences and severely affect brand reputation.

In Guyana, the food control system is weak, characterized by overlapping and outdated legislations, overlapping of responsibilities among various organizations, a weak food safety infrastructure, poor coordination, limited human resources, and a lack of incentives for stakeholders to implement food safety measures. These weaknesses are more pronounced in the rice sector, where food safety gaps exist in current legislation governing the sector and stakeholder non-compliance are more evident. To safeguard rice from physical hazards, it is important to improve safety of the grains at every stage, from harvesting, transportation, milling, storage, retail, and consumption. This requires clear understanding of hazards, their risks and sources and routes of contamination; collaborative efforts from all stakeholders; and the implementation of preventive measures tailored to the rice sector. This research addresses these critical gaps in the rice sector by identifying major physical hazards in rice, determining their risks, mapping their sources and transmission routes along the supply chain, and proposing practical, stakeholder-driven interventions to ensure the safety of rice in Guyana.

References

[1]. Prasad R, Shivay YS, Kumar D. Current Status, Challenges, and Opportunities in Rice Production. In: Chauhan BS, Jabran K, Mahajan G, editors. Rice Production Worldwide [Internet]. Cham: Springer International Publishing; 2017 [cited 2025 May 27]. p. 1–32. Available from: http://link.springer.com/10.1007/978-3-319-47516-5_1

[2]. Abdo AI, Tian M, Shi Z, Sun D, Abdel-Fattah MK, Zhang J, et al. Carbon footprint of global rice production and consumption. J Clean Prod. 2024; 474(1):143560.

[3]. Damalas CA, Koutroubas SD. Herbicide-resistant barnyardgrass (Echinochloa crus-galli) in global rice production. Weed Biol Manag. 2023;23(1):23–33.

[4]. Persaud R, Payman G, Khan K, Singh N, Persaud DA, Subramanian5 G. Effectiveness of new fungicides and neem plant aqueous extract against brown spot disease of rice. Int J Agric Policy Res [Internet]. 2023 [cited 2025 Mar 6];11(1). Available from: https://grdb.gy/research-papers/

[5]. Persaud R, Peters A, Joseph P, David T, Amichand S, Persaud DA, et al. Steps Taken to Mitigate the Threats of Maximum Residue Limits (MRL) of Pesticides in Rice and Protecting Guyana Rice Exports Markets: Present and Future Prospects. Eur J Agric Food Sci. 2024;6(2).

[6]. Shrestha RK, Stratton J, Bianchini A. Overview of grain-based foods. In: Food Safety [Internet]. Elsevier; 2025 [cited 2025 May 27]. Available from: https://doi.org/10.1016/C2018-0-03984-5

[7]. Vadivambal R, Jayas DS. Food Safety Considerations for Cereal Grains. In: Food Supplies and Food Safety: Production, Conservation and Population Impact [Internet]. Nova; 2011 [cited 2025 Jun 4]. Available from: https://openurl.ebsco.com/contentitem/e000xna:411424?sid=ebsco:plink:crawler&id=ebsco:e000xna:411424&crl=c

[8]. World Bank. Guyana Rice Supply Chain Risk Assessment [Internet]. 2011 [cited 2025 Jun 4]. Available from: https://hdl.handle.net/10986/27392

[9]. United Nations for Food and Agriculture and World Health Organization. Codex Alimentarius Commission: Procedural Manual [Internet]. 10th ed. Rome, Italy; 1997 [cited 2025 May 27]. Available from: https://www-fao-org.proxy.lib.umich.edu/4/w5975e/w5975e00.htm#Contents

[10]. Ghazanfar S, Abid R, Ajmal W, Haider Z, Khan B, Rani S, et al. An Introduction to Food Safety and its Impact on Human Health. In: Food Safety: Contaminants and Risk Assessment [Internet]. Taylor & Francis; 2024 [cited 2025 Jun 7]. p. 1–22. Available from: https://www.taylorfrancis.com/books/edit/10.1201/9781003333913/food-safety-mohammed-kuddus-syed-amir-ashraf-pattanathu-rahman

[11]. Pan American Health Organization. Food safety is everyone's business [Internet]. 2019 [cited 2025 Jun 7]. Available from: https://www.paho.org/en/news/6-6-2019-food-safety-everyones-business

[12]. World Health Organization. Food Safety [Internet]. 2025 [cited 2025 Jun 7]. Available from: https://www.who.int/health-topics/food-safety

[13]. Aladjadjiyan A. Physical Hazards in the Agri-food Chain. In: Safety in the Agri-Food Chain. In Wageningen Academic Publishers; 2005 [cited 2025 Jun 8]. Available from: https://www.researchgate.net/publication/207706204_Physical_Hazards_in_the_Agri-food_Chain_In_Safety_in_the_Agri-Food_Chain

[14]. Bahatsi LF, Stratton J. Physical hazards in grain-based foods. In: Food Safety: Grain Based Foods [Internet]. Elsevier Inc.; 2025. p. 225–41. Available from: https://doi.org/10.1016/C2018-0-03984-5

[15]. Onyeaka H, Jalata DD, Mekonnen SA. Mitigating physical hazards in food processing: Risk assessment and preventive strategies. Food Sci Nutr [Internet]. 2023 Oct 7 [cited 2025 Jun 8];11(12). Available from: https://pubmed.ncbi.nlm.nih.gov/38107102/

[16]. Rhodehamel EJ. Overview of Biological, Chemical, and Physical Hazards. In: HACCP [Internet]. Springer, Boston, MA; 1992 [cited 2025 Jun 8]. p. 8–28. Available from: https://link.springer.com/chapter/10.1007/978-1-4684-8818-0_3

[17]. US Food & Drug Administration. Good Manufacturing Practices for the 21st Century for Food Processing (2004 Study). FDA [Internet]. 2024 Aug 30 [cited 2025 Jun 11]; Available from: https://www.fda.gov/food/current-good-manufacturing-practices-cgmps-food-and-dietary-supplements/good-manufacturing-practices-21st-century-food-processing-2004-study-section-2-literature-review

[18]. US Department of Food & Agriculture. Recalls & Public Health Alerts | Food Safety and Inspection Service [Internet]. 2024 [cited 2025 Jun 17]. Available from: http://www.fsis.usda.gov/recalls

[19]. Dessì C, Okoffo ED, O'Brien JW, Gallen M, Samanipour S, Kaserzon S, et al. Plastics contamination of store-bought rice. J Hazard Mater. 2021;416:125778.

[20]. Mortimore S, Wallace C. Hazards, Their Significance, and Control. In: HACCP [Internet]. Springer, Boston, MA; 2013 [cited 2025 Jun 8]. p. 67–111. Available from: https://link.springer.com/chapter/10.1007/978-1-4614-5028-3_3

[21]. Singh PK, Singh RP, Singh P, Singh RL. Food Hazards: Physical, Chemical, and Biological. In: Singh RL, Mondal S, editors. Food Safety and Human Health [Internet]. Academic Press; 2019 [cited 2025 Jun 8]. p. 15–65. Available from: https://doi.org/10.1016/B978-0-12-816333-7.00002-3

[22]. Marshall DL, Dickson JS, Nguyen NH. Ensuring Food Safety in Insect Based Foods: Mitigating Microbiological and Other Foodborne Hazards. In: Insects as Sustainable Food Ingredients [Internet]. Academic Press; 2016 [cited 2025 Jun 16]. p. 223–53. Available from: https://www.sciencedirect.com/science/article/pii/B9780128028568000089

[23]. US Food & Drug Administration. FDA. FDA; 2024 [cited 2025 Jun 17]. Recalls, Market Withdrawals, & Safety Alerts. Available from: https://www.fda.gov/safety/recalls-market-withdrawals-safety-alerts

[24]. Edwards M. Food hygiene and foreign bodies. In: Hygiene in Food Processing [Internet]. Woodhead Publishing; 2014 [cited 2025 Jun 16]. p. 441–64. Available from: https://www.sciencedirect.com/science/article/pii/B9780857094292500139

[25]. Fărcaș AC. Food Safety in Cereal Grains: Contaminants, Legislation, and Mitigation Strategies. In: Worldwide Megatrends in Food Safety and Food Security [Internet]. 2024. Available from: https://www.intechopen.com/online-first/1207360

[26]. Baidhe E, Clementson CL, Senyah J, Hammed A. Appraisal of Post-Harvest Drying and Storage Operations in Africa: Perspectives on Enhancing Grain Quality. AgriEngineering. 2024 Sep;6(3):3030–57.

[27]. Singh N, Singh D, Daynauth RCG. An Investigation of the Drying Methods and their Effects on Milling Quality of Rice in Guyana. Farm Bus - J Caribb Agro-Econ Soc [Internet]. 2021 [cited 2025 Jun 10];13(01). Available from: https://ideas.repec.org//a/ags/fabtho/312448.html

[28]. Munguia N. How to Help Prevent Physical Hazards in Food: A Guide for QC Teams [Internet]. FSNS. 2024 [cited 2025 Jun 8]. Available from: https://fsns.com/how-to-help-prevent-physical-hazards-in-food-a-guide-for-qc-teams/

[29]. Khairi MTM, Ibrahim S, Yunus MAM, Faramarzi M. Noninvasive techniques for detection of foreign bodies in food: A review. J Food Process Eng [Internet]. 2018 [cited 2025 Jun 21];41(6). Available from: https://onlinelibrary.wiley.com/doi/10.1111/jfpe.12808

[30]. Kumar N, Kumar V, Singh C, Shukla V. Studies on Association Between Rodents Infestation in Different Stage of Rice Cultivation. Int J Agric Sci Res. 2013;3(3):117–26.

[31]. Thakur M, Kumar V. Management of Stored Grain - Rice Pests. In: Rice Production: Modern Techniques [Internet]. New Delhi: Biotech Book; 2009. p. 441–57. Available from: https://www.researchgate.net/publication/352020162_Management_of_stored_grain_rice_pests

[32]. Cogburn RR. Insect Pests of Stored Rice. In: Rice Production [Internet]. Springer, Boston, MA; 1991 [cited 2025 Jun 11]. p. 269–85. Available from: https://link.springer.com/chapter/10.1007/978-1-4899-3754-4_7

[33]. Parris N. Guyana sees 'record high' rice production in 2024. 2024; Available from: https://guyanachronicle.com/2024/12/31/guyana-sees-record-high-rice-production-in-2024/

[34]. United Nations for Food and Agriculture. FAO GIEWS Country Brief on Guyana - [Internet]. 2025 [cited 2025 Jun 15]. Available from: https://www-fao-org.proxy.lib.umich.edu/giews/countrybrief/country.jsp?code=GUY&lang=fr

[35]. Attrey DP. Food safety in international food trade—imports and exports. In: Food Safety in the 21st Century [Internet]. Academic Press; 2017 [cited 2025 Jun 15]. p. 455–68. Available from: https://www.sciencedirect.com/science/article/pii/B9780128017739000376

[36]. Fanfair S. Infested container found with holes, insects – Jamaican authorities [Internet]. Guyana Times. 2019 [cited 2025 Jun 15]. Available from: https://guyanatimesgy.com/infested-container-found-with-holes-insects-jamaican-authorities/

[37]. Sareen S. Guidance on hygiene and safety in The food retail sector. Bangkok: FAO Regional Office for Asia and the Pacific; 2014.

[38]. Giri S, Lamichhane G, Khadka D, Devkota HP. Microplastics contamination in food products: Occurrence, analytical techniques and potential impacts on human health. Curr Res Biotechnol. 2024 Jan 1;7:100190.

[39]. Jin M, Wang X, Ren T, Wang J, Shan J. Microplastics contamination in food and beverages: Direct exposure to humans. J Food Sci. 2021;86(7):2816–37.

[40]. Gamarro EG, Costanzo V. Microplastics in Food Commodities A Food Safety Review on Human Exposure Through Dietary Sources [Internet]. Rome: United Nations for Food and Agriculture; 2022. (Food Safety and Quality Series No. 18). Available from: https://openknowledge.fao.org/server/api/core/bitstreams/1af02111-204a-4fcb-a622-e5edb856074b/content#:~:text=In%20addition%20to%20environmental%20matrices,to%20these%20small%20plastic%20particles.

[41]. Rezania S, Park J, Md Din MF, Taib SM, Talaiekhozani A, Yadav KK, et al. Microplastics pollution in different aquatic environments and biota: A review of recent studies. Mar Pollut Bull. 2018 Aug 1;133:191–208.

[42]. Lee Y, Sohn J, Kim C. Health Effects of Microplastic Exposures: Current Issues and Perspectives in South Korea. Yonsei Med J. 2023;64(5):301–8.

[43]. Lalrinfela P, Vanlalsangi R, Lalrinzuali K, Babu PJ. Microplastics: Their effects on the environment, human health, and plant ecosystems. Environ Pollut Manag. 2024;1:248–59.

[44]. Payne K, O'Bryan CA, Marcy JA, Crandall PG. Detection and prevention of foreign material in food: A review. Heliyon. 2023 Sep 4;9(9):e19574.

[45]. Trafialek J, Kaczmarek S, Kolanowski W. The Risk Analysis of Metallic Foreign Bodies in Food Products. J Food Qual. 2016 Aug;39(4):398–407.

[46]. Sheeba VA, Rahim HU, Surendran U. Microplastic contamination in soil: Sources, identification, interaction, and risk assessment. In: Microplastics in Agriculture and Food Science [Internet]. Elsevier; 2025 [cited 2025 Jun 12]. p. 109–34. Available from: https://linkinghub.elsevier.com/retrieve/pii/B9780443222108000092

[47]. Graves M, Smith A, Batchelor B. Approaches to foreign body detection in foods. Trends Food Sci Technol. 1998;9(1):21–7.

[48]. Kong W, Zhang C, Liu F, Nie P, He Y. Rice Seed Cultivar Identification Using Near-Infrared Hyperspectral Imaging and Multivariate Data Analysis. Sens Basel. 2013;13(7):8916–27.

[49]. Haff RP, Toyofuku N. X-ray detection of defects and contaminants in the food industry. Sens Instrum Food Qual Saf. 2008 Dec 1;2(4):262–73.

[50]. Inamdar AA, Suresh DS. Application of color sorter in wheat milling. Int Food Res J. 2014;21(6):2083–9.

[51]. Hoffmann V, Moser C, Saak A. Food safety in low and middle-income countries: The evidence through an economic lens. World Dev. 2019 Nov 1;123:104611.

[52]. Mwambi M, Bijman J, Mshenga P, Oosting S. Adoption of food safety measures: The role of bargaining and processing producer organizations. NJAS Wagening J Life Sci. 2020 Dec 1;92(1):1–9.

[53]. Phillips M, Badrie N, Singh M. The National Food Control System in Guyana: Evaluation of the Current Regulatory Framework For Food Control Systems. In: International Conference on Emerging Trends in Engineering & Technology. University of the West Indies, St. Augustine; 2020. p. 35.

[54]. Gordon A. Introduction: effective implementation of food safety and quality systems: prerequisites and other considerations. In: Food Safety and Quality in Developing Countries [Internet]. Elsevier; 2017 [cited 2025 Jul 2]. p. 1–19. Available from: https://linkinghub.elsevier.com/retrieve/pii/B9780128012260000013

[55]. Government of Guyana. The Rice Factories Act Chapter 95:05 [Internet]. 1998. Available from: https://mola.gov.gy/laws/Volume%2018%20Cap.%2091.02%20-%2096.011695661047.pdf

[56]. Government of Guyana. The Guyana Rice Development Board Act Chapter 72:01 [Internet]. 1994. Available from: https://faolex.fao.org/docs/pdf/guy43219.pdf

[57]. Government of Guyana. Food Safety Act - Act No. 19 of 2019 [Internet]. 2019. Available from: https://faolex.fao.org/docs/pdf/guy201895.pdf

[58]. Swainson M. The food safety and quality management system (FS & QMS). In: Swainson's Handbook of Technical and Quality Management for the Food Manufacturing Sector [Internet]. Elsevier; 2019 [cited 2025 Jul 2]. p. 29–46. Available from: https://linkinghub.elsevier.com/retrieve/pii/B9781782422754000034

[59]. Lawley R, Curtis L, Davis J. The Food Safety Hazard Guidebook [Internet]. 2nd ed. The Royal Society of Chemistry; 2012 [cited 2025 Jul 2]. Available from: https://books.rsc.org/books/book/987/The-Food-Safety-Hazard-Guidebook

[60]. Lorenzo LC. HACCP System Auditing for Food Safety [Internet]. John Wiley & Sons, Inc.; 2024 [cited 2025 Jul 2]. Available from: https://onlinelibrary.wiley.com/doi/book/10.1002/9781394254750

[61]. Bühler. Food Safety at the Heart of Rice Processing [Internet]. 2014 [cited 2025 Jul 1]. Available from: https://www.food-safety.com/articles/2452-food-safety-at-the-heart-of-rice-processing

[62]. Mortimore S, Wallace C. Prerequisites for Food Safety: PRPs and Operational PRPs. In: HACCP - A Practical Approach [Internet]. Springer, Boston, MA; 2013 [cited 2025 Jul 4]. p. 113–54. Available from: https://link.springer.com/chapter/10.1007/978-1-4614-5028-3_4

[63]. US Food & Drug Administration. HACCP Principles & Application Guidelines | FDA [Internet]. 2022 [cited 2025 Jul 4]. Available from: https://www-fda-gov.proxy.lib.umich.edu/food/hazard-analysis-critical-control-point-haccp/haccp-principles-application-guidelines

[64]. Wallace CA, Sperber WH, Mortimore SE. Formalised Prerequisite Programmes in Practice. In: Food Safety for the 21st Century [Internet]. John Wiley & Sons, Ltd; 2018 [cited 2025 Jul 4]. p. 187–214. Available from: https://onlinelibrary.wiley.com/doi/abs/10.1002/9781119053569.ch10

[65]. United Nations for Food and Agriculture. Manual on the Application of the HACCP System in Mycotoxin Prevention and Control [Internet]. 2003 [cited 2025 Jul 4]. Available from: https://www-fao-org.proxy.lib.umich.edu/4/y1390e/y1390e00.htm#Contents

[66]. Barach JT. What are the Essential Elements of a Food Safety System? In: FSMA and Food Safety Systems [Internet]. 2016 [cited 2025 Jul 4]. p. 21–33. Available from: https://onlinelibrary.wiley.com/doi/10.1002/9781119258094.ch3

[67]. Gordon A. Effective implementation of food safety and quality systems: prerequisites and other considerations. In: Food Safety and Quality Systems in Developing Countries [Internet]. Elsevier Inc.; 2016 [cited 2025 Jul 4]. p. 1–19. Available from: http://p5070-www.sciencedirect.com/book/9780128012260/food-safety-and-quality-systems-in-developing-countries

[68]. Mortimore S, Wallace C. An introduction to hazards — their significance and control. In: HACCP A Practical Approach [Internet]. 1st ed. New York: Springer; 1994. p. 35–53. Available from: https://doi-org.proxy.lib.umich.edu/10.1007/978-1-4615-2063-4

[69]. Sharma P. Microplastic Contamination in Food Processing: Role of Packaging Materials. Food Sci Eng. 2024 Jul 4;271–87.

[70]. Sharma S, Sharma P, Bala N, Sharma A, Sharma M, Atri P, et al. Microplastics in soil and water: Unveiling environmental risks and implications. In: Advances in Food Security and Sustainability [Internet]. Elsevier; 2024 [cited 2025 Jul 5]. p. 75–101. Available from: https://linkinghub.elsevier.com/retrieve/pii/S2452263524000156

[71]. Ziani K, Ioniță-Mîndrican CB, Mititelu M, Neacșu SM, Negrei C, Moroșan E, et al. Microplastics: A Real Global Threat for Environment and Food Safety: A State of the Art Review. Nutrients. 2023 Jan 25;15(3):617.