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Towards improving food safety in Cambodia: Current status and emerging opportunities

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ABSTRACT

Cambodia has made significant efforts to improve nutritional outcomes while demonstrating increasing interest in ensuring that food safety challenges do not negate these efforts. This integrative review examines food safety in Cambodia to identify areas where efforts, both existing and recommended, could focus to best limit Cambodians' exposure to foodborne disease. The review considers: 1) documented foodborne disease outbreaks in Cambodia; 2) aggregated food safety research taking place in Cambodia; 3) current food safety regulatory structures in the country; and 4) gaps in food safety knowledge or practices. Lastly, the review proposes an framework to bridge food safety gaps through the integration of improved surveillance, targeted intervention research informed, and a comprehensive understanding of Cambodians motivations, opportunities, and capabilities to adopt food safety practices.

1. Introduction

By most metrics, Cambodia has developed rapidly over the past two decades, and in 2015 transitioned from a low-income country to a lower middle-income country (World Bank, 2020). The Cambodian economy has grown at an average of 8% from 1998 to 2018 and the country's gross domestic product (GDP; 4.5 billion USD) ranks 81st globally (World Bank, 2020; World Trade Organization [WTO], 2019). Cambodian child mortality rates have dropped from 124 to 35 out of every 1000 live births from 2000 to 2004 (UNICEF, 2015). Likewise, Cambodia ranked seventh in the world in fastest improvement rate in the Human Development Index (HDI; life expectancy at birth, average years of schooling/expected years of schooling, and gross national income, etc.) from 1990 to 2017 (Jensen and Marshall, 2019).

The burden of disease (BOD) in Cambodian children, however, is still predominantly comprised of diarrheal diseases (Conseil Sante, 2016) and of the 288 disease outbreaks recorded in Cambodia from 2010 to 2015, 146 (51%) were caused by diarrheal or foodborne diseases (Lawpoolsri et al., 2018). More recently, the Cambodian Department of Drugs and Food stated that 134 foodborne disease outbreaks were reported from 2014 to 2019, resulting in 5825 illness cases, 5598 hospitalizations, and 81 deaths (Mekong Institute, 2019). Descriptions of larger foodborne disease outbreaks occurring in Cambodia as reported in the popular press are presented in Table 1. It is important to note, however, that the etiological agent(s) responsible for the outbreaks were not clearly defined or identified in most cases.

In low- and middle-income countries alone, foodborne diseases result in 95 billion USD in lost productivity and an additional 15 billion USD in treatment costs annually (Jaffe et al., 2019). In Cambodia, where the real GDP per capita is approximately 4389 USD (USCIA 2021), hospitalization costs for foodborne diseases are estimated to range from 25 to 185 USD per individual per stay (Srey 2019).

Cambodia's commitment to reducing malnutrition throughout the country has led to increased investments in the production and marketing of high-value, nutritionally rich foods (World Bank, 2017). Many nutritionally dense food products, however, are also considered higher risk in terms of food safety, including vegetables that are traditionally consumed raw, such as lettuce, tomatoes, and cucumbers, among others. Likewise, animal-sourced foods, while providing high-quality protein, are highly perishable and often become contaminated during the collection or slaughter process. These issues are exacerbated in the absence of consistent cold chains. The following is an integrative review of food safety in Cambodia that considers: 1) documented foodborne disease outbreaks in Cambodia; 2) aggregated food safety research

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taking place in Cambodia; 3) current food safety regulatory structures in the country; and 4) gaps in food safety knowledge or practices. The review was conducted in an effort to identify areas where new and existing food safety efforts could focus to effectively reduce the risk of foodborne disease for Cambodians and ensure positive nutritional outcomes. To our knowledge, this review is the first of its kind, and as Cambodia's economy and trade partnerships continue to grow rapidly, this review is of direct relevance to neighboring countries in the Greater Mekong Subregion (GMS; Cambodia, Vietnam, Thailand, Laos, and Southern China [Yunnan Province and Guangxi Zhuang Autonomous Region]) and beyond.

2. Methods

Various sources were utilized in effort to generate an integrative review of food safety in Cambodia focusing on: 1) documented foodborne disease outbreaks in Cambodia; 2) aggregated food safety research taking place in Cambodia; 3) current food safety regulatory structures in the country; and 4) gaps in food safety knowledge or practices. Information about various food safety efforts or initiatives in Cambodia was collected primarily through Google Scholar in effort to identify both peer-reviewed published research as well as gray literature not indexed by PubMed, including governmental and development organization reports (e.g., Government of the Kingdom of Cambodia, World Bank, UNICEF, etc.) focused on food safety and/or health security in the country. As publicly available data is minimal regarding characteristics of food-related infections in Cambodia, reports on foodborne disease outbreaks found in popular press (past five years) were also included, taking care not to duplicate reporting of individual events. To provide a characterization of current Cambodia-specific research in food safety (e.g., contamination rates, pathogen identification, etc.), a primary literature search was conducted using the PubMed® database to collect peer-reviewed research using search terms identified in the appropriate sections below.

2.1. Food safety oversight and regulation in Cambodia

Currently, food safety in Cambodia is federally regulated by six ministries: the Ministry of Health (MOH), the Ministry of Commerce (MOC), the Ministry of Tourism (MOT), the Ministry of Industry and Handicraft (MIH; now renamed the Ministry of Industry, Science, Technology and Innovation [MISTI]), the Ministry of Agriculture, Forestry, and Fisheries (MAFF), and the Ministry of Economy and Finance (MEF; Inrasothythep, 2019). Some ministries are responsible for multiple stages within the food supply chain and jurisdictions occasionally overlap where two ministries may have some level of oversight within the same stage. At the import stage, the MAFF and the General Department of Customs and Excise (GDCE; part of the MAFF since 1988) regulate raw and live products, as well as genetic material, seeds, and livestock feed (Inrasothythep, 2019; General Department of Customs and Excise Control [GDCE]). After the import stage, the MAFF maintains responsibility for the primary production stage, which includes farm and aquaculture production as well as wild harvest. The MAFF also oversees the primary processing stage, which frequently involves hygiene regulation for processes such as slaughtering. Further hygiene and sanitation regulations are enforced by the MOH at the manufacturing stage, where the production of processed foods occurs. At this step in the food supply chain, there is another import point for processed products such as ingredients. These goods are integrated at either the manufacturing stage or the wholesale and retail stage following manufacturing. The MAFF is not responsible for these imports; instead the MOC and GDCE share authority over processed imports. After manufacturing, the wholesale and retail stages, both formal and informal, are controlled by the MOC. The food services stage, which includes formal restaurants as well as street vendors, is regulated by the MOH and MOT. Lastly, the consumer stage is managed by the MOH and covers formal and informal establishments (similar to food services; Inrasothythep, 2019). The storage and transportation of goods is regulated by the MOC.

2.2. Food safety legislation

In 1997, the MOH was given responsibility for the management and control of food safety by creating the Department for Drugs and Food (Parsons, 2008; Deutsche Gesellschaft für Internationale Zusammenarbeit [GIZ], 2013). The Law on Management of Quality and Safety of Products and Services was established in 2000 with the goal of prioritizing the health and safety of the consumer; this law pertains to activities conducted by Camcontrol, which is part of the Ministry of Commerce (Government of the Kingdom of Cambodia [GOKC], 2000). In 2003, the sub-decree on Hygiene of Food for Human Consumption established hygiene standards for food produced for human consumptions (Parsons, 2008; GIZ, 2013). These guidelines relate to manufacturing, transportation, solid and liquid waste management, as well as safe practices for workers. The MOC and the MOH share responsibility for inspecting and enforcing guidelines (Parsons, 2008; GIZ, 2013). In 2010, the Inter-Ministerial Prakas on the Implementation and Institutional Arrangement of Food Safety Based of the Farm to Table Approach worked to integrate more regulation on food safety through institutional mechanisms that would enforce business registration and certification, inspections, and research aimed toward monitoring risks (GOKC, 2010). Most recently, the MOC released a draft for a new law on food safety in 2015. The law was drafted with help from the FAO in an effort to further protect domestic consumers and ensure quality exports (Retka and Chhengpor, 2015). An update regarding the Law on Food Safety was released in May of 2019, which stated that the law was under review by the Council of Ministers (Kunthear, 2019).

Table 1
Examples of foodborne disease outbreaks in Cambodia as reported in popular press.

Year	Province	Source	Etiological Agent	Impact	Reference
2015	Siem Reap	Prepared lunches	Unknown	−800 affected, >120 hospitalized	Dara (2015)
2015	Cambodia	Unknown	*Salmonella* (Paratyphi A)	US and EU tourists affected	Judd et al. (2015)
2016	Kompong Chhnang	Rice wine	Methanol	78 hospitalizations, 15 deaths	Thul (2016)
2016	Takeo	Prepared lunches	Unknown	80 school children affected	API (2016)
2017	Battambang	Prepared meals	Unknown	27 monks and nuns affected	Sotheary (2017)
2017	Kampong Thom	Pork (wild)	Trichinella	33 hospitalizations, 8 deaths	Caron et al. (2020)
2017	Pursat	Prepared lunches	Unknown	197 primary school students hospitalized	Suy (2017)
2017	Siem Reap	Noodles	Possible chemical contamination	37 hospitalizations	Suy (2017)
2018	Kratie	Prepared lunches	Unknown	53 children and 22 women affected	Rathavong (2018)
2018	Kampong Thom	Prepared lunches	Unknown	>50 (47 students) affected	Sarom (2018)
2019	Banteay Meanchey	Prepared lunches	Unknown	>100 hospitalized, 2 deaths	Sovuthy (2019)
2019	Prey Veng	Noodles	Unknown	>70 affected	Sotheary (2019)
2020	Banteay Meanchey	Rice wine	Methanol	12 hospitalizations, 4 deaths	AP News (2020)
2020	Kompong Chhnang	Rice wine	Methanol	131 "injured", >2 deaths	Kognov (2020)
2020	Banteay Meanchey	Prepared snacks	Unknown	35 high-school students affected	Xinhua News (2020)

3. Cambodian food Safety Research

Although food safety research in Cambodia is still comparatively new, there are growing numbers of studies aimed at measuring rates at which Cambodian food are contaminated with microbial pathogens (e.g., *Salmonella*, *Camplylobacter*, etc.) or chemical adulterants (e.g., antibiotic residues, mycotoxins, heavy metals, phthate esters). An initial search of published, peer-reviewed food safety-related research taking place in Cambodia or conducted on Cambodian food products resulted in the following references: 1) Cambodia AND food AND safety (73 references); 2) Cambodia AND food AND quality (114 references); 3) Cambodia AND foodborne AND disease (28 references); 4) Cambodia AND foodborne AND illness (25 references); 5) Cambodia AND food AND poisoning (27 references); 6) Cambodia AND food AND contamination (46 references); 7) Cambodia AND food AND microbial (39 references); and 8) Cambodia AND food AND chemical (58 references). These search results were further refined by eliminating duplications and including only those studies taking place in Cambodia and/or assessing Cambodian food products (e.g., microbial analysis of food sample collected in Cambodia, etc.). The resulting studies were then divided into three groups for discussion: 1) studies examining microbial contamination of food; 2) studies examining chemical contamination of food; and 3) studies examining perceptions or barriers to food safety.

3.1. Cambodian food Safety Research: Microbial contamination

Thermophilic *Campylobacter* is recognized as the most common foodborne pathogen associated with gastric enteritis globally (Nguyen et al., 2017). Traditionally, *Campylobacter* has been associated with poultry products, but the organism is now considered ubiquitous and can be isolated from all types of food products, from milk to ready-to-eat (RTE) vegetables. *Campylobacter* is prevalent in Cambodia as well, and Osbjer et al. (2016) reported isolating *Campylobacter* from 12% of 681 patient fecal samples in Phnom Penh. *Campylobacter coli* and *Campylobacter jejuni* were found in both diseased and otherwise healthy children under five in Phnom Penh. Carriage rates were correlated with age of patient, with *Campylobacter* isolated from 19% of samples collected from patients 16 years and younger, but only from 8% of samples collected from adults. The authors also found that individuals producing *Campylobacter*-positive samples were more likely to conduct home slaughter of animals, allowed animals access to sleeping and food preparation areas, and more often consumed undercooked meat (Osbjer et al., 2016).

Measuring coliform concentrations in foods is usually done to determine the level at which the food may be contaminated with fecal bacteria. *Escherichia coli* (*E. coli*) in particular is also often used as a sentinel organism in characterizing antibiotic resistance in bacterial populatios. In 2019, Nadimpalli et al. reported on the prevalence of extend-spectrum Β-lactamase (ESBL) producing *E. coli* in meat (fish, pork and chicken) sold in markets in Phnom Penh. This group also compared *E. coli* isolated from food samples and *E. coli* isolated from both healthy and infected patients. ESBL-producing *E. coli* were isolated from 62% of the 150 meat samples and whole genome sequencing of *E. coli* strains indicated that ESBL-producing *E. coli* isolated from meat matched *E. coli* isolated from individuals in the community and clinical samples from hospital patients. Taken together, their results offer evidence of community spread of ESBL-producing *E. coli* originating from animals or animal-sourced foods (Nadimpalli et al., 2019). Similar results were reported by Trongjit et al. (2017) who examined antibiograms of *E. coli* isolated from pig and chicken carcasses at slaughterhouses and markets in the Cambodia (Banteay Meanchey) - Thailand (Sa Keao) border area.

Water contaminated with livestock waste is thought to be a significant cause of Hepatitis E virus (HEV), and Tei et al. (2003) confirmed the causal relationship between infected meat and Hepatitis E onset. Yamada et al. (2015) also studied the prevalence of HEV in the Siem Reap province and found that 18.4% of participants were sero-positive for HEV (n = 868). Furthermore, the HEV RNA sequence isolated from participants shared significant homology to that of three swine-based isolates (95.57%, 94.37%, and 91.94%) from China (Yamada et al., 2015).

Food safety research in Cambodia expands beyond just animal-sourced foods. A 2017 study compared *E. coli*, *Salmonella*, and coliform prevalence in lettuce, saw-leaf herbs, and cucumbers obtained from roadside stalls, mobile vegetable carts, wholesale markets, and supermarkets in the Phnom Penh area (Phoeurk et al., 2019). Overall, coliforms, *E. coli*, and *Salmonella* were detected in 97.2%, 30.7%, and 55.7% of lettuce samples, respectively. Similarly, coliforms, *E. coli*, and *Salmonella* were detected in 97.2%, 36.1%, and 55.7% of saw-leaf herb samples, respectively. Finally, coliforms, *E. coli*, and *Salmonella* were detected in 50%, 5.7%, and 11.1% of cucumber samples, respectively (Phoeurk et al., 2019).

Desiree et al. (2021) reported on the presence of coliforms, generic *E. coli*, and *Salmonella enterica* (*Salmonella*) in lettuce, cucumbers, and tomatoes produced and sold during the dry and rainy seasons in Battambang and Siem Reap provinces. *Salmonella* was detected in 28.3% of vegetable samples, with lettuce samples having a significantly higher prevalence of *Salmonella* compared to the other vegetable types in the study (56.5%). Interestingly, quantification estimates for *Salmonella* showed a higher level of *Salmonella* in lettuce in rainy season, as compared to the dry season (6.4 log CFU/g and 5.0 log CFU/g, respectively). Lettuce during the rainy season also contained the highest prevalence of generic *E. coli* and highest levels of coliforms (52.4% and 5.2 log CFU/g, respectively) compared to the other vegetables. The lowest concentrations of generic *E. coli* and coliforms were found on tomatoes and cucumbers during the dry season.

Since fresh vegetables are not always available throughout the year in Cambodia, fermentation is often used for vegetable preservation and fermented products are often sold in wet markets. Chrun et al. (2017) collected 68 fermented vegetable samples from wet markets in Phnom Penh. *Enterococcus* spp., *Bacillus* spp., coliform bacteria, and *E. coli* were isolated from 34%, 31%, 24% and 10% of samples, respectively. Other bacteria were isolated at lower frequencies; 10% of samples contained opportunistic bacteria (e.g., *Aeromonas salmonicida, Rhizobium radiobacter,* and *Shwanella putrefaciens* group), 6% of samples contained *Staphylococcus* spp., and 6% of samples contained *Listeria* spp. The authors concluded that high levels of bacterial contamination were due to poor sanitation while handling/processing vegetables, high pH levels in the case of fermented products, and exposure of the product to the outside environment. The authors also emphasized the importance of identifying the stage in the production chain where most contamination occurs. In contrast, Ly et al. (2020) either did not detect or found acceptable concentrations (as recommended by the European Food Safety Authority) of microorganisms in 57 samples of fermented foods (42 fish and 15 vegetable products) that were randomly selected from wet markets in Phnom Penh.

While there are usually numerous sources along a production chain that contribute to overall contamination of a product, there is a lack of data in Cambodia as to which step or steps contribute greatest to vegetable contamination. Identifying the most important critical control points could lead to more effective or focused intervention strategies. Schwan et al. (2020) examined the prevalence of *Salmonella* spp. in non-food and food contact surfaces in informal market vegetables. The authors reported that *Salmonella* spp. was isolated from 75% of food contact surfaces tested and 25% of non-food contact surfaces tested. The overall estimated prevalence of *Salmonella* was 25%, with significantly higher prevalence in the dry season (41% on food contact surfaces vs. 17% non-food contact surfaces). These authors recommended various practices that could reduce the risk of bacterial contamination such as frequently sanitizing food contact surfaces or improving airflow and ventilation in indoor markets.

3.2. Food Safety Research: Chemical contamination

In Cambodia, Holm et al. (2010) measured concentrations of chemical contaminants in Cheung Ek Lake, which serves as a deposit for domestic and industrial wastewater from Phnom Penh but is also the site for much of the city's water spinach production. Concentrations of potentially toxic elements (PTE's) such as cadmium, copper, zinc, and other heavy metals in spinach grown in the lake's vicinity were comparable (either same or only slightly higher) to those of water spinach grown in soil not exposed to the lake's water. The authors concluded that consuming water spinach from Cheung Ek Lake did not increase the risk of exposure to chemicals. The authors also reported similar findings for fish harvested from the same lake (Holm et al., 2010).

Arsenic is a food safety concern, especially in rice grown in water sourced from the Mekong River. Murphy et al. (2018) found that the high levels of arsenic in rice in Cambodia were mostly the result of arsenic in its organic form, which is considered less toxic than inorganic arsenic. Additionally, these authors reported that highest levels of arsenic found in Cambodia were still acceptable (per kg of rice) under Codex guidelines (Murphy et al., 2018). Phan et al. (2016) also analyzed arsenic exposure in Kandal Province, an area thought to have high arsenic contamination rates. Arsenicosis symptoms were found in 131 of area patients, 101 of which were women, and 24.7% of all patient samples had urine arsenic levels greater than 100 μg L^{-1}, which is indicative of recent arsenic exposure. Out of the 246 participants in the greater study, 8.9% were children (less than 12 years old), none of whom displayed symptoms of arsenicosis. The authors concluded that females were more at-risk for arsenicosis than men, due to greater consumption of arsenic-contaminated water in the home, compared to men whose places of work may have safer drinking water (Phan et al., 2016).

A 2016 study compared phthalate ester concentrations in food samples from the Kampong Cham, Kratie, and Kandal provinces in Cambodia (Cheng et al., 2016). Phthalates are synthetic chemical compounds that are typically used as plasticizers; phthalates are also used in insecticides and can easily contaminate foods. The authors found that rice was the greatest contributor to Cambodians' daily intake of phthalate (67.6%), followed by fish (14.54%), vegetables (8.24%), meat (5.95%), and organ meat (3.71%). Concentrations of Di-2-Ethylhexyl phthalate (DEHP) phthalates from foodstuffs in Cambodia were significantly higher than those from US and China (Cheng et al., 2016).

Ly et al. (2020) detected concentrations of biogenic amines histamine and tyramine at levels that could pose a health risk in four and one of the 57 fermented sampled foods, respectively. A variety of physiological consequences can result from high concentrations of biogenic amines, including hypertension, hypotension, cardiac palpitation, and death in severe cases (Rawles et al., 1996).

An older study by Feldman et al. (2007) included characterizations of chemical profiles of drinking water sources from 13 of Cambodia's provinces. Aside from elevated arsenic concentrations, ten other chemicals were identified at levels that considered health concerns according to WHO's Guideline Values and Cambodia's Drinking Water Quality Standards. These ten chemicals were detected in at least one sample throughout the study area; concentrations of manganese, nitrate and nitrite, and fluoride were most often found to exceed recommended levels (Feldman et al., 2007).

Unlike data from other low-resource countries, particularly those in Africa, Cambodia lacks country-specific assessments on the contamination of food with fungal-associated toxins such as aflatoxin, which are often associated liver damage and cancers. In recent years, Ly et al. (2012) measured levels of aflatoxin B1, ochratoxin A, total aflatoxins, as well as fumonisin B1 and B2 in 40 paddy rice and 20 milled rice samples in Cambodia. Levels all toxins were under European Union tolerances (Ly et al., 2012).

In 2013, Cheng et al. collected fish, meat, produce, and rice samples across three provinces (Kratie, Kampong Cham, and Kandal) in Cambodia, along with food consumption patterns, to estimate daily dietary intake of total mercury (THg) and methylmercury (MeHg). Levels of THg and MeHg were three to four times higher in fish when compared to the other food groups. As rice constitutes a large component of the Cambodian diet, the authors determined that fish and rice were likely the greatest contributors of THg and MeHg in Cambodian diets. Based on measured THg and MeHg levels coupled with survey results, the authors estimated that the daily intake of MeHg by Cambodians in Kratie and Kampong Cham provinces likely exceeds daily intake limits set by the US EPA (0.1 μg kg^{-1} body weight d^{-1}) and provisional tolerable weekly intake recommendations (1.6 μg kg^{-1} body weight per week) from WHO (Cheng et al., 2013).

3.3. Cambodia food safety research: Perceptions/barriers

Food safety efforts and research in Cambodia are relatively new. As such, studies describing food safety perceptions among Cambodians are still rare. Desiree et al. (2021), however, conducted a study cataloging agricultural practices of farmers, collectors, distributors, and vendors involved in the Cambodian vegetable value chain to begin identifying which stages of production contributed greatest to contamination of vegetables. Respondents were asked how frequently they engaged in safe vegetable handling practices, such as basic hygiene, handwashing, washing vegetables, and use of gloves. The authors also characterized handling practices that could promote vegetable contamination, including storage conditions, use of contaminated irrigation water, and poor composting practices. The authors concluded that increased food safety training and education programs for value-chain members, more developed regulatory frameworks, increased communication with consumers about safe food practices, and improved infrastructure, such as clean market buildings, washing stations, and cool storage could each improve food safety outcomes (Desiree et al., 2020).

Roesel et al. (2018) examined Cambodian's perceptions of the consequences of foodborne disease and barriers Cambodians face in obtaining safer foods. The authors characterized facilitated discussion on food safety involving 66 participants from five low-income and five middle-income areas of Phnom Penh. Together, participants identified over 600 consequences of consuming unsafe food with "getting sick", "losing time", and "cost of treatment" most frequently mentioned. However, some consequences exhibited higher levels of interactivity (where one consequence influenced another and/or vice versa) than others. The most interactive consequences were "get sick", "living standard goes down", and "effect on family income". Similarly, participants identified more than 250 barriers to avoiding unsafe foods with little to no expendable income, expense of safe food, unavailability of shops selling safe products, and lack of time as barriers most frequently stated (Roesel et al., 2018).

LeGrand et al. (2018) established Shared Interest Savings Groups (SISGs) amongst smallholder Cambodian farmers across six villages in an effort to lower barriers to accessing consumer-driven markets. The group conducted focus groups, workshops, and interviews with SISG members and marketers to understand perceptions of the SISG activities, while comparing yield and cost data from farmers over a three-year period. Hygiene, sanitation, and pesticide overuse of local produce were identified by participants as primary barriers to linking farmers with more formal retail outlets. The study found that adoption of net tunnels to reduce pesticide usage improved the quality of produce and a cost-benefit analysis found that farmers' earning potential was higher with net houses compared to traditional cultivation (LeGrand et al., 2018). The authors concluded that modernizing smallholder farms could result in safer and higher quantity food/products for consumers, provide more economic opportunities for the farming household, and improve individual (household) and national food insecurity (FAO High Level Panel of Experts on Food Security and Nutrition [FAOHLPE], 2013).

Implementing food safety practices often comes at a cost to producers or processors. To our knowledge, however, no studies yet exist measuring Cambodian's willingness-to-pay for foods perceived as safer. Kouya et al. (2016), however, examined Cambodian's motivations for purchasing "organic" food products. While not a direct measurement of attitudes towards food safety, the authors included "food safety concerns" as a possible motivation for purchasing organic food products. Their results indicated that Cambodian purchasers of organic foods were motivated primarily by "health consciousness". Food safety concerns, however, were not correlated to respondents' intention to purchase organic foods. While not a direct measurement of Cambodian's attitudes toward food safety, these results do offer a proxy, albeit preliminary measurement of Cambodians' willingness-to-pay for food products they perceive as safer and speak to possible barriers to changes in behavior required in the adoption of most food safety practices. Behavior change as it relates to food safety is discussed in more detail in later sections.

3.4. Surveillance and identification of etiological agents and their transmission

Preventing foodborne disease outbreaks requires knowing what pathogens are causing illnesses and how those pathogens enter and are transmitted throughout food production chains. Cambodia does not currently have a robust foodborne pathogen surveillance system. In turn, while etiological agents have been identified in some of the large foodborne disease outbreaks in Cambodia (Table 1), very little is known regarding causes of smaller outbreaks and less is known regarding individual cases of foodborne disease. While there is a growing number of studies characterizing pathogens that can be recovered from different food products, most studies have focused on specific pathogens (e.g., *Salmonella*, *Campylobacter*). Those studies, by design, are narrow and identify several pathogens that Cambodians are likely to be exposed to through food. They do not, however, necessarily identify causative agents for foodborne disease throughout the country (e.g., a food item may contain *Salmonella*, but illness could be caused by the myriad of other potential foodborne pathogens, including viruses, which may be also present, but not targeted in the study).

As in other countries, these recognized outbreaks also likely represent only a small fraction of the total numbers of outbreaks and individual cases of foodborne disease in Cambodia. Total foodborne disease estimates usually result from modeling. While Cambodia-specific modeling studies are to our knowledge not available, the number of foodborne disease outbreaks and individual cases is likely several orders of magnitude higher than what is reported or confirmed due to limits in surveillance, diagnostics, and epidemiology.

Similarly, there are few longitudinal studies or studies that examine contamination of food products over time in Cambodian. Most of the food safety research studies described above measuring microbial or chemical contamination in foods are "snap-shots". Likewise, to date most studies have examined only single parts (e.g., meat sold retail) of what are often complex production chains. While such studies are informative and can be aggregated to give a better idea of contamination, they are still limited in explaining the gestalt of food safety challenges in Cambodian food systems.

4. A strategic approach to improving food safety in Cambodia

There is growing enthusiasm for food safety in Cambodia across ministries, universities, and other research centers (personal observations), which has led to an increase in activities for addressing food safety challenges. The review of these efforts presented here, including what is known about recent foodborne disease outbreaks, current food safety research in Cambodia, legislative/regulatory factors relevant to food safety, and Cambodian's awareness of foodborne disease and its impacts, provides a background to developing an overarching model to quickly and effectively reduce the risk of foodborne disease in Cambodia. The model proposed here consists of four highly integrated and inter-dependent components that together could streamline and focus food safety efforts on those challenges most pressing and most impactful (Fig. 1).

4.1. Component 1: Surveillance and identification of causes of Foodborne disease

Standardized surveillance of foodborne pathogens is needed to provide a more complete understanding of pathogen transmission or chemical contamination along entire production chains in Cambodia. A more complete understanding of what contaminants are making people sick and how those contaminants enter food systems would allow identification of critical control points to target to maximize reductions in contamination. Of note, Cambodia has significantly improved its health security capacities (surveillance, diagnostics, response, etc.). These efforts, however, have focused largely on reportable infectious diseases (Cholera, HPAI, HIV, etc.; Conseil Sante, 2016). There are likely significant opportunities to integrate food safety programming into the existing surveillance infrastructures described above, which could allow more targeted food safety outreach and research programs.

4.2. Component 2: Identifying effective food safety interventions

While the development of effective food safety interventions is hampered by lack of data of etiological agents and transmission routes, there are hundreds of different interventions shown to be effective elsewhere that are likely to be as effective in Cambodia. Currently,

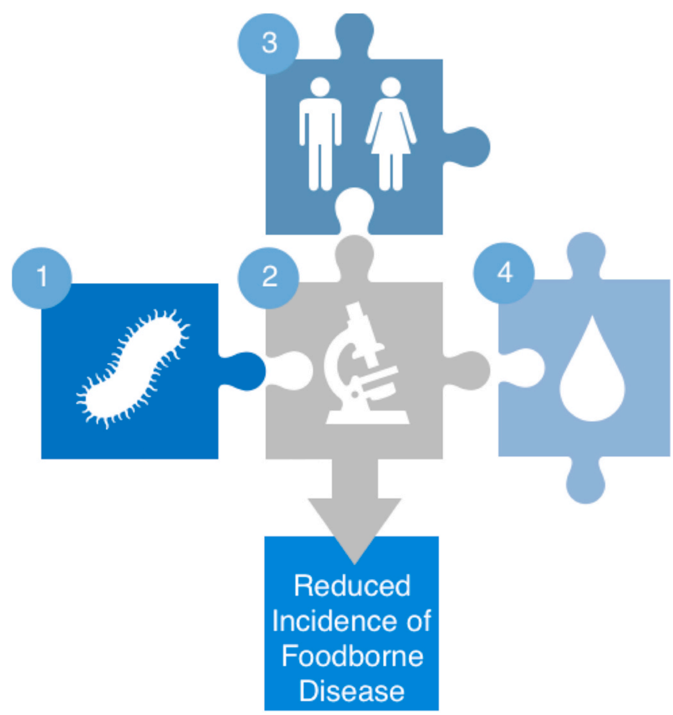

Fig. 1. An integrated approach to improving food safety outcomes in Cambodia. 1) The causes (etiological) agents responsible for the most foodborne diseases need to be identified. Once identified, risk-based surveillance systems can describe how these pathogens enter and are transmitted through food systems; 2) Identifying critical control points can streamline the development of interventions by focusing research on specific critical control points; 3) characterizing motivations, opportunities, and capabilities to adopting food safety practices among producers, processors, and consumers will highlight where sources of behavior that guide adoption of food safety practices are present or absent. This knowledge can also inform food safety intervention research such that research solutions are translatable; 4) continued improvements in access to clean water in rural areas will afford producers and processors a key resource needed to implement new food safety practices.

however, there is very little research focused on assessing the impact or efficacy of food safety interventions in reducing foodborne disease or increasing adoption of food safety practices in Cambodia. Likewise, there is little research focused on the development of interventions specifically designed for the Cambodian context.

Cambodian production systems and markets (e.g., informal markets vs. higher-end groceries) are complex and dynamic. Thus, food safety intervention research should consider critical control points and other characteristics that may be specific to certain scales of production or market structures. This information should guide food safety intervention research and help ensure that technologies are appropriate for specific contexts.

4.3. Component 3: Facilitating behavior change

Ultimately, many foodborne diseases are preventable through changes in behavior, whether that entails implementing new production practices, adopting of new food preparation methods, or avoiding certain risks. Importantly, such changes in behavior often come with costs. Therefore, strategies to improve food safety must reconcile the host of interventions or practices that could possibly reduce foodborne disease risk with what people will actually do, accept, or adopt to improve food safety. Michie et al. (2011) synthesized existing behavior models in developing their "behaviour change wheel" that describes how specific conditions, namely opportunity, capability, and motivation, interact to drive (or prevent) behaviors. These conditions or sources of behavior are, in turn, influenced by numerous “intervention functions” including incentivization, education, training, restrictions, persuasion, coercion, among others. Very often these interventions are made possible by policies which could include regulation, legislation, fiscal measures, among others. The efficacy of food safety programs in Cambodia would likely be enhanced by more clearly understanding food safety through such a Behavior Change Theory framework. Such research could identify deficiencies in motivation, capability, or opportunity that will prevent the success of food safety programming aimed at encouraging adoption of food safety practices. Likewise, a better understanding of sources of behavior as they apply to food safety can guide food safety intervention research and translation and even create an environment that enables desired changes in behavior through awareness campaigns, quantitative assessments of consumers' willingness-to-pay for “safe” foods that could provide incentivization (or show where there may be little incentive), or targeted policies at local or national levels. Again, such an analysis would need to consider the numerous differences, both significant and nuanced, across production scales and market structures throughout the country.

4.4. Component 4: Improved access to clean water in rural areas

While the availability and use of safely managed water and sanitation services in Cambodia has increased, there still exist disparities across income levels and geography (e.g., urban vs. rural). Nationally, 26% of the population utilizes safely managed water supplies; however, usage in rural populations, where 77% of Cambodians reside, is at only 17% (urban: 57%). Similarly, rural use of improved sanitation services (e.g., toilets, latrines, etc.) is at 48%, whereas use of similar services in urban areas is at 96%. Gaps are even larger in use of basic sanitation services when income is considered (wealthiest quintile: 92%; least wealthy quintile: 15%; UNICEF, 2019). In Cambodian children between 6 and 23.9 months of age, 30–40% of stunting and wasting is attributed to poor sanitation and unclean water as well as poor child feeding index scores (Laillou et al., 2020).

Consistent access to safe water supplies is a cornerstone of Good Agricultural Practices (GAPs). Decreased access to safe water in rural areas limits the efficacy of sanitation and hygiene practices in vegetable production. In turn, the impact of poor water quality becomes decentralized beyond rural areas as vegetables are transported and consumed throughout the country. As such, Cambodia's improvements to clean water access must continue if producers in rural areas are to be equipped with resources necessary to implement many of the farm- and processor-level practices required to ensure safe food products.

5. Conclusions

Cambodia has committed numerous resources towards improving nutritional outcomes on a national level. However, as in all countries, important foodborne pathogens have been isolated from the Cambodian food supply and foodborne diseases associated with such pathogens can negate benefits of access to more nutritious foods. As Cambodia's economy, health security, and infrastructure continue to improve, however, the country is well-positioned to build on established and emerging food safety efforts.

A review of Cambodian food safety efforts presented here, including what is known about recent foodborne disease outbreaks, current food safety research in Cambodia, legislation and other regulatory factors relevant to food safety, and Cambodian's awareness of foodborne disease and its impacts, provides the background to developing an overarching model to strategically reduce the risk of foodborne disease in Cambodia. This proposed model consists of four highly integrated components (Fig. 1). Foremost, the etiological agents responsible for the greatest number of foodborne disease outbreaks, large and small, must be identified. This information will allow the development of risk-based surveillance systems that more comprehensively identify when, how, and where these key pathogens enter food production systems. In turn, knowing the pathogens most responsible for foodborne disease in Cambodia and how these pathogens enter food systems would allow for more targeted research that identifies interventions that effectively reduce transmission rates at these key critical control points. Concurrently, increased access to clean water in rural areas will provide producers and processors the resources necessary to implement Good Agricultural Practices aimed at reducing contamination at producer and processor levels.

Finally, as improving food safety often requires changes in behavior, “bench” science efforts need to be coupled with research identifying motivations, opportunities, and capabilities as they relate to adopting food safety practices. Such research, using a framework of Behavior Change Theory, could offer an assessment of not only the barriers or impediments to adopting food safety practices across different actors in food production chains, including consumers, but how such barriers can be lowered. Taken together, this integrative approach can maximize resources by facilitating targeted research that produces food safety solutions that are readily adoptable by and beneficial to Cambodian producers, processors, and consumers.

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Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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