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EDITED BY
Hung Nguyen-Viet,
International Livestock Research Institute (ILRI), Kenya

REVIEWED BY
Sujata A. Sirsat,
University of Houston, United States
Richmond Nii Okai Aryeetey,
University of Ghana, Ghana

*CORRESPONDENCE
Paul Ebner
✉ pebner@purdue.edu

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Describing food safety perceptions among growers and vendors in Cambodian informal vegetable markets

Sabrina Mosimann[1], Keorimy Ouk[2], Nora M. Bello[3], Malyheng Chhoeun[2], Leah Thompson[1], Jessie Vipham[4], Lyda Hok[2,5] and Paul Ebner[1]*

[1]Department of Animal Sciences, Purdue University, West Lafayette, IN, United States, [2]Center of Excellence on Sustainable Agricultural Intensification and Nutrition, Royal University of Agriculture, Phnom Penh, Cambodia, [3]Department of Animal Science, The Ohio State University, Columbus, OH, United States, [4]Department of Animal Sciences and Industry, Kansas State University, Manhattan, KS, United States, [5]Division of Research and Extension, Royal University of Agriculture, Phnom Penh, Cambodia

Improving food safety often requires individuals or groups to adopt new food safety behaviors. Understanding individuals' perceptions of food safety is an important step in creating programs that enable the adoption of such behaviors. To inform the design of food safety programs in Cambodia, this study measured perceptions of vegetable safety among vegetable growers ($n = 69$; Battambang, Siem Reap) and vendors ($n = 31$; Phnom Penh) involved in Cambodian informal vegetable markets using a quantitative questionnaire. The majority of respondents (≥ 62.7%, lower bounds of 95% confidence intervals at least 46.2%) across all groups (growers and vendors) were at least "moderately concerned" (scale: "extremely concerned," "moderately concerned," "slightly concerned," "not concerned at all") about the safety of vegetables sold in Cambodia. However, the mean estimated probability of respondents reporting that chemical contamination was of greater concern than microbial contamination was 84.9% [76.0, 90.9]%. Most respondents reported familiarity with the health effects of consuming chemically (71.4% [61.5, 79.6]%) or microbially (57.3% [47.2, 66.9]%) contaminated vegetables. However, less than half (between 7.3% and 48.4%) of all respondents provided a commonly recognized example of such health effects. Across all groups, respondents most frequently perceived contamination of vegetables as occurring primarily "at the farm" (≥ 76.7%, lower bounds of 95% confidence intervals at least 61.5%, and ≥ 39.3%, lower bounds of 95% confidence intervals at least 21.2%, respectively). Additionally, most respondents (≥ 51.6%, lower bounds of 95% confidence intervals at least 34.0%) perceived "vegetable farmers" as primarily responsible for preventing chemical contamination. Perceptions of responsibility for preventing microbial contamination varied across groups ($p = 0.02$). Of the vendors in Phnom Penh, growers in Battambang, and growers in Siem Reap involved in this research, 22.6%, 39.0%, and 53.6%, respectively, described at least one commonly accepted contamination prevention practice. These results suggest that food safety programs for each of the described groups should include efforts to increase participants' understanding of the health impacts of consuming contaminated vegetables. However, specific emphasis should be placed on increasing awareness on the health impacts of consuming vegetables contaminated with microbial pathogens as respondents were generally less aware and concerned with microbial vs. chemical contamination of vegetables. Additionally, programs targeting vegetable growers could leverage growers' sense

of personal responsibility for both contamination and contamination prevention, while programs for vegetable vendors may need to emphasize the importance of vendors in ensuring vegetable safety.

KEYWORDS

Cambodia, food safety, informal markets, perceptions, vegetables

Introduction

Cambodia, with a growing population of ~16.7 million (Central Intelligence Agency (CIA), 2022), has experienced significant economic and social progress in recent years. Poverty rates have declined from 47.8% in 2007 to 13.5% in 2014, and in 2015 the World Bank altered its classification of Cambodia from a low income to a lower-middle income economy (World Bank Group, 2017). Agriculture continues to play a central role in the Cambodian economy. Over 60% of the Cambodian population lives in rural areas, where approximately half of those employed between the ages of 15 and 64 work primarily in production agriculture (National Institute of Statistics & Ministry of Planning (NIS, MOP), 2020). Furthermore, the agricultural sector is estimated to represent 22% of Cambodia's GDP, supplying both international and domestic markets with fresh fruits and vegetables among many other products and commodities (U.S. Mission Cambodia, 2020; Agricultural Marketing Office (AMO), 2022; National Institute of Statistics and Ministry of Planning (NIS, MOP), n.d.).

Vegetables in particular are an important part of the Cambodian diet, both in terms of quantity and frequency of consumption (Windus et al., 2022). Many Cambodians purchase their vegetables in informal, open-air markets, which are comprised of networks of vegetable producers, collectors, distributors, and vendors (Sokhen et al., 2004; Desiree et al., 2020). These informal vegetable markets exist largely outside of governmental oversight (e.g., regulatory monitoring/surveillance, taxation, etc.), and numerous food safety gaps have been identified in these markets, including poor sanitation of vegetable transport vehicles, improper vegetable handling, insufficient composting time, inadequate cold storage, lack of sanitation facilities and infrastructure (e.g., toilets, handwashing stations, adequate drainage, etc.), presence of pests, use of poor quality water for irrigation or vegetable washing, and ample opportunity for cross-contamination between raw animal-source foods and raw vegetables, among others (Desiree et al., 2020). In addition, several groups have isolated *E. coli*, coliforms, and *Salmonella* spp. from raw vegetables and vegetable contact surfaces in informal vegetable markets in Cambodia (Phoeurk et al., 2019; Desiree et al., 2021; Schwan et al., 2021). Considering these food safety gaps along with the substantial role of informal vegetable markets in meeting the high demand for vegetables in Cambodia, improving food safety practices in these markets is clearly an essential component of reducing the risk of foodborne illness in Cambodia.

Foodborne illnesses are most frequently the result of diarrheagenic pathogens (Havelaar et al., 2015). For low and lower-middle income countries, information on the exact proportion of all diarrheal diseases that are caused by foodborne pathogens is generally not available. However, even conservative estimates indicate that the negative health impacts of diarrhea associated with the consumption of contaminated food are considerable in these contexts (Grace, 2015). Diarrhea may be either acute or chronic and can result in dehydration, malabsorption of nutrients, economic losses, and, in extreme cases, death (National Institute of Diabetes and Digestive and Kidney Diseases (NIDDK), 2016; World Health Organization (WHO), 2017; Nemeth and Pfleghaar, 2021; Niyibitegeka et al., 2021). Children are especially impacted by diarrheal disease: according to the World Health Organization (WHO), diarrhea is the second most common cause of death in children under 5 years old around the world (World Health Organization (WHO), 2017). In Cambodia, an estimated 7.4 and 15% of deaths in children 0–4 years old and 1–59 months old, respectively, are attributed to diarrhea (World Health Organization (WHO), 2018). In addition, inflammation of the GIT resulting from diarrhea inhibits the absorption of nutrients and can contribute to malnutrition. This is of particular concern in Cambodia, where rates of stunting (21.9%) and wasting (9.6%) in children under 5 years of age remain medium to high according to the prevalence thresholds set by the WHO (de Onis et al., 2018; National Institute of Statistics, Ministry of Health, and ICF (NIS, MoH, and ICF), 2022). Frequent exposure to foodborne pathogens may also contribute to the development of environmental enteropathy (environmental enteric dysfunction) in both children and adults, a condition associated with intestinal villus blunting, increased intestinal permeability, and nutrient malabsorption (Kelly et al., 2016; Louis-Auguste and Kelly, 2017).

Several Cambodian government policies and development organization initiatives have sought to improve nutritional outcomes in Cambodia by supporting increased production and consumption of nutrient-dense foods, including fresh fruits and vegetables (Ministry of Agriculture, Forestry and Fisheries, the European Union, and the United States Agency for International Development (MAFF, EU, and USAID), 2015; Royal Government of Cambodia, 2019; Feed the Future Innovation Lab for Collaborative Research on Sustainable Intensification, 2020; Save the Children, 2020). However, fruits and vegetables are considered high-risk foods in terms of food safety. Microbial contamination is of especial concern, as vegetables are frequently consumed raw and therefore are often not exposed to high temperatures or other control measures that would reduce or eliminate microbial loads. Given that vegetables in informal markets in Cambodia may be frequently contaminated with microbes, consuming fresh vegetables purchased from these markets may carry a particularly high risk of foodborne illness. As such, the malabsorption of nutrients caused by diarrheal diseases and other foodborne illnesses contracted through the consumption of fresh vegetables may ultimately negate the nutritional benefits of the produce itself.

To improve food safety in informal vegetable markets in Cambodia, those involved in the informal vegetable value chain must begin implementing positive food safety practices. In general, in order

to design programs that effectively facilitate the adoption of a new practice it is important to understand and account for the target audiences' existing perceptions about the problem that the new practice would address. Identifying the level of concern among members of the target audience regarding that problem, for instance, could help program developers determine whether sensitization to the issue itself is needed prior to the implementation of a program that promotes the practice in question. Evaluations of audience members' perceptions of who is responsible for the particular problem, how frequently the problem occurs, and the ramifications of the problem are needed to inform program development and implementation. For instance, information regarding these perceptions may facilitate recognition of potential barriers to and enablers of behavior change embedded in the mindset of the target audience. Once identified, both enablers and barriers can be harnessed or reduced, thereby improving the efficacy of engagement programs and increasing the likelihood of adoption of the behavior.

Research objectives

Assessing perceptions of food safety among actors involved in informal vegetable markets in Cambodia is a relatively new area of research and is not comprehensively understood. The purpose of this research was to explore and describe perceptions of vegetable safety among vegetable growers and vegetable vendors involved in informal vegetable markets in Cambodia. Specifically, the study aimed to measure participants' perceptions of: (1) the importance of vegetable safety; (2) the frequency of vegetable contamination; and (3) the health impacts of consuming contaminated vegetables. Additionally, the study aimed to understand participants' current practices for preventing vegetable contamination and their perceptions of where contamination primarily occurs and who is most responsible for preventing contamination. Describing these perceptions, as well as the differences in perceptions across participant groups (i.e., vegetable vendors in Phnom Penh and vegetable growers in Battambang and Siem Reap), was intended to facilitate the development of food safety programs tailored to specific participant groups that effectively promote the adoption of positive food safety behaviors within each group.

Methods

Ethical approval

All research protocols described here were reviewed by the Institutional Review Board of Purdue University (IRB-2020-383; West Lafayette, IN) and the Royal University of Agriculture (Phnom Penh, Cambodia).

Questionnaire design and pilot study

In order to inform the design of future food safety programs, the researchers designed a quantitative questionnaire intended to measure perceptions of food safety among vegetable growers and vegetable vendors involved in informal vegetable markets in Cambodia. Due to travel constraints between and within countries related to the COVID-19 pandemic, however, the questionnaire could not be piloted with targeted groups (i.e., vegetable producers, vendors, etc.) as that audience required in-person recruitment and in-person questionnaire completion. Thus, the questionnaire was modified to an online version and piloted with undergraduate students in food technology and related majors at Cambodian universities as connecting with this audience and completing the questionnaire could take place entirely online and did not require any travel. The pilot questionnaire sought to explore and describe participants' general familiarity with vegetable food safety practices, perceptions of the frequency and consequences of chemical and microbial contamination of vegetables, willingness to learn about food safety practices, and perceptions of the importance of implementing specific food safety practices. As prior research has indicated that there is greater awareness and concern for chemical contamination compared to microbial contamination among Cambodians (Consumers International, 2013; Ebner et al., 2020; Brown et al., 2022), the questionnaire explicitly distinguished these two types of contamination. The pilot questionnaire was composed of 32 content (i.e., non-demographic) questions, all of which were formatted in five-point Likert answer scales. These questions were translated into Khmer, reviewed by Cambodian members of the research team for cultural appropriateness and comprehensibility, and digitized using KoBo Toolbox (Kobo Inc, n.d.).

Potential participants in the pilot study were contacted via email. The first round of pilot data collection took place in March and April of 2021, yielding responses from a total of 215 participants. After removing responses from individuals who declined to participate ($n = 2$), responses that were less than 50% complete ($n = 14$), and responses for which it was not possible to confirm that the respondent was part of the target audience ($n = 87$), the data set included responses from 112 participants. After a qualitative assessment of the data, the questionnaire was revised for identifiable errors and for clarity, resulting in a subsequent pilot questionnaire containing 34 content questions.

A second round of pilot data collection was conducted in May and June of 2021 using the revised 34-question questionnaire. This data collection event yielded responses from 62 participants. Excluding two responses from individuals who did not consent to participate, six responses that were less than 50% complete, and four from respondents whose status as part of the targeted audience was unclear, the resulting data set contained responses from 50 participants.

Following preliminary analyses of descriptive statistics based on response data from the two rounds of pilot data collection, it became apparent that the scope of the questionnaire was too broad. For this reason, the questionnaire was once again revised. During this revision, the questionnaire was focused on respondents' general levels of concern regarding vegetable safety in Cambodia, their current contamination prevention practices, and their perceptions of the frequency of chemical and microbial contamination of vegetables, the potential health impacts of chemical and microbial contamination, the production stage at which most contamination occurs, and the participant group primarily responsible for preventing contamination.

The revised questionnaire (Supplementary material) consisted of a total of 17 content questions, including 14 quantitative questions and three free response questions. Free response questions were included to qualitatively explore participants' perceptions of the potential health impacts of chemical and microbial contamination and to

determine participants' current food safety practices without limiting responses to scaled answers. Questions that were modified or added as the questionnaire was revised were translated into Khmer by native Khmer-speaking members of the research team. At the end of the revisions process, the questionnaire was reviewed by Cambodian members of the research team in order to ensure that the questions were easily and consistently understood in Khmer and that the questions were worded in a culturally appropriate manner. The questionnaire was then digitized using KoBo Toolbox in preparation for data collection (Kobo Inc, n.d.).

Data collection with vendors and growers involved in informal vegetable markets

The revised questionnaire consisting of 17 content questions was first implemented in informal vegetable markets in Phnom Penh, Cambodia in August 2021. Phnom Penh was chosen as the location for initial data collection because informal vegetable markets in Phnom Penh were accessible to the research team when COVID-19-related travel restrictions were in effect. Participants were selected using availability sampling techniques (Daniel, 2012) and, as before, all participants were over 18 years of age and consented to participate in the research. Questionnaire enumerators implemented the questionnaire in person, approaching 31 vegetable vendors regarding participation in the study. All 31 individuals agreed to be surveyed and answered at least 50% of the questions on the questionnaire. To facilitate conceptualization of key terms in the questionnaire, each enumerator read the following statement aloud in Khmer to each participant prior to initiating questions:

Sometimes, foods can contain unwanted chemicals, microbes, and other substances that can make people sick. These unwanted chemicals, microbes, and other substances are often called "contaminants". Today, we will be talking about two types of harmful contaminants that are sometimes found in vegetables:

1. ***Chemical contaminants:*** *chemical contaminants can include pesticides or herbicides used to grow the vegetables, leftover cleaning chemicals, chemicals that form in the food on accident, or chemicals that are transferred from the soil to the vegetables, among others.*
2. ***Microbial contaminants:*** *microbial contaminants include bacteria* (e.g., *E. coli), viruses, fungi, among others.*

The term ***"Food safety"*** *refers to practices that each of us does to make sure the food we eat does not contain harmful chemicals or microbes.* ***"Safe"*** *food is* ***safe*** *to eat and does not make us sick.*

In order to ensure that participants had a clear and consistent understanding of the questionnaire's content regardless of literacy level, each question and its corresponding answer scale was read aloud in Khmer during questionnaire implementation. To note, although both men and women were eligible to participate in the research, a large majority (93.5%) of respondents were women, reflecting the fact that most vegetable vendors in Cambodia are women.

Once COVID-19 related travel restrictions were relaxed, enumerators traveled to the provinces of Battambang and Siem Reap in February 2022 for data collection. Battambang and Siem Reap were the geographic focus for data collection because these provinces are included in the current USAID Feed the Future Zone of Influence in Cambodia (United States Agency for International Development (USAID), n.d.). As before, availability sampling was used to identify potential participants (Daniel, 2012), all of whom voluntarily agreed to participate in the research and were over 18 years of age. The questionnaire was again implemented in person, with questionnaire enumerators reading each question and the appropriate answer scale aloud in Khmer to facilitate an accurate and consistent understanding of the questionnaire. During data collection in Battambang and Siem Reap, 69 vegetable growers ($n = 41$, Battambang; $n = 28$, Siem Reap) were invited to participate. All those who were approached agreed to take part and gave responses to at least 50% of the questions on the questionnaire. As a result, the data set presented and analyzed here included responses from all 69 producers in addition to the aforementioned 31 responses from vendors. There were again more female than male respondents (Siem Reap: 21.4% male, 78.6% female; Battambang: 36.6% male, 63.4% female).

Data analysis

Questionnaire responses from vendors in Phnom Penh, growers in Siem Reap, and growers in Battambang were retrieved from KoBo Toolbox (Kobo Inc, n.d.) and compiled into a single dataset in Excel. For all quantitative questions, preliminary descriptive statistics consisting of frequency tables were used to identify missing response values and to anticipate modeling problems related to quasi-complete separation of data points (i.e., extreme category). Problems with quasi-complete separation of data points were observed for one question (regarding the frequency of microbial contamination on domestically grown vegetables) and were addressed using Firth's penalized maximum likelihood estimation for bias reduction.

A logistic regression model was fitted separately to response data from each quantitative question. For response data from questions with a binary yes/no or other two-level categorical answer scale (i.e., questions 1, 3, 8, 9, and 16; Supplementary material), the model assumed a Bernoulli distribution fitted with a canonical logit link function. For response data from questions evaluated on a five-point Likert scale (i.e., questions 2, 4, 5, 6, and 7; Supplementary material), the model assumed a multinomial distribution of the conditional response fitted with a cumulative logit link function so as to recognize the ordered categorical nature of the response. Finally, for response data from questions with nominal four-level answer scales (i.e., questions 12, 13, 14, and 15; Supplementary material), the model assumed a multinomial distribution and implemented a generalized logit link function. In all cases, the linear predictor for the model included the fixed effect of participant group. This fixed effect consisted of three levels defined by the combination of occupation and location, namely, vegetable vendors in Phnom Penh, vegetable growers in Siem Reap, and vegetable growers in Battambang. The data generation process did not support the inclusion of random effects in the linear predictor in any instance. All statistical models were fitted using maximum likelihood estimation as implemented by the LOGISTIC and GLIMMIX procedures of SAS® data analysis software (SAS Version 9.4, SAS Institute, Cary, NC).

Following model fitting, overdispersion was evaluated for questions with a binary answer scale using the maximum-likelihood based fit statistic Pearson Chi-Square/DF. No evidence for overdispersion was apparent for any of the questions modeled. For

models fitted to ordinal responses, the proportional odds assumption was checked using a chi-square test statistic. In the one case in which the proportional odds assumption was violated, analysis proceeded using a generalized logit link function as described for data from questions with nominal answer scales.

For each question, response probability estimates and corresponding 95% confidence intervals were calculated based on fitted models and were reported for each participant group. Wald-based type III tests were performed to assess differences in the probability of the response outcomes between participant groups. Relevant pairwise comparisons were then conducted using Tukey–Kramer adjustment to avoid inflation of the Type I error rate.

Participants who reported that they were familiar with the health effects of consuming vegetables contaminated with chemicals (question 8; Supplementary material) or microbes (question 9; Supplementary material) were subsequently asked to provide examples of such effects (questions 10 and 11; Supplementary material). Response data were evaluated for clarity and relevance. Responses containing examples of health impacts that were unlikely to occur as a result of consuming contaminated vegetables, exceedingly vague, or irrelevant were not considered commonly recognized health effects. The number of respondents in each group who provided at least one commonly recognized example (e.g., diarrhea, vomiting, etc.) of the health effects of consuming vegetables contaminated with microbes or chemicals was compared to the total number of respondents reporting familiarity with these health effects. When >50% of the respondents who provided at least one commonly recognized example also gave an example that was not considered a commonly recognized health effect, the number of respondents who gave a combination of commonly recognized and not commonly recognized examples was noted. In addition, the percentage of respondents in each group who gave at least one commonly recognized example of the health effects of consuming contaminated vegetables was calculated in order to provide insight into respondents' level of familiarity with such effects. The most frequent responses to these questions were then identified for each group. Responses that were given by three or more respondents in a participant group were also noted, but examples mentioned by only one or two respondents are not presented unless those examples were the most frequently given examples in that participant group.

The third free response question asked participants who indicated that they were employing chemical or microbial contamination prevention practices to describe these practices (question 17; see Supplementary material). Response data from this question were evaluated for clarity and relevance. Responses that were exceedingly vague or unrelated to food safety were not considered to represent commonly accepted contamination prevention practices. The number of respondents in each group who described at least one commonly accepted contamination prevention practice was compared to the number of respondents who stated that they employed practices to prevent contamination. The percentage of respondents in each group who described at least one commonly accepted contamination prevention practice was also determined in order to investigate the prevalence of commonly accepted food safety practices within each participant group. The various contamination prevention practices described by respondents were grouped by practice type and the most frequently mentioned practices or practice types in each participant group were identified and presented. Practices mentioned by three or more respondents were also specifically noted.

Results

Concern about vegetable safety

Overall, the estimated mean probability of respondents reporting concern (i.e., extreme, moderate, or slight concern; scale: extremely concerned, moderately concerned, slightly concerned, not at all concerned) about the safety of vegetables sold in Cambodia was 97.4% (95% CI = [89.7, 99.4]%), with no evidence for significant differences observed between group (growers, vendors)-specific estimates ($p = 0.76$). Among respondents reporting concern ($n = 98$), an estimated 62.7% [46.2, 76.7]%, 79.5 [66.7, 88.2]%, and 79.1 [63.7, 89.1]% of vendors in Phnom Penh, growers in Battambang, and growers in Siem Reap, respectively, indicated being either "extremely" or "moderately" concerned about the safety of vegetables in Cambodia (out of a range of answer choices that further included "somewhat concerned," "slightly concerned," and "not at all concerned"; Figure 1). There was no evidence of between-group differences in respondents' levels of concern regarding the safety of vegetables in Cambodia ($p = 0.12$). The mean estimated probability of respondents reporting that chemical contamination was of greater concern than microbial contamination was 84.9% [76.0, 90.9]% (data not shown). No evidence for significant differences in relative perceptions was apparent between groups ($p = 0.36$).

Perceived contamination frequency

The estimated cumulative probabilities of respondents reporting that domestically grown or imported vegetables are "always," "very often," "sometimes," "rarely" or "never" contaminated with chemicals for each participant group are presented in Figure 2. For domestically grown vegetables, no evidence for differences between participant groups was apparent with regards to perceived frequency of chemical contamination ($p = 0.24$). There was a fairly even distribution of responses between "always" and "rarely" in all participant groups (Figure 2A).

Meanwhile, perceptions of the frequency of chemical contamination on imported, rather than domestically grown, vegetables, differed significantly between participant groups ($p = 0.008$). Specifically, differences were observed between vendors in Phnom Penh and growers in Siem Reap ($p = 0.006$; Figure 2B). No evidence for differences was apparent between either of these groups and growers in Battambang ($p \geq 0.13$), however. Among vendors in Phnom Penh, the estimated probability of imported vegetables being perceived as "always" chemically contaminated was 46.0% [30.1, 62.6]%, while the same estimate was 85.9% [67.8, 94.6]% among growers in Siem Reap (Figure 2B). Among growers in Battambang, this estimate was 64.3% [49.0, 77.2]% (Figure 2B). Estimated probabilities of respondents reporting that imported vegetables were at least "very often" chemically contaminated followed a similar pattern, with cumulative probability estimates of 75.4% [59.5, 86.4] among vendors in Phnom Penh, 95.6% [87.2, 98.6]% among growers in Siem Reap, and 86.6% [75.3, 93.2]% among growers in Battambang (Figure 2B).

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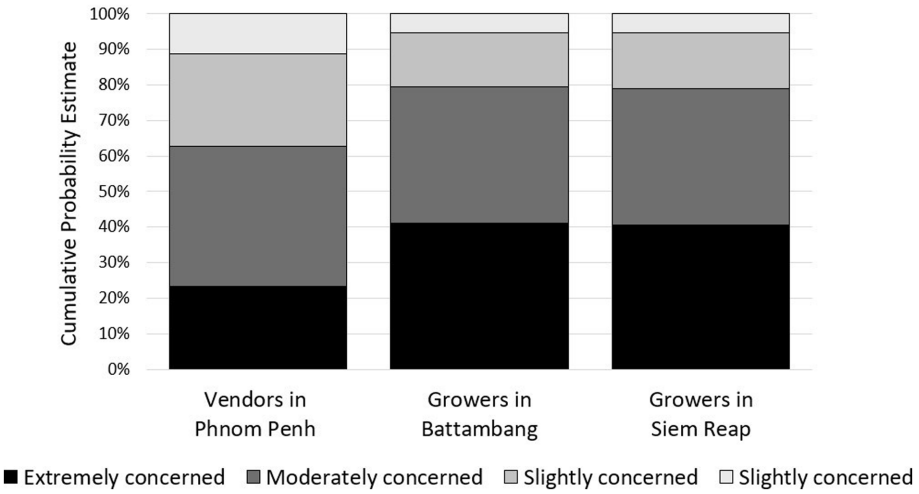

FIGURE 1
Assessment of the level of concern among Cambodian vegetable growers and vendors regarding the safety of vegetables consumed in Cambodia. Cumulative probability estimates for responses to the question "How concerned are you about the safety of vegetables sold in Cambodia?" amongst participants from each group that indicated concern. There was no evidence for differences in the ordinal distribution of responses across participant groups ($p = 0.12$).

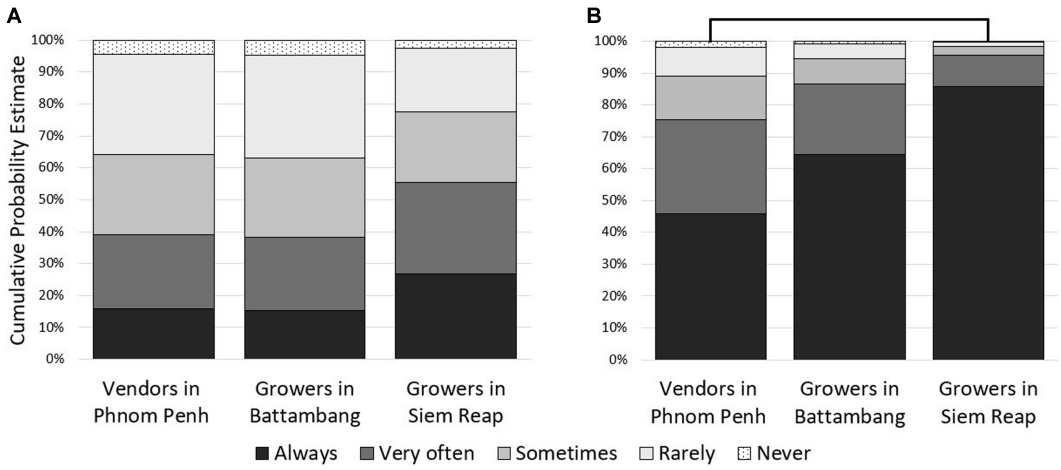

FIGURE 2
Perceptions among Cambodian vegetable growers and vendors regarding the level of chemical contamination of vegetables consumed in Cambodia. Cumulative probability estimates for responses to question **(A)** "Regarding chemical contamination, how often do you think vegetables **grown in Cambodia** are contaminated with chemicals?" and **(B)** "Regarding chemical contamination, how often do you think vegetables **imported to Cambodia from other countries** are contaminated with chemicals?" for each participant group. For question **(A)**, there was no evidence for differences in the ordinal distribution of responses across participant groups ($p = 0.24$). For question **(B)**, significant between-group differences ($p < 0.05$) in the ordinal distribution of responses were apparent. Significant differences have been indicated by a line connecting groups that significantly differ.

The estimated cumulative probabilities of respondents reporting the frequency of microbial contamination on domestically and internationally grown vegetables as "always," "very often," "sometimes," "rarely" or "never" for each participant group are presented found in Figure 3. Differences across participant groups were observed with regards to perceptions of the frequency of microbial contamination on domestically grown vegetables ($p = 0.004$). Specifically, the probability of growers in Siem Reap perceiving that domestically grown vegetables were "always" contaminated with microbes (42.9% [24.5, 61.2]) was significantly higher than said probability for both vendors in Phnom Penh (3.2% [0.0, 9.4]%; $p = 0.004$) and growers in Battambang (4.9% [0.0, 11.5]%; $p = 0.004$; Figure 3A). No evidence for significant between-group differences in probability estimates for the remaining response choices (i.e., "very often," "sometimes," "rarely," and "never") was observed, however ($p \geq 0.12$ in all cases; Figure 3A).

When participants were asked about microbial contamination on imported vegetables, differences in perceived frequency were observed between growers in Siem Reap and each of the two other groups, namely vendors in Phnom Penh ($p < 0.001$) and growers in Battambang ($p = 0.01$) (Figure 3B). Growers in Siem Reap had an 88.2% [75.8, 94.7]% estimated cumulative probability of perceiving

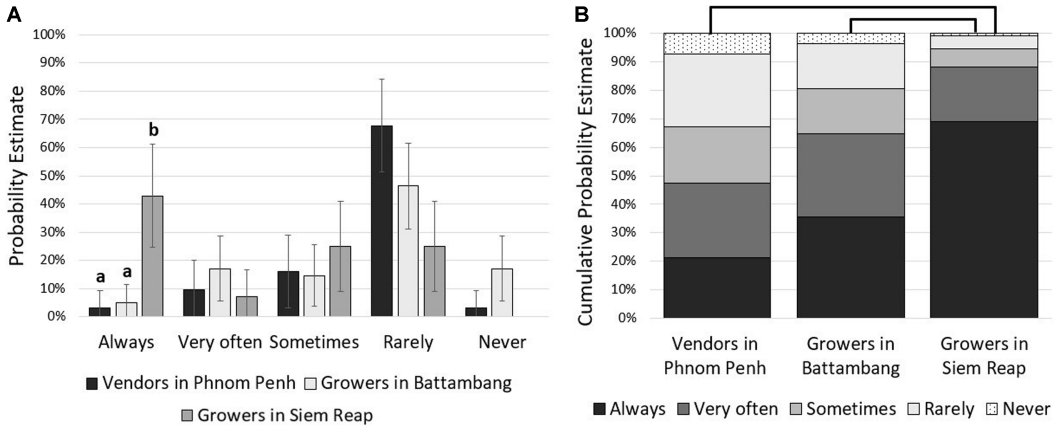

FIGURE 3
Perceptions among Cambodian vegetable growers and vendors regarding the level of microbial contamination of vegetables consumed in Cambodia. Cumulative probability estimates for responses to question **(A)** "Regarding microbial contamination, how often do you think vegetables **grown in Cambodia** are contaminated with microbes?" and question **(B)** "Regarding microbial contamination, how often do you think vegetables **imported to Cambodia from other countries** are contaminated with microbes?" for each participant group. Significant between-group differences were apparent for question **(A)**, as indicated by different letters **(A,B)**. Significant between-group differences ($p < 0.05$) in the ordinal distribution of responses to question **(B)** were apparent. Significant differences have been indicated by lines connecting groups that significantly differ.

imported vegetables as at least "very often" contaminated with microbes; this estimate was 64.9% [50.3, 77.2]% for vendors in Phnom Penh and 47.4% [31.8, 63.5]%) for growers in Battambang (Figure 3B). Perceptions of imported vegetables as either "rarely" or "never" contaminated with microbes were minimal among growers in Siem Reap, but non-negligible among vendors in Phnom Penh and growers in Battambang (Figure 3B).

Perceptions of the potential health effects of contamination

No evidence for group differences in reported familiarity with the health effects associated with consuming vegetables contaminated with chemicals ($p = 0.86$) or microbes ($p = 0.60$) was observed. For chemical contamination, the mean estimated probability of respondents reporting familiarity with such health effects was 71.4% [61.5, 79.6]% across occupations and locations. Meanwhile, the overall probability of respondents reporting familiarity with the health impacts of consuming microbially contaminated vegetables was estimated at 57.3% [47.2, 66.9]%.

In order to further investigate respondents' familiarity with the health effects of consuming contaminated vegetables, respondents who reported that they were familiar with these health effects were subsequently asked to provide examples of such effects. Of the vendors in Phnom Penh who reported familiarity with the impacts of chemical contamination ($n = 23$), 15 gave at least one commonly recognized example (e.g., vomiting, diarrhea, cancer, chronic disease, and gastrointestinal problems) of the health effects of consuming chemically contaminated vegetables. To note, however, nine of these vendors also gave examples that were vague or otherwise not considered as commonly recognized health effects (e.g., itchiness, poisoning, headache). Vomiting (mentioned by six respondents) and diarrhea (mentioned by five respondents) were most commonly cited as potential health effects of consuming chemically contaminated vegetables among vendors in Phnom Penh. Three or more vendors mentioned cancer, headache, or poisoning as examples of the potential health effects of consuming chemically contaminated vegetables. Of the 20 vendors indicating familiarity with the health effects of consuming microbially contaminated vegetables, 11 provided at least one commonly recognized example (e.g., diarrhea, vomiting, chronic disease, and fever) of the health effects of consuming vegetables contaminated with microbes. In this group, diarrhea (mentioned by nine respondents) was the most commonly given example of a potential health effect of consuming microbially contaminated vegetables. Taken together, these results indicate that 15 of the 31 vendors surveyed in Phnom Penh (48.4%) provided at least one commonly recognized example of the health effects of consuming chemically contaminated vegetables, while 11 of these 31 vendors (35.5%) gave at least one commonly recognized example of the health effects of consuming microbially contaminated vegetables.

Among growers in Battambang who indicated that they were familiar with the health effects of consuming chemically contaminated vegetables ($n = 28$), six gave at least one example of a commonly recognized health effect of consuming chemically contaminated vegetables. Diarrhea and headache (both mentioned by four respondents) were the two most common examples of potential health impacts of consuming vegetables contaminated with chemicals. In addition, three growers mentioned either nonspecific negative health effects or illness as an example of a potential health impact of chemical contamination. Of those growers in Battambang who reported familiarity with the health impacts of consuming microbially contaminated vegetables ($n = 22$), three provided at least one example of a commonly recognized health effect of the consuming of microbially contaminated vegetables. Diarrhea, vomiting, headache, and skin reactions were all mentioned twice as examples of potential health impacts of consuming microbially contaminated vegetables (to note, headache and skin reactions were not considered examples of commonly recognized health impacts of

consuming microbially contaminated vegetables). Overall, six of the 41 growers surveyed in Battambang (14.6%) provided at least one example of a commonly recognized health effect of consuming vegetables contaminated with chemicals, and three of these 41 growers (7.3%) provided at least one example of a commonly recognized health effect of consuming vegetables contaminated with microbes.

Of the 20 growers in Siem Reap who perceived themselves as familiar with the health impacts of the consumption of vegetables contaminated with chemicals, eight gave at least one example of a commonly recognized health effect of consuming chemically contaminated vegetables. However, five of these eight growers also gave examples that were not considered to be commonly recognized health effects (e.g., nonspecific negative health effects or illness, fatigue, and headache). Growers in Siem Reap most commonly cited diarrhea, headache, or nonspecific negative health effects or illness (mentioned by three respondents each) as examples of potential health impacts of consuming chemically contaminated vegetables. Among those growers in Siem Reap who indicated familiarity with the health effects of consuming vegetables contaminated with microbes ($n = 15$), four provided at least one example of a commonly recognized effect. Diarrhea (mentioned by four respondents) was the most commonly cited example of a health effect of consuming microbially contaminated vegetables. Considered as a whole, these results indicate that eight of the 28 growers surveyed in Siem Reap (28.6%) provided at least one commonly recognized example of the health impacts of consuming chemically contaminated vegetables, while four of these 28 growers (14.3%) provided at least one example of a commonly recognized health impact of consuming microbially contaminated vegetables.

Perceived primary source of contamination

Estimated probabilities (and corresponding 95% confidence intervals) for respondent perceptions of the primary source of chemical and microbial contamination of vegetables for each participant group are presented in Figure 4. When asked whether chemical contamination primarily occurs "at the farm," "during transportation from farm to market," "at the market," or "during food preparation," most respondents, regardless of occupation and location ($p = 0.84$), indicated that chemical contamination occurs primarily "at the farm." The estimated probability of this response was 76.7% [61.5, 91.8]% for vendors in Phnom Penh, 77.5% [64.6, 90.4]% for growers in Battambang, and 78.6% [63.4, 93.8]% for growers in Siem Reap. Probability estimates for the remaining responses were small ($\leq$ 16.7%, with upper bounds of corresponding 95% confidence intervals at most 30.0%) in all cases (Figure 4A).

Respondents were also asked to identify the step in the vegetable value chain at which they perceived most microbial contamination to occur. Across all groups, respondents most frequently perceived that microbial contamination primarily occurs "at the farm," with probability estimates of 39.3% [21.2, 57.4]%, 42.5% [27.2, 57.8]%, and 57.1 [38.8, 75.5]% for this response among vendors in Phnom Penh, growers in Battambang, and growers in Siem Reap, respectively (Figure 4B). Probability estimates for the responses "during transportation from farm to market," "at the market," and "during food preparation" were less than or equal to 25.0% across all participant groups, with upper bounds of corresponding 95% confidence intervals at most 41.0% (Figure 4B). To note, there was no evidence for significant differences between participant groups with regards to perceptions of the primary source of microbial contamination ($p = 0.67$).

Perceived responsibility for contamination prevention

For each participant group, estimated probabilities (corresponding 95% confidence intervals) for respondent perceptions of which vegetable value chain actor (i.e., "vegetable farmers," "vegetable transporters," "vegetable marketers," or "food preparers") has primary responsibility for preventing chemical and microbial contamination of vegetables are presented in Figure 5. When respondents were asked to identify which vegetable value chain actor they perceived as most responsible for preventing chemical contamination of vegetables, no evidence for between-group differences was apparent in their responses ($p = 0.20$). Across all groups, "vegetable farmers" were most frequently perceived as having primary responsibility for preventing chemical contamination, with probability estimates of 51.6% [34.0, 69.2]%, 60.0 [44.8, 75.2]%, and 62.3 [44.8, 81.2]% for this response among vendors in Phnom Penh, growers in Battambang, and growers in Siem Reap, respectively (Figure 5A). "Vegetable transporters," "vegetable marketers," and "food preparers" were perceived as most responsible for chemical contamination prevention somewhat less frequently, with probabilities of these responses estimated at 12.9% [1.1, 24.7]%, 3.2 [0.0, 9.4]%, and 32.3 [15.8, 48.7]% for vendors in Phnom Penh, 5.0% [0.0, 11.8]%, 15.0 [3.9, 26.1]%, and 20.0 [7.6, 32.4]% for growers in Battambang, and 7.4% [0.0, 17.3]%, 22.2 [6.5, 37.9]%, and 7.4 [0.0, 17.3]% for growers in Siem Reap, respectively (Figure 5A).

Respondents' perceptions of which actor in the vegetable value chain was most responsible for preventing vegetables from becoming microbially contaminated were found to significantly differ across participant groups ($p = 0.02$). Specifically, vendors in Phnom Penh were estimated to have a significantly lower probability (17.2% [3.5, 31.0]%) of perceiving "vegetable farmers" as primarily responsible for preventing microbial contamination compared to growers in both Battambang ($p = 0.008$, 53.9% [38.2, 69.5]%) and Siem Reap ($p = 0.002$, 55.6% [36.8, 74.3]%) (Figure 5B). Conversely, vendors in Phnom Penh had a significantly higher probability of perceiving "food preparers" as most responsible for microbial contamination prevention compared to growers in either Battambang ($p = 0.008$) or Siem Reap ($p = 0.002$), with probability estimates at 58.6% [40.7, 76.6]%, 28.2 [14.1, 42.3]%, and 14.8 [1.4, 28.2]%, respectively (Figure 5B). There was no evidence for significant differences in the estimated probabilities of "vegetable transporters" or "vegetable marketers" being perceived as primarily responsible for preventing microbial contamination of vegetables across participant groups ($p \geq 0.08$ in all cases); probability estimates for these responses were $\leq$ 14.8% in all groups, with upper bounds of corresponding 95% confidence intervals 28.2% at most (Figure 5B).

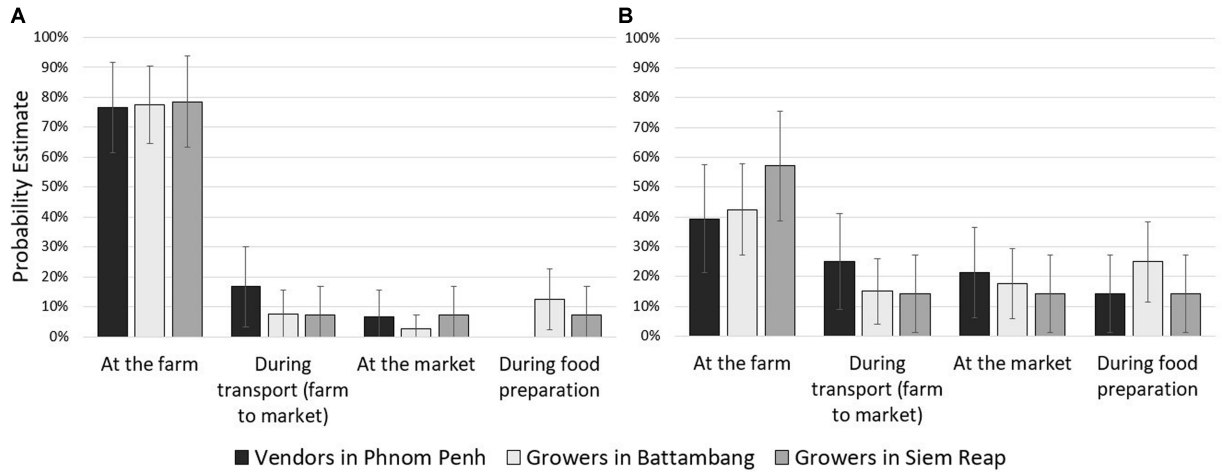

FIGURE 4
Perceptions among Cambodian vegetable growers and vendors regarding the sources of contamination in vegetables consumed in Cambodia. Probability estimates (and corresponding 95% confidence intervals) for responses to question **(A)** "When considering the different steps in vegetable production from the farm to the consumer, where do you think most **chemical** contamination of vegetables occurs?" and **(B)** "When considering the different steps in vegetable production from the farm to the consumer, where do you think most **microbial** contamination of vegetables occurs?" for each participant group. There was no evidence for differences between participant groups in the distribution of responses for either question **(A)** ($p = 0.84$) or question **(B)** ($p = 0.67$).

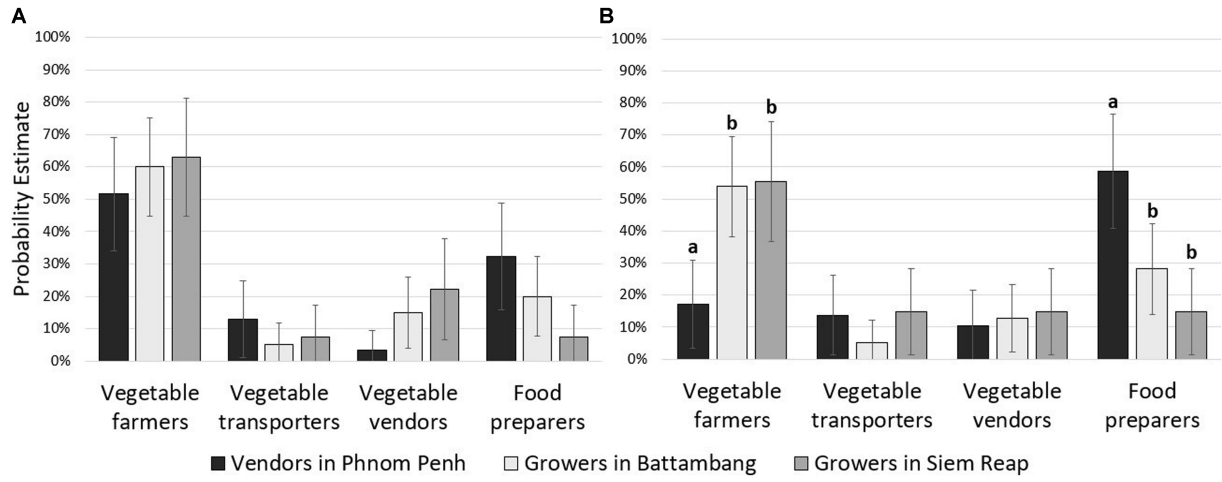

FIGURE 5
Perceptions among Cambodian vegetable growers and vendors regarding the responsibility for preventing contamination of vegetables consumed in Cambodia. Probability estimates (and corresponding 95% confidence intervals) for responses to question **(A)** "Thinking about the different steps of vegetable production from the farm to the consumer that we talked about earlier, who do you think has the most responsibility for preventing **chemical** contamination of vegetables?" and **(B)** "Thinking about the different steps of vegetable production from the farm to the consumer that we talked about earlier, who do you think has the most responsibility for preventing **microbial** contamination of vegetables?" for each participant group. For question **(A)**, there was no evidence for differences between participant groups in the distribution of responses ($p = 0.20$). For question **(B)**, significant between-group differences in probability estimates for individual response categories are indicated by different letters **(A,B)**.

Current contamination prevention practices

In addition to being asked about who had the primary responsibility for contamination prevention, respondents were also asked whether or not they themselves were doing anything to prevent vegetables from becoming contaminated with chemicals or microbes. The majority of growers in Battambang and Siem Reap indicated that they were taking steps to prevent contamination, with a 75.6% [60.1, 86.5]% and 75.0 [55.8, 87.7]% probability of a "yes" response to this question, respectively, in these groups ($p > 0.99$). However, vendors in Phnom Penh had a significantly lower estimated probability (35.5% [20.7, 53.7]%) of reporting that they performed practices intended to prevent contamination in comparison to both growers in Battambang ($p = 0.004$) and growers in Siem Reap ($p = 0.01$).

When vendors in Phnom Penh were asked to describe the practices that they were employing to prevent vegetables from

becoming contaminated with chemicals or microbes, seven of the 11 vendors in Phnom Penh who had previously reported employing such a practice clearly described at least one commonly accepted contamination prevention practice. All seven of these vendors indicated that they washed their vegetables, with six vendors mentioning washing their vegetables with water specifically. Among growers in Battambang who indicated that they were implementing practices to prevent chemical or microbial contamination ($n = 31$), 16 growers clearly described at least one commonly accepted contamination prevention practice. In this group, practices involving decreasing or eliminating pesticide use were the most commonly described practices that were considered commonly accepted contamination prevention practices (mentioned by six growers), though washing was the most frequently cited practice overall (mentioned by seven growers). In addition, three to four growers in Battambang gave responses involving knowledge gathering strategies, decreasing or eliminating chemical use, or using natural pesticides. Of the growers in Siem Reap who reported that they were employing practices to prevent chemical or microbial contamination ($n = 21$), 15 described at least one commonly accepted contamination prevention practice. Responses describing the use of natural or organic pesticides were the most common responses given by growers in Siem Reap (mentioned by eight growers). Other common responses involved decreasing or limiting pesticide use (mentioned by five growers) and variations of "washing" (mentioned by three growers). Taken together, these results indicate that seven of the 31 surveyed vendors in Phnom Penh (22.6%), 16 of the 41 surveyed growers in Battambang (39.0%), and 15 of the 28 surveyed growers in Siem Reap (53.6%) described at least one commonly accepted contamination prevention practice. To note, there was no group in which >50% of the respondents who described at least one commonly accepted contamination prevention practice also described a practice that is not commonly accepted as a contamination prevention practice. For this reason, the number of respondents who described a combination of commonly accepted and not commonly accepted practices has not been presented here.

Discussion

The aim of this study was to measure perceptions of food safety among vegetable vendors and vegetable growers involved in informal vegetable markets in Battambang, Siem Reap, and Phnom Penh in order to inform future food safety programs in Cambodia. The findings presented here provide a basis for understanding food safety perceptions among these audiences, thereby addressing a substantial gap in knowledge regarding Cambodians' perceptions of food safety. In turn, these results provide food safety program designers with information that can enable them to more effectively tailor food safety programs to specific Cambodian audiences and promote the adoption of positive food safety practices.

The existing body of literature on food safety perceptions in Cambodia is limited, being primarily composed of research and reports regarding common food safety concerns (Consumers International, 2013), the perceived consequences of unsafe foods and perceived barriers to consuming safe foods (Roesel et al., 2018), perceptions of the presence of arsenic in rice (Pravalprukskul et al., 2018), drivers of vegetable risk perceptions (Nguyen et al., 2020), the perceived health effects of pesticide contamination (Bureau-Point, 2021), perceived access to safe, high quality foods (Duong et al., 2021), and general perceptions of food safety and nutrition among particular Cambodian audiences (Brown et al., 2022). Only one study that we are aware of has included participants from the Province of Battambang (Bureau-Point, 2021). In addition, previous research on food safety perceptions in Cambodia has typically focused on assessing the perceptions of Cambodians in their role as consumers (Consumers International, 2013; Nguyen et al., 2020; Duong et al., 2021; Brown et al., 2022) to our knowledge, no study has focused solely or primarily on perceptions of food safety among any of the other actors involved in informal vegetable markets in Cambodia. Many prior studies have also either chosen not to distinguish between chemical and microbial food safety concerns (Roesel et al., 2018) or have focused exclusively on participants' perceptions of chemical contamination (Consumers International, 2013; Pravalprukskul et al., 2018; Bureau-Point, 2021; Duong et al., 2021).

The findings of this research address several of the limitations of previous work and suggest that food safety program designers have ample opportunity to increase the implementation of food safety practices among actors in the informal vegetable value chain in Cambodia, as only 22.6% of the vendors interviewed in Phnom Penh, 39.0% of growers interviewed in Battambang, and 53.6% of growers interviewed in Siem Reap reported implementing even one commonly accepted contamination prevention practice. In particular, there seems to be substantial opportunity for increased adoption of microbial contamination prevention practices, as evidenced by a scarcity of responses describing practices related to microbial contamination prevention. Encouragingly, many respondents reported being moderately or extremely concerned about the safety of vegetables sold in Cambodia, suggesting that, in general, vegetable safety is recognized as an important issue by those positioned to improve it. However, in alignment with previous research (Consumers International, 2013; Ebner et al., 2020; Brown et al., 2022), respondents were 84% likely to be more concerned with chemical contamination vs. microbial contamination of vegetables. This prioritization of chemical contamination over and above microbial contamination suggests that future food safety programs may need to include an emphasis on the significance of microbial contamination for food safety, particularly with regards to the severity of the health impacts that result from consuming vegetables contaminated with microbial pathogens. Food safety programs for vendors in Phnom Penh and growers in Battambang may especially benefit from an emphasis on the importance of microbial contamination, as respondents in these groups perceived vegetables as being less often contaminated with microbes than did growers in Siem Reap. Conversely, program designers targeting growers in Siem Reap may be able to draw on the existing perception within this group that vegetables in Cambodia are frequently contaminated with chemicals or microbes, using this perception as support for both the importance of microbial contamination and, more generally, of implementing effective food safety practices.

Program designers should also consider that only a small percentage of vegetable vendors in Phnom Penh identified "vegetable marketers" (i.e., vegetable vendors) as having the primary responsibility for preventing either chemical or microbial

contamination of vegetables. The vendors' response in this case was significantly different from the response of growers. The difference in responses could be due to location (all vendors were located in the capital, Phnom Penh), previous exposure of either vendors or growers to food safety programs, or as of yet unknown reasons. Regardless, while it is possible that, given the opportunity, vegetable vendors would have indicated that all actors in the vegetable supply chain had equal responsibility for contamination prevention, food safety programs for this group may need to highlight the importance of the role of vegetable vendors in ensuring the safety of vegetables in Cambodia. As the majority of growers in Battambang and Siem Reap perceived "vegetable farmers" as primarily responsible for preventing vegetable contamination, food safety programs that explain how the adoption of food safety practices can allow growers to fulfill this perceived responsibility may effectively encourage the adoption of such practices among these audiences. Such programs must also consider growers' capacity for implementing new food safety practices, however, as it is possible that growers are motivated to change but lack, or perceive that they lack, the resources or knowledge to do so. Additionally, while growers in Siem Reap and Battambang most often identified "vegetable farmers" as principally responsible for preventing contamination, further research is needed to investigate whether growers are identifying themselves as most responsible for contamination prevention or if they are identifying other growers as principally responsible for contamination prevention. Similarly, research exploring whether growers in Siem Reap and Battambang perceive their own farms or other growers' farms as the primary location of contamination is needed.

The majority of respondents in all groups reported being familiar with the health effects of consuming chemically contaminated vegetables, and many respondents indicated familiarity with the health effects of consuming microbially contaminated vegetables. However, regardless of contamination type, less than half of the respondents in each participant group had enough familiarity to be able to articulate at least one commonly recognized example of such effects. Additionally, participants' responses seemed narrow in scope and did not reflect the full spectrum of the potential health impacts of consuming chemically or microbially contaminated vegetables. More severe, yet commonly understood, health outcomes (e.g., severe malnutrition, organ failure, death, etc.) were either not mentioned often or were not mentioned at all (Bhunia, 2018). These low levels of familiarity and the limited scope of participants' responses indicate respondents may not recognize food safety as a pressing problem and, thus, may be less likely to undertake efforts to address the problem. As such, program designers should integrate educational components to clearly articulate the array of negative health effects associated with the consumption of contaminated vegetables into food safety programs. Additionally, the dischord in perceptions as to who has the most responsibility to improving food safety may indicate that respondents are not clear as to how food safety can be improved. As such, food safety education programs should also promote food safety practices that are both adoptable and effective in the Cambodian informal vegetable market context.

The findings of this study are primarily meant to inform the design and implementation of food safety programs for vegetable growers and sellers involved in informal vegetable markets in Battambang, Siem Reap, and Phnom Penh. Several findings that were consistent across all three groups, namely the perception of chemical contamination as a greater concern than microbial contamination and low levels of familiarity with the health effects of consuming contaminated vegetables, may also serve to inform programs across a wider context. Program designers working with vegetable growers and sellers involved in informal markets in other provinces, for instance, may also find these results useful. Generalizing about Cambodians' perceptions of food safety should be done with caution, however, as the differences observed across the three participant groups included in this research indicate that food safety perceptions can be context specific.

Data availability statement

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

Ethics statement

The studies involving human participants were reviewed and approved by the Institutional Review Board of Purdue University (IRB-2020-383; West Lafayette, IN) and the Royal University of Agriculture (Phnom Penh, Cambodia). The patients/participants provided their written informed consent to participate in this study.

Author contributions

SM: responsible for questionnaire design, testing, revision, data analysis, and manuscript preparation. KO: responsible for questionnaire design, testing, revision, and data collection. NB: responsible for data analysis and manuscript preparation. MC: responsible for questionnaire design, testing, revision, and data collection. LT: responsible for questionnaire design, testing, and revision. JV: responsible for experimental design and manuscript preparation. LH: responsible for experimental design and manuscript preparation. PE: responsible for experimental design, questionnaire design, testing, revision, data analysis, and manuscript preparation. All authors contributed to the article and approved the submitted version.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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Supplementary material

The Supplementary material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fsufs.2023.1111580/full#supplementary-material

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