Food safety risks in traditional fermented food from South-East Asia

Anil Kumar Anal, Giorgia Perpetuini, Awanwee Petchkongkaew, Reasmey Phary Tan, Sylvie Avallone, Rosanna Tofalo, Hai Van Nguyen, Son Chu-Ky, Phu Ha Ho, Thanh Tam Phan, et al.

Food safety risks in traditional fermented food from South-East Asia

Anil Kumar Anal[1,2], Giorgia Perpetuini[2,3,4], Awanwee Petchkongkaew[2,5], Reasmey Tan[2,6], Sylvie Avallone[7], Rosanna Tofalo[4], Hai Van Nguyen[2,8], Son Chu-Ky[2,8], Phu Ha Ho[2,8], Thanh Tam Phan[2,8], Yves Waché[2,3]

[1]Department of Food Agriculture and Bioresources, School of Environment, Resources and Development, Asian Institute of Technology, PO Box 4; Klong Luang 12120, Thailand

[2]Tropical Fermentation Network

[3]International Joint Laboratory « Tropical Bioresources & Biotechnology » (Univ. Bourgogne Franche-Comté, AgroSup Dijon, PAM UMR A 02.102 and School of Biotechnology and Food Technology, Hanoi University of Science and Technology), Dijon France

[4] Faculty of BioScience and Technology for Food, Agriculture and Environment, University of Teramo, Via R. Balzarini 1, 64100, Teramo, Italy

[5]School of Food Science and Technology, Faculty of Science and Technology, Thammasat University, 12120, Thailand

[6]Food Technology and Nutrition Research Unit, Research and Innovation Center, Institute of Technology of Cambodia, Russian Federation Blvd., P.O. Box 86, 12156 Phnom Penh, Cambodia

[7]QualiSud, Univ Montpellier, CIRAD, Montpellier SupAgro, Université d'Avignon, Université de la Réunion, Montpellier, France.

[8]International Joint Laboratory « Tropical Bioresources & Biotechnology » (Univ. Bourgogne Franche-Comté, AgroSup Dijon, PAM UMR A 02.102 and School of Biotechnology and Food Technology, Hanoi University of Science and Technology), Hanoi, Vietnam

Abstract

South-East Asia is well-known for traditionally fermented foods. However, these products are generally still produced at small scale following traditional procedures. Nowadays, consumers are particularly aware of the health concerns regarding food additives; the health benefits of "natural" and "traditional" foods, processed with no added chemical preservatives, are becoming more and more attractive. Therefore, their confidence towards safety and quality of Asian fermented foods is low. Major food safety concerns are related not only to food production methods, but also to how foods are processed, stored, sold and consumed. In this review the main factors affecting food safety are analysed. They are not limited only to the improper use of chemicals such as pesticides or antibiotics, but also to improper processing and handling during storage which could provoke the accumulation of toxic compounds such as mycotoxins or biogenic amines. Urgent attention is required to improve the quality of the ingredients and the integration of food safety management systems for industrial growth. Therefore, in the last part of this review directions to improve the food safety of fermented foods are proposed.

Keywords: fermented foods, South-East Asia, food safety

1. Introduction

In South-East Asia, the economic and demographic developments together with the migration of the population to urban areas resulted in many changes in the organisation of the food production system. This increased the consumer concern about food safety (Ha, Shakur, & Pham Do, 2019). However, the level of concern is not only coming from an undefined perception of this change but it follows also several outbreaks that occurred in the recent years. Drivers of food safety unconformity have been analysed (Kendall, Kaptan, Stewart, Grainger, Kuznesof, Naughton, et al., 2018). They have multiple origins among them the lack of resources, the economic pressure, the structuration, the training and the will. As confirmed by the achievement of the Asifood Erasmus+ project (Anal, Waché, Louzier, Roy, Mens, Avalllone et al. submitted), the demand of actors of the field for food safety is huge. Among the various food products concerned, the case of traditional fermented food is special as these foods are usually produced at small scale, very popular and considered as delicacies in Asia but also, often as risky (Sarter, Ho, & To, 2014). Taking into account the classification proposed by Steinkraus (Steinkraus, 1997), popular fermented food in continental South-East Asia (Valyasevi & Rolle, 2002; Vu & Nguyen, 2016) are belonging to the (i) High salt/meat-flavored amino acid/peptide sauce (various fish sauces or pastes like nuoc mam, prahok, pla ra, soy sauces like Tuong), (ii) Lactic acid fermentations (vegetable leaves, bamboo, onions, fermented meat that can be uncooked (Nem chua, nahm), fish, shrimp), (iii) alcoholic fermentation (rice wine), (iv) acetic fermentation (rice vinegar), (v) alkaline fermentation of soy (thua-nao). With the general economic idea of decreasing the risks and increasing the scale of production, these products could be the victim of a food diversity extinction. However, other economic models exist like in Europe where small-scale fermented foods are considered as a way to increase typicity and bring value-added.

The goal of this review is to evaluate the dangers and risks to which traditional fermented food are exposed in South-East Asia. Recent studies, from 2007 to 2019, concerning the detection of pathogens and chemical contaminants in some of the most risky products are reported. From these results, directions to improve the food safety of fermented foods in Vietnam, Cambodia and Thailand will be proposed.

2. Contamination of raw or fermented products with pathogenic bacteria

In South-East Asia, and in particular in Vietnam, consumers' confidence towards fermented products is low, especially because of the microbial safety risks of the raw material such as meat and vegetable (Sarter, Ho, & To, 2014).

One of the riskiest traditional fermented meat products is an uncooked pork sausage eaten after a short lactic fermentation. It is called *nem chua* in Vietnam, *nahm* in Thailand and *nem chrouk* in Cambodia. To elaborate this product, pork is bought in the wet market or supermarket and then the minced meat is mixed with herbs and spices such as garlic, guava leaf, fresh chili, etc. The finish products are packed into banana leaves to provide an anaerobic environment for the fermentation process and to inhibit entry of potentially pathogenic microorganisms. The products are stored at room temperature for spontaneous fermentation for several days.

The highest risk of *nem chua* is related to meat since this fermented sausage is uncooked and unheated. In pork raw meat from South-East Asia, *Escherichia coli*, *Salmonella, Campylobacter, Listeria monocytogenes* and *Staphylococcus aureus* are the main food-borne pathogens and they are frequently found in intestinal tract and faeces of food animals (Dao & Yen, 2006) (Nguyen Thi Nhung, Van, Cuong, Duong, Nhat, Hang, et al., 2018) (Ananchaipattana, Hosotani, Kawasaki, Pongsawat, Md.Latiful, Isobe, et al., 2012; Carrique-Mas, Bryant, Cuong, Hoang, Campbell, Hoang, et al., 2014; Dang-Xuan, Nguyen-Viet, Unger, Pham-Duc, Grace, Tran-Thi, et al., 2017; T. N. M. Nguyen, Hotzel, El-Adawy, Tran, Le, Tomaso, et al., 2016; Takeshi, Itoh, Hosono, Kono, Tin, Vinh, et al., 2009; Toan, Nguyen-Viet, & Huong, 2013). These bacteria as well as antibiotic resistance genes can be horizontally transferred to human through direct and indirect contacts with the source of infection which can be animals or contaminated foods. In raw food, in the examples given in Table 1, these bacteria are found with at least 10% probability of contamination. The probability could rise up to 83% depending on the species, the raw food, and the origin of the sample.

In fermented meat, the contamination is still very high in the examples presented in Table 1 and they even reach 100% in the neighboring regions of India (Keisam, Tuikhar, Ahmed, & Jeyaram, 2019) although in one study not presenting whether fermented meat was cooked or not, contaminations ranged from 0 to 19% (Ananchaipattana, et al., 2012). A study focusing on *Salmonella* in the food chain and in nem chua confirmed through serovar analysis and genotyping that contamination of the raw meat was usually responsible for contamination of the fermented product (Le Bas, Hanh, Thành, Cuong, Quang, Binh, et al., 2008). The microbial safety of *nem chua* in Vietnam has been discussed in several studies ((Phan, Pham et al. 2006; Nguyen et al., 2010; 2013 ; Le, Do et al. 2012). Indeed, the concentration of *E. coli* and *S. aureus* in raw meat for preparing *nem chua* was 10-100 and 100-1000 fold higher than the National Vietnamese Standard (TCVN 7046:2002 for fresh meat), respectively. Consequently, the final products *nem chua* could not meet the requirement for hygiene and safety standard (TCVN 7050:2002 for unheated fermented products) (Le, Do, Le, Tran, & Van, 2012; Phan, Pham, & Hoang, 2006). However, cases of illness in human beings due to the consumption of *nem chua* have beeen rarely reported in Vietnam. Several explanations can contribute to this fact, including small scale production combined with incomplete epidemiological data, as well as the presence of a number of lactic acid bacteria (LAB) present in the final product. These LAB and their metabolites can produce organic acid and bacteriocins able to inhibit the growth of pathogenic microorganisms. The LAB of 30 samples of *nem chua* were isolated and the presence of *Lactobacillus plantarum* (prevalence of 67.6%), *Pediococcus pentosaceus* (21.6%), *Lactobacillus brevis* (9.5%) and *Lactobacillus farciminis* (1.3%) was reported (Tran, May, Smooker, Van, & Coloe, 2011). *L. plantarum* was also reported as the most prevalent in meat and legume fermentation products (La Anh, 2015; D. T. L. Nguyen, Van Hoorde, Cnockaert, De Brandt, Aerts, & Vandamme, 2013). Some authors investigated thus the antibacterial properties of some *L. plantarum* strains isolated from fermented food. *L. plantarum* B33 isolated from *nem chua* could inhibit food-borne bacteria including *E. coli* NC31, *E. coli* K12TG1, *E. coli* 320 LCB, *S. aureus, S.* Typhimurium with a zone of inhibition ranging from 4-14 mm (Lê, Hồ, Trần, Chu, Lê, Lê, et al., 2011). Recently, the bacteriocins produced by other LAB isolated from *nem chua* were characterized (Pilasombut, Rumjuankiat, Ngamyeesoon, & Duy, 2015). It was shown that *L. plantarum* KL-1 could produce a bacteriocin inhibiting the growth of pathogens and of some LAB such as *Lactobacillus sakei, Leuconostoc mesenteroides* and *Enterococcus faecalis*. Additionally, 47% LAB isolates from *nem chua* exhibited strong antimicrobial activity against moulds from the same products and *L. plantarum* and *P. pentosaceus* showed the best antifungal activities (Phong, Van, Thanh, Long, & Dung, 2016). These strains could thus be useful as backslop and/or starter cultures.

Vegetables can also be the source of microbiological contamination (Ha et al., 2019). In South-East Asia, there are different kinds of fermented vegetables including cucumbers, mustard greens, young melons, cabbages, chinese cabbages, papayas, bamboo shoots, and bean sprouts with Asian spider flower. They are usually produced in small-scale using mostly spontaneous fermentation and sometime back-slopping fermentation. The production of fermented foods and beverages through spontaneous fermentation and back-slopping represents an inexpensive and reliable preservation method in less developed countries (Owens, 2014). Most of the sellers of these fermented vegetables are producers and these products are usually sold in the local markets in open containers. The results of two studies carried out in Phnom Penh wet markets are reported in Table 1.

In these studies, the microbiological quality of fermented vegetables sold in Phnom Penh markets was investigated, showing a correlation between microbial contamination and hygienic conditions (quality and material of container, use of hands, hands with gloves, the same rice paddle for all the products, open containers, etc…). The authors supposed that the lack of hygienic precautions and bad cultural practices could be extended upward to the production of vegetables (González García, Fernández-López, Polesel, & Trapp, 2019).

This paragraph deals with pathogen bacteria but it should be noted that another source of disease has been characterized in Thai fermentd fish. Indeed, liver fluke in its development cycle is ingested by fishes that, if eaten without cooking, can inoculate the disease in human consumers (Sriraj, Boonmars, Aukkanimart, Songsri, Sripan, Ratanasuwan, et al., 2016). It is particularly dangerous as liver fluke can be a factor of development of cholangiocarcinoma, especially when it is linked to high concentrations of nitrosamine (Mitacek, Brunnemann, Suttajit, Martin, Limsila, Ohshima, et al., 1999). However, it can be noted that the level of such cancers is not higher in North-East Thailand, the region where this fermented fish is produced and consumed.

3. Toxin or toxic compounds producing microorganisms

3.1 Mycotoxin risks

Mycotoxins are toxic secondary fungal metabolites mainly produced by five genera of filamentous fungi i.e. *Alternaria, Aspergillus*, *Cladosporium, Fusarium* and *Penicillium*. These molds can produce different types of mycotoxins, among them, some are unique to one species, but most can be produced by several fungi (Bräse et al., 2009). FAO reported that 25% of the world's crops are affected by mold or fungal growth with losses of around 1 billion metric tons of food products annually. Economic losses occur because of: 1) yield loss due to diseases induced by toxigenic fungi; 2) reduced crop value resulting from mycotoxin contamination; 3) losses in animal productivity from mycotoxin-related health problems; and 4) human health costs. Moreover, additional costs associated with mycotoxin also include the cost of management at all levels (prevention, sampling, mitigation, litigation, and research costs). These economic impacts affect all along the food and feed supply chains: crop producers, animal producers, grain handlers and distributors, processors, consumers, and the society as a whole (due to health care impacts and productivity losses). Nowadays, more than 400 mycotoxin metabolites have been discovered but the eight most important mycotoxins (Top 8) with worldwide relevance in regard to public health are aflatoxins, ochratoxin A, fumonisin B_1, zearalenone, deoxynivalenol, nivalenol, T-2 toxin and patulin (FAO, 2001). Mycotoxin can contaminate various agricultural commodities and particularly cereals and legumes such as wheat, barley, rye, oats, rice, maize, peanuts, alfalfa, clover, beans, peas, chickpeas, lentils, lupine, mesquite, carob, soybeans, tamarind and some other cereal grains that are normally used as substrates for traditional fermented food in South-East Asia. Those substrates can be contaminated with mycotoxin either before harvest or under post-harvest conditions (FAO, 1991), resulting in mycotoxin contamination in the finished products. Mycotoxin is relatively stable to cooking and processing temperatures. Once they contaminate food and feed, they cannot be removed safely. This means that once foods are contaminated, human exposure is almost certain if the foods go into the market.

In South-East Asia, this problem is acute due to favorable humidity and temperature conditions for the development of molds. It is even hypothesized that the consumption of aflatoxin contaminated foods, which is recognized as a risk factor for human hepatocellular carcinoma, may contribute to the high incidence of this disease in South-East Asia (Tran-Dinh, Kennedy, Bui, & Carter, 2009). Several studies report a high level of contamination of agricultural products and, due to the great stability of mycotoxins, these compounds remain present in agriculture soils (Tran-Dinh, Kennedy, Bui, & Carter, 2009). They also remain in the raw product after processing and, if the raw material is used for animal feeding, they can contaminate meat products. As a result, despite a 20-year-old study showing in the north of Thailand that vegetarians can be more exposed to mycotoxins (Vinitketkumnuen, Chewonarin, Kongtawelert, Lertjanyarak, Peerakhom, & Wild, 1997), animal products are also likely to be contaminated. For instance in Vietnam, aflatoxins and zearalenone were found in all feed samples analyzed (Thieu, Ogle, & Pettersson, 2007) and then aflatoxin M1, in more than half of pig urine samples collected in various slaughterhouses of Vietnam (Lee, Lindahl, Nguyen-Viet, Khong, Nghia, Xuan, et al., 2017). As a result, mycotoxins can be expected in fermented products in a way similar to unfermented ones (Sivamaruthi, Kesika, & Chaiyasut, 2018). Although analyses of mycotoxins present in fermented products are rare, some have been detected in soy fermented products like Thua-nao (Petchkongkaew, Taillandier, Gasaluck, & Lebrihi, 2008) and Tuong (Vu & Nguyen, 2016). This latter soy sauce is fermented by *Aspergillus orizae* which is very near, and considerd as the domesticated form of, *A. flavus*, the aflatoxin producer, a fact that can explain the presence of aflatoxin in 4/14 brands of Tuong. A review presenting mycotoxins in world fermented products has been published recently confirming that mycotoxins are often present in this class of products (Sivamaruthi, Kesika, & Chaiyasut, 2018).

3.2 Biogenic amines

Biogenic amines (BAs) are low molecular weight nitrogenous compounds naturally present in animals, plants, and microorganisms where they play several functions including gene expression regulation, cell growth and differentiation, etc. (Suzzi and Torriani, 2015). On the basis of their chemical structure, BAs are divided into aliphatic (putrescine, cadaverine, spermine and spermidine), aromatic (tyramine and phenylethylamine) or heterocyclic (histamine and tryptamine). Considering the number of amine groups, they are classified in monoamines (tyramine and phenylethylamine), diamines (putrescine and cadaverine) or polyamines (spermine and spermidine) (Park et al., 2019). The occurrence of some BAs (histamine, putrescine, cadaverine, tyramine, tryptamine, 2-phenylethylamine, spermine and spermidine) in fermented foods such as fish, meat, cheese, vegetables, and wines, has been widely described (for a review see Spano et al., 2010). Unfortunately, the consumption of foods or beverages containing high amounts of BAs is a risk for consumer health since they can have toxic effects (Park et al., 2019). The BAs encountered in fermented foods are mainly produced by microbial decarboxylation of amino acids (Mah et al., 2019). The main microbial groups associated with BAs accumulation are several Gram negative (enterobacteria and pseudomonads) and Gram positive bacteria including staphylococci, *Bacillus* spp. and lactic acid bacteria (LAB). The presence of decarboxylase positive microorganisms is not the only factor influencing BAs accumulation in foods, in fact, specific environmental conditions are required (e.g. availability of BAs precursors, presence of proteolytic enzymes involved in the release of free amino acids). Other factors involved are: raw materials characteristics in terms of composition, pH, ion strength, physico-chemical parameters (NaCl, pH and ripening temperature) and processing, storage and distribution conditions (Suzzi and Torriani, 2015; Linares et al., 2012).

Several traditional fermented foods from South-East Asia including fish sauce and fermented soybean foods are characterized by a high amount of BAs (for reviews see Prester, 2011, Zaman et al., 2009; Park et al., 2019). The most popular fermented soybean foods are produced through bacterial fermentation and the main are: Natto, Miso, Cheonggukjang, Doenjang, Gochujang, Chunjang, Doubanjiang, and Douchi. The BAs composition of these products is reported in Table 2 (it should be noted that for Doenjang, the very high maximal concentration detected comes from one isolated study and most studies report values below thresholds).

Fermented fish products represent a source of BAs and especially histamine, which is one of the most dangerous for human health. In fact, it is the only BA with regulatory limits. The US FDA set a guidance level of 50 mg/kg for histamine in the edible portion of fish (FDA, 2011), and the European Commission established up to a maximum of 200 mg/kg in fresh fish and 400 mg/kg in fishery products treated by enzyme maturation in brine (EFSA, 2011). BA content in seafood for South-Korea and China is regulated imposing maximum limits of histamine content in fish, at 200 mg/kg and 200–400 mg/kg, respectively. According to EFSA (2011) dried anchovies and fish sauce are the fermented foods showing the highest mean content of histamine, with values of 348 mg/kg and 196-197 mg/kg, respectively. More in general, fish sauce is characterized by the highest mean values for the sum of BAs (582 - 588 mg/kg). The histamine content of some Asian fish products is reported in Table 3.

4. Chemical contaminations

4.1 Pesticides, heavy metals

In the past century, agriculture has increased productivity through mechanization, fertilization, pesticides, and selective breeding. Furthermore, intensification of cash-crop production and conventional agriculture with fertilizers and pesticides impair local resources (soil fertility, biodiversity). Some trace elements (e.g. iron, potassium, etc…) have undergone historical decrease in food in Finland, United States and United Kingdom (Mayer, 1997; Ekholm et al., 2007). This decline was attributed to varietal selection based mainly on yield and soil degradation due to intensive agriculture.

Great transitions are at work in Europe. The Ecophyto plan is implemented with the purpose of progressively reducing the use of pesticides. With international trades, food products are imported from numerous countries where the environmental rules do not correspond to European ones. In Northern Europe, foods imported from Asia contained 111 distinct pesticides and in some cases concentration exceeded the Maximum Residue Levels with leafy vegetables particularly concerned (chives, thai basil) (Skretteberg, 2015). In 2010, among 245 plant foods from Phnom Penh markets, 15% of the long beans and 95% of the kale contained noticeable levels of organophosphate and carbamate pesticides (Neufeld et al., 2010).

It is true that, apart from the war inheritances like agent orange which still results in daily intakes of dioxins far above the WHO recommendation in some parts of Vietnam (Tuyet-Hanh, Minh, Vu-Anh, Dunne, Toms, Tenkate, et al., 2015), South-East Asian cultures can be potentially contaminated by chemicals and metals. Several studies have highlighted the poisoning of agriculture workers (Thetkathuek & Jaidee, 2017; Thetkathuek, Suybros, Daniell, Meepradit, & Jaidee, 2014) and of the environment (Harnpicharnchai, Chaiear, & Charerntanyarak, 2014) but the main concern for fermented food products is related to pesticides encountered in raw materials. A survey in the Red river delta showed that pesticides used in agriculture were frequently detected in biota, leading to repeated analyses above the acceptable daily intakes in fishes and vegetables (Hoai, Sebesvari, Minh, Viet, &

Renaud, 2011). Even banned organochlorine pesticides still persists in these environments. Among vegetables reaching the residue limits established by the European Union, some vegetables used for fermentation like chinese cabbage and some herbs are cited (Sapbamrer & Hongsibsong, 2014; Wanwimolruk, Kanchanamayoon, Phopin, & Prachayasittikul, 2015) while some fruits (watermelon and durian) despite the presence of chemicals, were considered as safe (Wanwimolruk, Kanchanamayoon, Boonpangrak, & Prachayasittikul, 2015). The fate of pesticides in food products depends on the specific physicochemical properties of the compounds as well as of the conditions of preparation of food (presence of water, temperature and pH etc). During fermentation, the concentration of pesticides usually decreases significantly, giving rise to degradation products. In addition to non fermented products, fermented products are characterized by the presence of microorganisms. The presence of pesticides as well as of their degradation products tend to limit the activity of microorganisms and modify the sensorial properties of the product but in the mean time, microorganisms can degrade these products and help decreasing the contamination of fermented products (Regueiro, López-Fernández, Rial-Otero, Cancho-Grande, & Simal-Gándara, 2015). Studies on pesticides in food are still at the preliminary level and their degradation, the risk related to their degradation products, the potential catalysis by microorganisms, thought of paramount importance, need to be further studied.

5. Antibiotics resistance of microbes from traditional fermented foods from South-East Asia

Antibiotics are either microbial secondary metabolites or the analogous compounds synthesized or semi-synthesized chemically, that could inhibit the growth and survival of other bacteria. These compounds are used as therapeutic agents against infectious disease in humans, livestock and aquaculture. However, haphazard and extensive use of antibiotics may select antibiotic resistant bacteria (Ben et al., 2019). Bacteria can develop antibiotic resistance by several mechanisms via enzymatic degradation; antibiotic target modification; changing the bacterial cell wall permeability and alternative pathways to escape the activity (Verraes et al., 2013). Antibiotic resistance can be inherited or acquired. Inherited antibiotic resistance is exhibited by all isolated of the same species while acquired antibiotic resistance occurs when susceptible bacteria gain the genes encoding a resistance mechanism via mutation or the transfer of genetic material from other bacteria (MacGowan & Macnaughton 2017).

Foodborne diseases not only affect people's well-being, but also cause hospitalization and economic loss. Approximately 22.8 million cases of diarrheal illness caused by Salmonellosis outbreak annually, with 37,600 deaths in South-East Asia (Van et al., 2012). Generally, food contributes as an important part for transfer of antibiotic resistance in terms of antibiotic residues or resistant genes from food microflora to pathogenic bacteria (Akbar & Anal, 2013). It is important to monitor the prevalence of pathogenic bacteria along with antibiotic resistant foodborne pathogens in food chain to improve and implement food safety (Chanseyha et al., 2018). For instance, for the contamination of raw products by pathogenic bacteria as discussed above, the resistance of bacteria to antibiotic is thus also an important issue. The resistance of *E. coli* to antibiotic isolated from pork collected in pig farm, supermarket and wet market from Hochiminh city and Tien Giang province was reported. The resistance to tetracycline, sulphafurazole, ampicillin/amoxicillin, trimethoprim, chloramphenicol, streptomycin, nalidixic acid, ciprofloxacin, gentamicin, colistin and ceftazidime were 100, 70, 55, 60, 50, 65, 30, 42.2, 73.3, 22.2 and 1.1%, respectively (N. T. Nguyen, Nguyen, Nguyen, Nguyen, Nguyen, Thai, et al., 2016; Van, Chin, Chapman, Tran, & Coloe, 2008). Nguyen et al. (2016a) described for the first time a strain – isolated from pork – resistant against colistin (a last-resort antibiotic). Multi-resistance of *E. coli* to at least 3 different classes of antibiotics was observed with rates up to 75% in pork (Van, Chin, Chapman, Tran, & Coloe, 2008).

Campylobacter and *Salmonella* spp. from pork meat showed high resistance rate (>50%) against streptomycin and tetracycline in addition, with different levels of antimicrobial susceptibility to ciprofloxacin, nalidixic acid, ampicillin, chloramphenicol, erythromycin and streptomycin (0-<50%) (T. N. M. Nguyen, et al., 2016; Vo, van Duijkeren, Gaastra, & Fluit, 2010). Moreover, 52.2% of *Salmonella* strains from pork, beef and chicken meat showed multidrug resistance (Nguyen Thi Nhung, et al., 2018).

Traditional fermented foods and beverages are popular for their nutritional balance and food security. In many Asian countries, techniques for fermenting cereals, vegetables and meat products are well developed. Such fermented foods are highly priced for improved nutritional and organoleptic quality as well as for beneficial microorganisms (Anal, 2019). Several studies have indicated that along with beneficial microorganism, fermented foods can act as vehicles of antibiotic resistant bacteria (see Table 4). Therefore, through the food chain involving traditional fermented food, antibiotic resistant genes may be transferred to other bacteria including pathogens and commensals and into the gastrointestinal tract (Abriouel et al., 2017).

South-East Asia region is rapidly developing, and food products are exported globally. Since this region is a hotspot of antibiotic resistant bacteria, there is a risk of dissemination of antibiotic resistant bacteria and genes to consumers worldwide (Nhung et al., 2016). In Asia, numerous fermented foods are categorized into five groups including fermented soybean; fish; vegetable; bread and porridges; and alcoholic beverage. Lactic acid bacteria (LAB) are the commonly involved bacteria in these products to a varying extent, having either positive or negative effects (Rhee *et al.,* 2011). Some of the antibiotic resistant LAB isolated from traditionally fermented foods are summarized in the Table 4.

6. Analysis and main recommendations

Despite huge differences between South-East Asian countries, concerns about risk of pathogens in fermented meat product such as *nem chua,* due to the contamination in raw meat material, are common (Hoang & Vu, 2017). The high level of contaminations in farms can be related to hygiene (Dang-Xuan, Nguyen-Viet, Pham-Duc, Unger, Tran-Thi, Grace, et al., 2019). However, several studies have highlighted an increase in the level of contaminations in slaughterhouses. These contaminations were likely to come from faeces to carcasses (Dang-Xuan, et al., 2019; Le Bas, et al., 2008). Cross contaminations between species have also been observed as shown in Table 1: although infections by *Campylobacter* concerned mostly poultry and poultry products, this species was also found in swine carcasses and retail products as the meat could be contaminated with faeces at the slaughterhouse and processing facilities during the evisceration process, leading to the contamination of food products (T. N. M. Nguyen, et al., 2016). Taking into account that pigs are still mainly slaughtered in small structures in Vietnam despite the existence of big modern structures, one axis of improvement could be the improvement of hygiene conditions in those small slaughterhouses in a way sustainable for small structures. These recommendations for good hygiene practices could be: (1) separate gut rinsing and carcass dressing, (2) separate lairage and carcass dressing, (3) use specific working surface for the carcass during slaughter, (4) cleaning and disinfection of these surfaces after work, (5) give clean water to the pigs at lairage (well water, not tank water), (6) clean and disinfect tanks and tools after work, (7) waste management avoiding contamination (Le Bas, et al., 2008). Other steps can be causes of contaminations such as handling in pork shops where management of flies and handling avoiding contact between meat and worker clothes could be improved (Dang-Xuan, et al., 2019). Finally, although the original load of raw pork meat is certainly the main contributor to the pathogen contamination in the sausage, some additional contaminations may also result from the processing, especially during the forming of the sausages into the guava and banana leaves, usually done by hand. Leaves being usually considered as the source of inoculation of fermenting lactic acid bacteria, a maintained spontaneous fermentation would require an improvement of the leave production while another perspective would be the use of starters. Recommendation could also target consumers and a Thai study recommended also to cook nahm before eating (Paukatong & Kunawasen, 2001), however, such a step would introduce a completely new way of consumption in Vietnam.

For vegetables, basic hygiene could improve significantly the situation concerning pathogens. Contrary to the general consumer perception, hygienic problems are not limited to wet markets but are also present in supermarkets. For instance, a Thai study detected almost no significant contamination differences between open markets and supermarkets however, it could not take into account differences concerning fermented products as they were only available in open markets at that time (Ananchaipattana, et al., 2012). It is likely that a training of producers and handlers to good practices could improve greatly the hygienic quality of fermented products. One particular care should be taken to cross contaminations which have also been observed in vegetables as mixed vegetables are far more contaminated than fermented monoproducts. Moreover, the use of hurdle technologies like biopreservation, involving the use of efficient starters could also contribute to improve pathogenic control through sustainable solutions (Ho, 2017).

The problem of mycotoxin comes mainly from conditions of mold development, which can be decreased through the respect of good practice, and from the high stability of concerned molecules that can stay in the environment a long time after the production by molds. One concern is the price of analyses, which makes difficult any actions for basic farmers. There are however also some solutions to decrease the level of contamination by using adsorbant materials like bentionite clays for piglet farming (Thieu, Ogle, & Pettersson, 2008) or microbial catalysts able to degrade the toxins (Petchkongkaew, Taillandier, Gasaluck, & Lebrihi, 2008).

The fluctuations in the BAs concentration suggest the lack of standardized processes. Improvements in this direction could be useful. In this context, it is essential to implement control strategies and develop methods to reduce BAs content in fermented products in order to face consumers demand for healthier and safe foods.

Food contamination by pesticides is a world-wide problem but, concerning specific contaminations in the region, the agricultural practices are obviously a way to improve results as, for mangosteen, 97% of the fruits for local market are exceeding the MRLs whereas no problems are detected for the GAP production of fruits intended for the European Union (Wanwimolruk, Kanchanamayoon, Phopin, & Prachayasittikul, 2015). Organic agriculture could also be a mean to improve this point but some steps are still required to secure production especially in less controlled area. Indeed, the safety of organic foods is still unclear as the use of untreated irrigation or washing water or inappropriate organic fertilizers (i.e manure or composts) is possible (Taban et al., 2011; Nguyen-the et al, 2016). Data related to the microbial communities associated to the surface of fresh fruits and vegetables have shown significant differences, quantitatively and qualitatively, between conventional and organic products (Leff & Fierer, 2013; Bigot et al., 2015). Using *E. coli*, *Salmonella* and *Listeria* which are the most contaminating pathogen bacteria for leafy vegetables as indicator, different studies have been carried out to evaluate the contamination level of organic vs conventional vegetables, notably leafy ones (Tango et al., 2014; Karp et al., 2016). Results are contrasted with no real trend or a slight impact on organically-grown vegetables (Leff & Fierer, 2013; Tango et al., 2014). Studies on the mycotoxin contamination of agricultural products have mainly been carried out on cereals or fruits and rarely on leafy vegetables (van der Walt et al., 2006; Sanzani et al., 2016). Mycotoxin contaminations in organic cereal crops were variable and inconclusive but their levels were sometimes higher than those observed in conventional samples (Baert et al., 2006; Magkos et al., 2006; Piqué et al., 2013). In this field, more studies are needed before establishing precise recommendations.

In all cases, training of farmers, retailers and transformators would greatly improve the situation.

7. Conclusion

Fermented foods from South-East Asia exhibit several safety risks in a similar way to raw agriculture products (Figure 1). The presence of pathogens is one of the main and immediate risk as it contaminates many clean samples during slaughter and handling. However, the presence of chemicals, biogenic amins, mycotoxins and parasites can be a more difficult risk to take into account as it can be more hidden with a long-term effect. Risks could be greatly diminished by the use of good agriculture/manufacturing practice, especially concerning pathogen and chemical contamination and antibiotic resistance. For mycotoxin, good producing and storage practice could also help a lot and, for biogenic amines, a survey of strains present during fermentation might be required as a first step before strategies to avoid their development. For all food safety concerns, starters can also be used for biopreservation and bioremediation purposes and thus decrease risks (Ho, Nguyen, Petchkongkaew, Nguyen, Chu-Ky, Nguyen, et al., in minor revision).

This validates the drivers of food unsafety as cited above (Kendall, et al., 2018). Among the various ways to improve safety, training of all actors of the production/transformation chain may be one of the main active ones. This was the subject of the AsiFood Erasmus+ project which just finished recently (Anal et al., in press).and, in the future, it would be interesting to evaluate the impact of training on food safety in the different partner countries. It should also be added that the level of food safety in the various ASEAN countries is very diverse as a result of economic development, culture, motivation (export to world region exerting a big control) etc.

Acknowledgements : This work was funded by the Erasmus+ AsiFood «Universities as key partners for the new challenges regarding food safety and quality in ASEAN» project, the Bualuang ASEAN chair professorship of Thammasat University, the Investissement d'Avenir ISITE BFC ANR-15-IDEX-0003 and the French Embassy in Thailand. The author are thankful to Dr Guillaume Da for his precious help to establish the network.

References

Abriouel, H., Knapp, C. W., Gálvez, A., & Benomar, N. (2017). Antibiotic resistance profile of microbes from traditional fermented foods. In J. Frias, C. Martinez-Villaluenga, & E. Peñas (Eds.), Fermented Foods in Health and Disease Prevention (pp. 675–704). Academic Press.

Akbar, A., & Anal, A. K. (2013). Prevalence and antibiogram study of *Salmonella* and *Staphylococcus aureus* in poultry meat. *Asian Pacific journal of tropical biomedicine*, 3, 163–168.

Ananchaipattana, C., Hosotani, Y., Kawasaki, S., Pongsawat, S., Md.Latiful, B., Isobe, S., & Inatsu, Y. (2012). Prevalence of Foodborne Pathogens in Retailed Foods in Thailand. *Foodborne Pathogens and Disease*, 9(9), 835-840.

Anal, A. K. (2019). Quality Ingredients and Safety Concerns for Traditional Fermented Foods and Beverages from Asia: A Review. *Fermentation*, 5, 8.

Anal, A. K., Waché Y., Louzier V., Roy L., Mens, F. Avalllone, S., Mahakarnchanakul W, Udompijitkul P., Tantikitti C, Nguyen, T. B. T., Phan T.P., Nguyen, T, M, T, Nguyen H.M.X., Kong T, Hul, S., Schleining G, Lindner L, Schippo, M.L., Guidi, A (in press). AsiFood and its Output and Prospects: An Erasmus+ Project on Capacity Building in Food Safety and Quality for South-East Asia. *Food Control*.

Baert, K., De Meulenaer, B., Kamala, A., Kasase, C., & Devlieghere, F. (2006). Occurrence of patulin in organic, conventional, and handcrafted apple juices marketed in Belgium. *Journal of Food Protection,* 69, 1371–1378.

Ben, Y., Fu, C., Hu, M., Liu, L., Wong, M. H., & Zheng, C. (2018). Human health risk assessment of antibiotic resistance associated with antibiotic residues in the environment: A review. *Environmental Research*, 169, 483–493.

Bigot, C., Meile, J.C., Kapitan, A., & Montet, D. (2015). Discriminating organic and conventional foods by analysis of their microbial ecology: An application on fruits. *Food Control*, 48, 123–129.

Binh, D. X., Minh, N. N., & Nguyet, D. T. (2017). Prevalence of Listeria monocytogenes, E. coli, Salmonella spp. and Staphylococcus aureus Bacteria Contamination on Meat at Public Market in the North of Vietnam. *SOJ Microbiology & Infectious Diseases*, 5, 1–22.

Bräse, S., Encinas, A., Keck, J., & Nising, C. F. (2009). Chemistry and Biology of Mycotoxins and Related Fungal Metabolites. *Chemical Reviews*, 109, 3903–3990.

Carrique-Mas, J. J., Bryant, J. E., Cuong, N. V., Hoang, N. V., Campbell, J., Hoang, N. V., Dung, T. T., Duy, D. T., Hoa, N. T., Thompson, C., Hien, V. V., Phat, V. V., Farrar, J., & Baker, S. (2014). An epidemiological investigation of Campylobacter in pig and poultry farms in the Mekong delta of Vietnam. *Epidemiology and Infection*, 142, 1425–1436.

Chanseyha, C., Sadiq, M. B., Cho, T. Z. A., & Anal, A. K. (2018). Prevalence and analysis of antibiotic resistant genes in *Escherichia coli* and *Salmonella* isolates from green leaf lettuce. *Chiang Mai Journal of Science*, 45, 1274–1286.

Chrun, R., Hosotani, Y., Kawasaki, S, & Inatsu, Y. (2017). Microbioligical Hazard Contamination in Fermented Vegetables Sold in Local Markets in Cambodia. *Biocontrol Science*, 22, 181–185.

Dang-Xuan, S., Nguyen-Viet, H., Pham-Duc, P., Unger, F., Tran-Thi, N., Grace, D., & Makita, K. (2019). Risk factors associated with *Salmonella* spp. prevalence along smallholder pig value chains in Vietnam. *International Journal of Food Microbiology*, 290, 105-115.

Dang-Xuan, S., Nguyen-Viet, H., Unger, F., Pham-Duc, P., Grace, D., Tran-Thi, N., Barot, M., Pham-Thi, N., & Makita, K. (2017). Quantitative risk assessment of human salmonellosis in the smallholder pig value chains in urban of Vietnam. *International journal of public healt*h 62, 93–102.

Dao, H. T. A. & Yen, P. T. (2006). Study of Salmonella, Campylobacter, and Escherichia coli Contamination in Raw Food Available in Factories, Schools, and Hospital Canteens in Hanoi, Vietnam. *Annals of the New York Academy of Sciences*, 1081, 262–265.

Ekholm, P., Reinivuo, H., Mattila, P., Pakkala, H., Koponen, J., Happonen, A., Hellstrom, J., & Ovaskainen, M. L. (2007). Changes in the mineral and trace element contents of cereals, fruits and vegetables in Finland. *Journal of Food Composition and Analysis*, 20, 487–495.

Ezzat, M. A., Zare, D., Karim, R., & Ghazali, H. M. (2015). Trans- and cis-urocanic acid, biogenic amine and amino acid contents in ikan pekasam (fermented fish) produced from Javanese carp (Puntius gonionotus) and black tilapia (Oreochromis mossambicus). *Food Chemistry,* 172, (2015) 893–899.

González García, M., Fernández-López C., Polesel F., & Trapp S. (2019). "Predicting the uptake of emerging organic contaminants in vegetables irrigated with treated wastewater – Implications for food safety assessment." Environmental Research 172, 175–181.

Ha, T. M., Shakur, S., & Do, K. H. P. (2019). Consumer concern about food safety in Hanoi,Vietnam. *Food Control,* 98, 238–244.

Harnpicharnchai, K., Chaiear, N., & Charerntanyarak, L. (2014). Residues of organophosphate pesticides used in vegetable cultivation in ambient air, surface water and soil in Bueng Niam Subdistrict, Khon Kaen, Thailand. *The Southeast Asian journal of tropical medicine and public health*, 44, 1088–1097.

Ho, P.-H. (2017). Sécurité alimentaire et microbiologie des produits fermentés. La sécurité sanitaire des aliments au Vietnam. État des lieux pluridisciplinaire sur les enjeux au niveau de la production, de la distribution, des politiques publiques et des risques microbiologiques. H.-V. Pham and D. Marie-Vivien. Dijon, AgroSup Dijon: 85–100.

Ho, P.H., Nguyen, T.K.C., Petchkongkaew, A., Nguyen, H.V., Chu-Ky, S., Nguyen, T.V.A., Lorn D., Licandro, H., Waché, Y. How fermentation by lactic acid bacteria can address safety issues in legumes food products? *Food Control* (in minor revision).

Hoai, P. M., Sebesvari Z., Tu, B. M., Pham, H. V., Renaud, F. G. (2011). Pesticide pollution in agricultural areas of Northern Vietnam: Case study in Hoang Liet and Minh Dai communes. *Environmental Pollution* 159(12): 3344–3350.

Hoang, V.-Q. & T.-H.-V. Vu (2017). Sécurité alimentaire de viande porcine. De la perception des consommateurs Vietnamiens à la politique. La sécurité sanitaire des aliments au Vietnam. État des lieux pluridisciplinaire sur les enjeux au niveau de la production, de la distribution, des politiques publiques et des risques microbiologiques. H.-V. Pham and D. Marie-Vivien. Dijon, AgroSup Dijon: 69–84.

Karp, D.S., Moses, R., Gennet, S., Jones, M. S., Joseph, S., M'Gonigle, L. K., Ponisio, L. C., Snyder, W. E., & Kremen, C. (2016). Agricultural practices for food safety threaten pest control services for fresh produce. *Journal of Applied Ecology*, 53, 1402–1412.

Keisam, S., Tuikhar, N., Ahmed, G., & Jeyaram, K. (2019). Toxigenic and pathogenic potential of enteric bacterial pathogens prevalent in the traditional fermented foods marketed in the Northeast region of India. *International Journal of Food Microbiology*, 296, 21-30.

Kendall, H., Kaptan, G., Stewart, G., Grainger, M., Kuznesof, S., Naughton P., Clark B., Hubbard, C., Raley M., Marvin, H. J. P., & Frewer, L. J. (2018). Drivers of existing and emerging food safety risks: Expert opinion regarding multiple impacts. *Food Control*, 90, 440–458.

La Anh, N. (2015). Health-promoting microbes in traditional Vietnamese fermented foods: A review. *Food Science and Human Wellness*, 4, 147–161.

Le Bas, C., Hanh, T.T., Thành, N.T., Cuong, N.M., Quang, H.V., Binh, V.T., Minh, N.X., Gardon, C., Patin, A., Chu-Ky, S., Mai, L.T., Bily, L., Labbé, A., Denis, M., & Fravalo, P. (2008). *Salmonella enterica* subsp. *enterica* along the pig commodity chain in Vietnam. *In* : Environmental, health and socio-economic : Risks associated with livestock intensification : Proceedings of the PRISE Scientific Committee, Hanoi, Vietnam, 4th December 2008. 37-57.

Lê, T. M., P. H. Hồ, et al. (2011). " Khai thác hệ vi sinh vật trong thực phẩm lên men truyền thống Việt nam để cải thiện chất lượng và an toàn sản phẩm." Vietnam Journal of Sience and Technology (Tạp chí khoa học công nghệ) 49(6A): 93–101.

Le, T. M., T. N. Do, et al. (2012). "Evaluation of hygiene and safety status of nem chua production in Hanoi." Vietnam Journal of Sience and Technology 50(2): 231–237.

Lee, H. S., Lindahl, J., Nguyen-Viet, H., Khong, N. V., Nghia, V. B., Xuan, H. N., & Grace, D. (2017). An investigation into aflatoxin M1in slaughtered fattening pigs and awareness of aflatoxins in Vietnam. *BMC Veterinary Research,* 13, 363.

Leff, J. W. & Fierer, N. (2013). Bacterial Communities Associated with the Surfaces of Fresh Fruits and Vegetables. *Plos One*, 8, e59310.

Linares, D. M., del Río, B., Ladero, V., Martínez, N., Fernández, M., Martín, M. C., & Alvarez, M. A. (2012). Factors influencing biogenic amines accumulation in dairy products. *Frontiers in Microbiology*, 28, 180.

Lucas, P. M., Wolken, W. A. M., Claisse, O., Lolkema, J. S., & Lonvaud-Funel, A. (2005). Histamine-producing pathway encoded on an unstable plasmid in *Lactobacillus hilgardii* 0006. *Applied and Environmental Microbiology*, 71, 1417–1424.

MacGowan, A., & Macnaughton, E. (2017). Antibiotic resistance. *Medicine*, 45, 622–628.

Magkos, F., Arvaniti, F., & Zampelas, A. (2006). Organic food: Buying more safety or just peace of mind? A critical review of the literature. *Critical Reviews in Food Science and Nutrition*, 46, 23–56.

Mah, J. H., Park, Y. K., Jin, Y. H., Lee, J. H., & Hwang, H. J. (2019). Bacterial production and control of biogenic amines in asian fermented soybean foods. *Foods*, 8, 85.

Mayer, A. M. (1997). Historical changes in the mineral content of fruits and vegetables. *British Food Journal*, 99, 207–211.

Mitacek, E. J., Brunnemann, K. D., Suttajit, M., Martin, N., Limsila, T., Ohshima, H., & Caplan, L. S. (1999). Exposure to N-nitroso compounds in a population of high liver cancer regions in Thailand: volatile nitrosamine (VNA) levels in Thai food. *Food and Chemical Toxicology*, 37(4), 297-305.

Nawaz, M., Wang, J., Zhou, A., Ma, C., Wu, X., Moore, J. E., Millar, B. C., & Xu, J. (2011). Characterization and transfer of antibiotic resistance in lactic acid bacteria from fermented food products. *Current Microbiology*, 62, 1081–1089.

Neufeld, D. S. G., Savoeun, H., Phoeurk, C., Glick, A., & Hernandez, C. (2010). Prevalence and Persistence of Organophosphate and Carbamate Pesticides in Cambodian Market Vegetables. *Asian Journal of Water, Environment and Pollution*, 7, 89–98.

Nguyen D. T. L., van Hoorde, K., Cnockaert, M., de Brandt, E., de Bruyne, K., Le, B. T., & Vandamme, P. (2013). A culture-dependent and-independent approach for the identification of lactic acid bacteria associated with the production of Nem chua, a Vietnamese fermented meat product. *Food Research International*, 50, 232–240.

Nguyen, H., Elegado, F., Librojo-Basilio, N., Mabesa, R., & Dizon, E. (2010). Isolation and characterisation of selected lactic acid bacteria for improved processing of Nem chua, a traditional fermented meat from Vietnam. *Beneficial Microbes*, 1, 67–74.

Nguyen, N. T., Nguyen, H. M., Nguyen, C. V., Nguyen, T. V., Nguyen, M. T., Thai, H. Q., Ho, M. H., Thwaites, G., Ngo, H. T., Baker, S., & Carrique-Mas, J. (2016a). Use of Colistin and Other Critical Antimicrobials on Pig and Chicken Farms in Southern Vietnam and Its Association with Resistance in Commensal Escherichia coli Bacteria. *Applied and Environmental Microbiology*, 82, 3727–3735.

Nguyen, T. N. M., Hotzel, H., El-Adawy, H., Tran, H. T., Le, M. T., Tomaso, H., Neubauer, H., & Hafez, H. M. (2016b). Genotyping and antibiotic resistance of thermophilic *Campylobacter* isolated from chicken and pig meat in Vietnam. *Gut Pathogens* 8, 19.

Nguyen-the, C., Bardin, M., Berard, A., Berge, O., Brillard, J., Broussolle, V., Carlin, F., Renault, P., Tchamitchian, M., & Morris, C. E. (2016). Agrifood systems and the microbial safety of fresh produce: Trade-offs in the wake of increased sustainability. *Science of the Total Environment*, 562, 751–759.

Nhung, N. T., Van, N. T. B., Cuong, N. V., Duong, T. T. Q., Nhat, T. T., Hang, T. T. T., Nhi, N. T. H., Kiet, B. T., Hien, V. B., Ngoc, P. T., Campbell, J., Thwaites, G., & Carrique-Mas, J. (2018). Antimicrobial residues and resistance against critically important antimicrobials in non-typhoidal Salmonella from meat sold at wet markets and supermarkets in Vietnam. *International Journal of Food Microbiology*, 266, 301–309.

Nhung, N., Cuong, N., Thwaites, G., & Carrique-Mas, J. (2016). Antimicrobial usage and antimicrobial resistance in animal production in Southeast Asia: a review. *Antibiotics*, 5, 37.

Osiriphun, S., Pongpoolponsak, A., Tuitemwong, K., 2004. Quantitative Risk Assessment of *Salmonella* spp. in Fermented Pork Sausage (Nham). *Kasertsart J. (Nat. Sci.).* 38, 52-65.

Park, Y. K., Lee, J. H., & Mah, J. H. (2019). Occurrence and reduction of biogenic amines in traditional Asian fermented soybean foods: A review. *Food Chemistry,* 278, 1–9.

Paukatong, K., & Kunawasen, S. (2001). The Hazard Analysis and Critical Control Points (HACCP) generic model for the production of Thai fermented pork sausage (Nham). *Berl Munch Tierarztl Wochenschr,* 114(9-10), 327-330.

Petchkongkaew, A., Taillandier, P., Gasaluck, P., & Lebrihi, A. (2008). Isolation of *Bacillus* spp. from Thai fermented soybean (Thua-nao): screening for aflatoxin B1 and ochratoxin A detoxification. *Journal of Applied Microbiology*, 104, 1495–1502.

Phan, T. T., C. T. Pham, et al. (2006). "Evaluation of food hygiene and safety of nem chua product (Khảo sát mức độ vệ sinh an toàn thực phẩm của sản phẩm nem chua)." Journal of Science and Technology Technical Universities 55: 112–116.

Phong, H. X., Van, T. H., Ngamyeesoon, N, & Duy le, N. D. (2016). Antifungal Activity of Lactic Acid Bacteria Isolated from Nem Chua. *Chemical and Biomolecular Engineering,* 1, 49–54.

Pilasombut, K., Rumjuankiat, K., Ngamyeesoon, N., & Duy le, N. D. (2015). *In vitro* Characterization of Bacteriocin Produced by Lactic Acid Bacteria Isolated from Nem Chua, a Traditional Vietnamese Fermented Pork. *Korean journal for food science of animal resources,* 35, 473–478.

Piqué, E., Vargas-Murga, L., Gomez-Catalan, J., de Lapuente, J., & Llobet, J. M. (2013). Occurrence of patulin in organic and conventional apple-based food marketed in Catalonia and exposure assessment. *Food and Chemical Toxicology*, 60, 199–204.

Prester, L. (2011). Biogenic amines in fish, fish products and shellfish: a review. *Food Additives and Contaminants*, 28, 1547–1560.

Regueiro, J., López-Fernández, O., Rial-Otero, R., Cancho-Grande, B., & Simal-Gándara, J. (2015). A Review on the Fermentation of Foods and the Residues of Pesticides—Biotransformation of Pesticides and Effects on Fermentation and Food Quality. *Critical Reviews in Food Science and Nutrition*, 55(6), 839-863.

Rhee, S. J., Lee, J. E., & Lee, C. H. (2011). Importance of lactic acid bacteria in Asian fermented foods. *Microbial Cell Factories*, 10, S5.

Riebroy, S., Benjakul, S., Visessanguan, W., Kijrongrojana, K., & Tanaka, M. (2004). Some characteristics of commercial Som-fug produced in Thailand. *Food Chemistry*, 88, 527–535.

Saaid, M., Saad, B., Hashim, N. H., Ali, A. S. M., & Saleh, M. I. (2009). Determination of biogenic amines in selected Malaysian food. *Food Chemistry,* 113, 1356–1362.

Sanzani, S. M., Reverberi, M., & Geisen, R. (2016). Mycotoxins in harvested fruits and vegetables: Insights in producing fungi, biological role, conducive conditions, and tools to manage postharvest contamination. *Postharvest Biology and Technology*, 122, 95–105.

Sapbamrer, R. & Hongsibsong, S. (2014). Organophosphorus Pesticide Residues in Vegetables From Farms, Markets, and a Supermarket Around Kwan Phayao Lake of Northern Thailand. *Archives of Environmental Contamination and Toxicology,* 67, 60–67.

Sarter, S., Ho, P.-H., & Ka, T. O. (2014). Current context of food safety in Vietnam: a glance at food of animal origin. *Quality Assurance Safety of Crops & Foods,* 7, 57–62.

Satomi, M., Furushita, M., Oikawa, H., Yoshikawa-Takahashi, M., & Yano, Y. (2008). Analysis of a 30 kbp plasmid encoding histidine decarboxylase gene in *Tetragenococcus halophilus* isolated from fish sauce. *International Journal of Food Microbiology*, 126, 202–209.

Sivamaruthi, B. S., Kesika, P., & Chaiyasut, C. (2018). Toxins in Fermented Foods: Prevalence and Preventions—A Mini Review. *Toxins,* 11, 4.

Skretteberg, L. G., Lyran, B., Holen, B., Jansson, A., Fohgelberg, P., Siivinen, K., J. H. Andersen, & Jensen, B. H. (2015). Pesticide residues in food of plant origin from Southeast Asia–A Nordic project. *Food Control*, 51, 225–235.

Spano, G., Russo, P., Lonvaud-Funel, A., Lucas, P., Alexandre, H., Grandvalet, C., Coton, E., Coton, M., Barnavon, L., Bach, B., Rattray, F., Bunte, A., Magni, C., Ladero, V., Alvarez, M., Fernandez, M., Lopez, P., de Palencia, P. F., Corbi, A., Trip, H., & Lolkema, J. S. (2010). Biogenic amines in fermented foods. *European Journal of Clinical Nutrition*, 64, S95–S100.

Sriraj, P., Boonmars, T., Aukkanimart, R., Songsri, J., Sripan, P., Ratanasuwan, P., Boonjaraspinyo, S., Wongchalee, N., & Laummaunwai, P. (2016). A combination of liver fluke infection and traditional northeastern Thai foods associated with cholangiocarcinoma development. *Parasitology Research*, 115(10), 3843-3852.

Steinkraus, K. H. (1997). Classification of fermented foods: worldwide review of household fermentation techniques. *Food Control*, 8(5), 311-317.

Sukmarini, L., Mustopa, A. Z., Normawati, M., & Muzdalifah, I. (2014). Identification of Antibiotic-Resistance Genes from Lactic Acid Bacteria in Indonesian Fermented Foods. *HAYATI Journal of Biosciences*, 21, 144–150.

Suzzi, G. and Torriani, S. (2015) Editorial: Biogenic amines in foods. *Frontiers in Microbiology,* 6, 472

Taban, B. M., & Halkman, A. K. (2011). Do leafy green vegetables and their ready-to-eat [RTE] salads carry a risk of foodborne pathogens?. *Anaerobe*, 17, 286–287.

Takeshi, K., Itoh, S., Hosono, H., Kono, H., Tin, V. T., Vinh, N. Q., Thuy, N. T., Kawamoto, K., & Makino, S. (2009). Detection of *Salmonella* spp. Isolates from specimens due to pork production chains in Hue City, Vietnam. *Journal of Veterinary Medical Science*, 71, 485–487.

Tango, C. N., Choi, N. J., Chung, M. S., & Oh, D. H. (2014). Bacteriological Quality of Vegetables from Organic and Conventional Production in Different Areas of Korea. *Journal of Food Protection*, 77, 1411–1417.

Thetkathuek, A. & Jaidee, W. (2017). Factors that contribute to insecticide poisoning among immigrant agricultural workers in Thailand. *International Journal of Occupational and Environmental Health*, 23, 60–70.

Thetkathuek, A., Suybros, N., Daniell, W., Meepradit, P., & Jaidee, W. (2014). Factors influencing poisoning symptoms: a case study of vegetable farmers exposed to mixed insecticides in Prek Balatchheng Village, Cambodia. *Journal of agromedicine*, 19, 337–345.

Thieu, N. Q., Ogle, B., & Pettersson, H. (2007). Screening of Aflatoxins and Zearalenone in feedstuffs and complete feeds for pigs in Southern Vietnam. *Tropical Animal Health and Production* 40, 77.

Thieu, N. Q., Ogle, B., & Pettersson, H. (2008). Efficacy of bentonite clay in ameliorating aflatoxicosis in piglets fed aflatoxin contaminated diets. *Tropical Animal Health and Production*, 40, 649–656.

Thumu, S. C. R., & Halami, P. M. (2012). Presence of erythromycin and tetracycline resistance genes in lactic acid bacteria from fermented foods of Indian origin. *Antonie Van Leeuwenhoek*, 102, 541–551.

Toan, L. Q., Nguyen-Viet, H., & Huong, B. M. (2013). Risk assessment of Salmonella in pork in Hanoi, Vietnam. *Vietnamese Journal of Preventive Medicine,* 23, 10–17.

Tran, K. T. M., May, B. K., Smooker, P. M., Van, T. T. H., & Coloe, P. J. (2011). Distribution and genetic diversity of lactic acid bacteria from traditional fermented sausage. *Food Research International*, 44, 338–344.

Tran-Dinh, N., Kennedy, I., Bui, T., & Carter, D. (2009). Survey of Vietnamese Peanuts, Corn and Soil for the Presence of *Aspergillus flavus* and *Aspergillus parasiticus*. *Mycopathologia,* 168, 257–268.

Tsai, Y. H., Lin, C. Y., Chien, L. T., Lee, T. M., Wei, C. I., & Hwang, D. F. (2006). Histamine contents of fermented fish products in Taiwan and isolation of histamine-forming bacteria. *Food Chemistry,* 98, 64–70.

Tuyet-Hanh, T. T., Minh, N. H., Vu-Anh, L., Dunne, M., Toms, L. M., Tenkate,T., Thi, M. H., & Harden, F. (2015). Environmental health risk assessment of dioxin in foods at the two most severe dioxin hot spots in Vietnam. *International Journal of Hygiene and Environmental Health*, 218, 471–478.

Van der Walt, A.M., van der Linde, E., Alberts, M., Modjajdi, P., Jivan, S. D., & Bezuidenhout, C. C. (2006). Fumonisin-producing *Fusarium* strains and fumonisins in African vegetables (morogo). *South African Journal of Science*, 102, 151–155.

Van, T. T. H., Chin, J., Chapman, T., Tran, L. T., & Coloe, P. J. (2008). Safety of raw meat and shellfish in Vietnam: An analysis of Escherichia coli isolations for antibiotic resistance and virulence genes. *International Journal of Food Microbiology,* 124, 217–223.

Van, T. T. H., Nguyen, H. N. K., Smooker, P. M., & Coloe, P.J. (2012). The antibiotic resistance characteristics of non-typhoidal Salmonella enterica isolated from food-producing animals, retail meat and humans in South East Asia. *International Journal Of Food Microbiology*, 154, 98–106.

Verraes, C., Van Boxstael, S., Van Meervenne, E., Van Coillie, E., Butaye, P., Catry, B., De Schaetzen, M. A., Van Huffel, X., Imberechts, H., Dierick, K., Daube, G., Saegerman, C., De Block, J., Dewulf, J., & Herman, L. (2013). Antimicrobial resistance in the food chain: a review. *International Journal of Environmental Research And Public Health*, 10, 2643–2669.

Vinitketkumnuen, U., Chewonarin, T., Kongtawelert, P., Lertjanyarak, A., Peerakhom, S., & Wild, C. P. (1997). Aflatoxin exposure is higher in vegetarians than nonvegetarians in Thailand. *Natural Toxins,* 5, 168–171.

Vo, A. T., van Duijkeren, E., Gaastra, W., & Fluit, A. C. (2010). Antimicrobial resistance, class 1 integrons, and genomic island 1 in Salmonella isolates from Vietnam. *PLoS One,* 5, e9440.

Vu, N. T., & Nguyen, T. V. A. (2016). Ethnic Fermented Foods and Beverages of Vietnam. In J. P. Tamang (Ed.), *Ethnic Fermented Foods and Alcoholic Beverages of Asia*, (pp. 383-409). New Delhi: Springer India.

Wanwimolruk, S., Kanchanamayoon O., Phopin, K., & Prachayasittikul, V. (2015). Food safety in Thailand 2: Pesticide residues found in Chinese kale (Brassica oleracea), a commonly consumed vegetable in Asian countries. *Science of The Total Environment*, 532, 447–455.

Wanwimolruk, S., Kanchanamayoon, O., Boonpangrak, S., & Prachayasittikul, V. (2015). Food safety in Thailand 1: it is safe to eat watermelon and durian in Thailand. *Environmental health and preventive medicine*, 20, 204–215.

Zaman, M. Z., Abdulamir, A. S., Abu Bakar, F., Selamat, J., & Bakar, J. (2009). A Review: Microbiological, Physicochemical and Health Impact of High Level of Biogenic Amines in Fish Sauce. *American Journal of Applied Sciences,* 6, 1199–1211.

Zaman, M. Z., Bakar, F. A., Selamat, J., & Bakar, J. (2010). Occurrence of biogenic amines and amines degrading bacteria in fish sauce. *Czech Journal of Food Sciences*, 28, 440–449.

Table 1 Contamination of raw and fermented products in Vietnam, Thailand, Cambodia and Northeast India.

Species	Samples	Origin	Place	Positive samples	Ref.
In raw products					
Salmonella	meat		HCMc		(Nguyen T. Nhung, Cuong, Thwaites, & Carrique-Mas, 2016)
	pork		Hanoi	25%	Toan et al. (2013)
	pork	Wet market	Hung Yen	32.8%	Takeshi et al. (2009)
	pork	Wet market	Hue	44%	Dang-Xuan et al. (2017)
	pork			11.6%	Nguyen et al. (2016)
	meat	Open markets	Bangkok /Pathum Thani	83%	(Ananchaipattana, et al., 2012)
	meat	supermarkets	Bangkok /Pathum Thani	67%	(Ananchaipattana, et al., 2012)
E. coli	Poultry	Factories, school, hospital canteens	Hanoi	45%	(Dao & Yen, 2006)
	Raw meat (beef, pork)			21.3%	
	Fish			6.6%	
	Veg.			18.5%	
Campylobacter			Vietnam	10%	Nguyen et al. (2016)
			Vietnam	15-32%	Carrique-Mas et al. (2014)

			Mekong delta	53.7%	
In fermented products					
Enterococcus sp.	vegetables	5 wet markets	Phnom Penh	34%	Chrun, Hosotani et al. (2017)
Bacillus sp.				31%	
coliforms				24%	
E. coli				10%	
E. coli	cucumber	22 sellers from 11 wet markets	Phnom Penh	4/11 markets	Tan Reasmey (unpublished data)
coliforms				9/11 markets	
S. aureus					
E. coli	pork and fish	Open markets	Bangkok /Pathum Thani	18%	Ananchaipattana et al. 2012
Salmonella				9%	
Staphylococcus				9%	
Listeria				0%	
Bacillus cereus	soybean	markets	North-east India	100%	Keisam et al. 2019
	bamboo			13%	
Clostridium botulinum	Soybean			60%	
	Bamboo			15%	
	Fish			44%	
	Milk			4%	
	pork			74%	
E. coli	Soybean			13%	
	milk			100%	
Proteus mirabilis	soybean			100%	
	pork			100%	
Salmonella	Nem chua	Along chain	Hanoi	35.2%	(Le Bas, et al., 2008)
Salmonella	Nahm		Bangkok	20%	(Osiriphun, Pongpoolponsak, & Tuitemwong, 2004)

Table 2 Minimum and maximum BAs content in some fermented soybean product. BAs concentration is expressed in mg/kg. Modified from Mah et al. (2019)

Fermented soybean product	**TRP**	**PHE**	**PUT**	**CAD**	**HIS**	**TYR**	**SPD**	**SPM**
Cheonggukjang	ND-236.4	ND-40.8	ND-121.3	ND-20.2	ND-755.4	ND-2539	ND-59.2	ND-14.7
Chunjang	13.3-31.35	ND-11.8	3.26-28.59	ND-6.6	1.85-272.55	19.78-131.27	0.24-12.8	ND-2.9
Doenjang	ND-2808.1	ND-8704	ND-4292.3	ND-3235.5	ND-2794.8	ND-6616.1	ND-8804	ND-9729.5
Doubanjiang	ND-62.43	1.43-185.61	1.15-129.17	ND-0.17	ND	ND-25.75	ND-0.18	ND-1.69
Douchi	ND-440	ND-239	ND-596	ND-191	ND-808	ND-529	ND-719	ND-242
Gochujang	ND-36.6	0.7-24.8	2.5-36.4	ND-18.1	0.6-59	2.1-126.8	ND-14.5	ND-1.8
Miso	ND-762	ND-11.76	ND-23.2	ND-201	ND-221	ND-95.3	ND-28.31	ND-216
Natto	ND-301	ND-51.5	ND-43.1	ND-42	ND-457	ND-300.2	ND-478.1	ND-80.1
Soy sauce	ND-45.8	1.5-121.6	2.5-1007.5	0.7-32.3	3.9-398.8	26.8-794.3	1.5-53.1	ND-16.1

TRP: tryptamine, PHE: β-phenylethylamine, PUT: putrescine, CAD: cadaverine, HIS: histamine, TYR: tyramine, SPD: spermidine, SPM: spermine

Table 3 Range of histamine concentrations found in Asian fish products

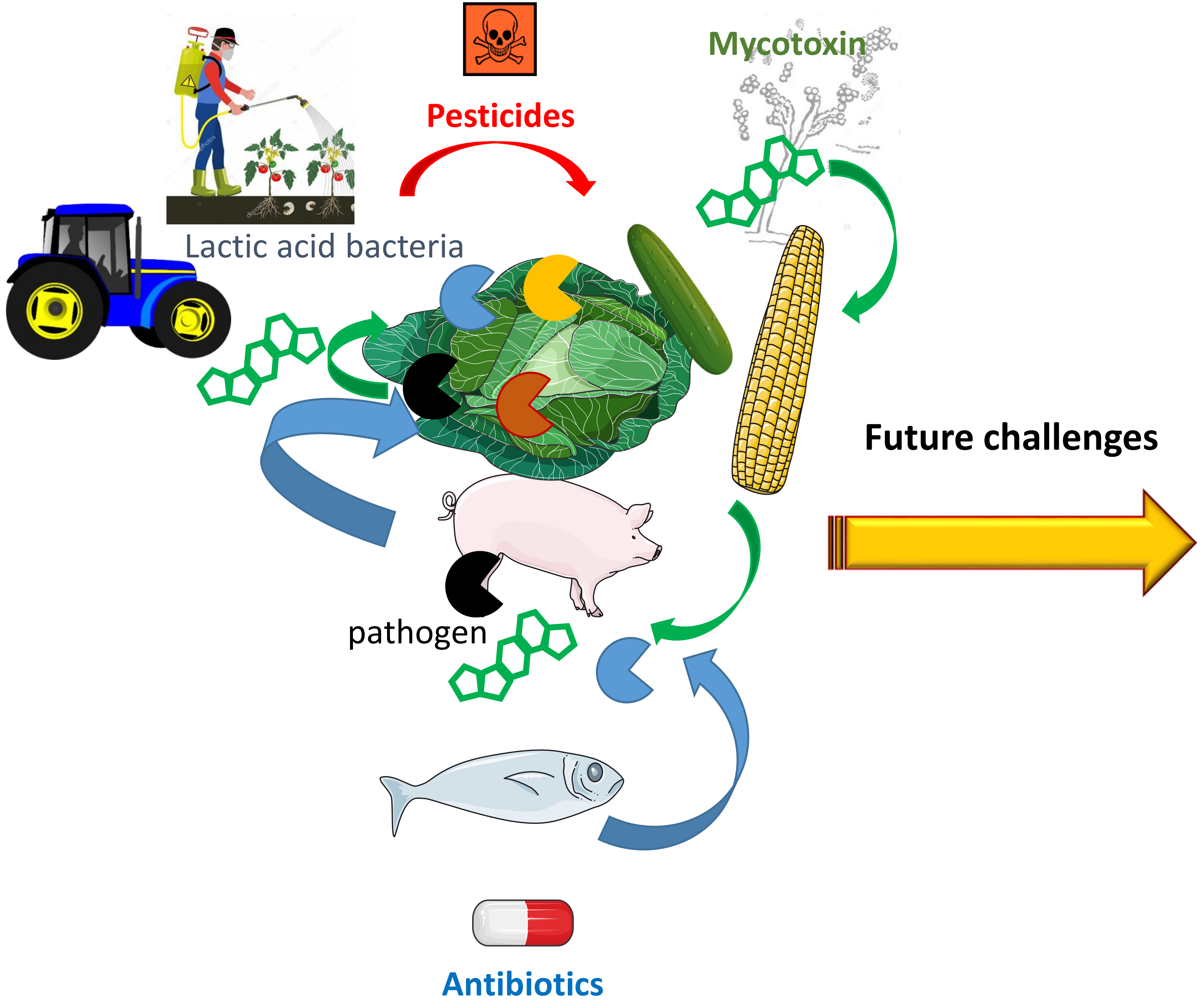
Product	Origin	HIS (mg/kg)	References
Fish sauce	Taiwan	45–1220	Tsai et al. 2006
Fish paste		0.1–760	
Shrimp paste		20–1180	
Anchovy sauces	Malaysia	63–393	Saaid et al. 2009, Zaman et al. 2010
Thai fish sauce (Som-fug)	Thailand	55.1-291	Riebroy et al. 2004
Ikan pekasam from black tilapia	Malaysia	18.8-71.3	Ezzat et al., 2015
Ikan pekasam from javanese carp		12.7-109.1	

Table 4 Antibiotic resistance of LAB isolated from Asian traditional fermented food products

Raw material	**Country**	**Product**	**LAB**	**Phenotypic antibiotic resistance**	**References**
Milk	China	Yogurt	*Lb. acidophilus, Lb. brevis, Lb. fermentum, Lb. plantarum, S. thermophilus*	ERY, TET	Nawaz et al. (2011)
	India	Dairy products	*E. casseliflavus, E. faecium, E. durans, E. lactis, Lb. fermentum, Lb. plantarum, P. pentosaceus, Ln. mesenteroides*	ERY, TET	Thumu and Halami (2012)
	Indonesia	*Dadih*	*Lb. fermentum, Lb. plantarum, P. acidilactici*	CHL, ERY	Sukmarini et al. (2014)
Meat	Indonesia	*Bekasam* or *tempoyak*	*Lb. fermentum, Lb. plantarum, P. acidilactici*	CHL, ERY	
Vegetable	China	*Jiang shui*	*Lb. plantarum*	TET	Nawaz et al. (2011)
		Pickle	*Lb. salivarius*	ERY, TET	
Cereal	India	*Idli* batter, *dosa* batter	*E. casseliflavus, E. faecium, E. durans, E. lactis, Lb. fermentum, Lb. plantarum, P. pentosaceus, Ln. mesenteroides*	ERY, TET	Thumu and Halai (2012)
Rice + ragi	Indonesia	*Tape ketan*	*Lb. fermentum, Lb. pantarum, P. acidilactici*	CHL, ERY	Sukmarini et al. (2014)

CHL, chloramphenicol; ERY, Erythromycin; TET, tetracycline

Figure 1°: Pre-processing



- Organic agriculture
- Standards and certifications
- Crop rotation and intercropping with nitrogen
- fixing leguminous crops
- Integrated pest management using biological controls
- Good practices
- Training

Figure 1B: Processing and post-processing