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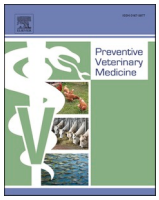
Preventive Veterinary Medicine 214 (2023) 105906

Contents lists available at ScienceDirect

Preventive Veterinary Medicine

journal homepage: www.elsevier.com/locate/prevetmed



Mapping chicken production and distribution networks in Vietnam: An analysis of socio-economic factors and their epidemiological significances

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ARTICLE INFO

Keywords:
Value chain mapping
Interdisciplinary analysis
Production and distribution network
Epidemiological significance

ABSTRACT

The growing chicken industry in Viet Nam has an increasingly important contribution to the country's food security, but its development requires careful planning to prevent disease risks. This study characterizes the chicken production and distribution networks in Vietnam and identifies potential factors that could promote disease emergence and transmission. Qualitative data were collected from interviews with 29 key informants from five stakeholder groups representing the main nodes from chicken production and distribution networks (PDN). Three main networks were identified based on production type: a colored broiler and spent hen network, a white (or exotic) broiler network, and an egg network. Colored chickens and spent hens are the most preferred commodity by vietnamese consumers and their PDN is composed of production units differing in their scale and management and with long distribution chains involving numerous small-scale independent stakeholders. Live bird markets plays a central role in this network, which is driven by consumers' preference for live chickens. The white chicken network presents an important duality, as it is composed of both a large number of independent household farms and traders operating independently with little chain coordination, and of large farms contracted by vertically-integrated companies. The egg PDN was the most organized network, being mostly controlled by large vertically-integrated companies. High level specialization and diversification of stakeholders is found in all three networks. Stakeholders' perceptions of the main factors promoting disease risk along the PDN were the low biosecurity in household farms and live bird markets, mobile traders, the informal slaughter of birds and the management of sick birds. Findings from this study can be used to plan future studies to support food system planners in the development of safer poultry production and distribution in Vietnam.

1. Introduction

Over the last five years, average poultry meat consumption per capita in Vietnam has increased from 5.6 kg/capita in 2010–8.1 kg/capita in 2015 and to around 10.0 kg/capita in 2020 (Department of Livestock Production, 2019). In 2020, the Vietnamese poultry sector produced over 1 million tons of poultry meat and over 11 billion eggs (FAO, 2020). Although most poultry meat produced in Vietnam is

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https://doi.org/10.1016/j.prevetmed.2023.105906
Received 2 November 2022; Received in revised form 22 February 2023; Accepted 22 March 2023
Available online 24 March 2023

channeled towards domestic consumption, poultry exports are gradually increasing both in term of quantity and product types. In 2018, Vietnam exported 1.5 million birds for breeding, 8000 tons of processed chicken meat, and 11 million salted eggs. However, Vietnam is also an importer of chicken meat, importing around 86,000, 122,000 and 128,000 tons of chicken meat in 2016, 2017, and 2018 respectively, equating to around 13% of domestic consumption (Department of Livestock Production, 2019; Vietnam National Assembly, 2020). Other imports includes around 21 million tons of materials annually to produce feed for poultry and aquaculture production (Ministry of Agriculture and Rural Development and Department of Livestock Production, 2021).

While the poultry sector significantly contributes to people's health and livelihoods, it can also generate health risks for both animals and people (Department of Animal Health, 2018). High disease incidence was considered one of the major challenges for poultry production (Yitayih et al., 2021). Common production poultry diseases such as Fowl Pox, Coccidiosis, Newcastle disease, Infectious Bursal Disease, Bronchitis, and Coccidiosis affect almost all production systems (Delabouglise et al., 2017; Carrique-Mas et al., 2019), particularly small-scale production, due to limited disease prevention and treatment (Phan Dang et al., 2013). Multiple zoonotic, including foodborne, pathogens, such as Non-Thyphoid Salmonella, Campylobacteriosis, Toxoplasmosis and Trichinellosis, are also endemic in the Vietnamese poultry population (Conan et al., 2012; Maki et al., 2019; Pan and Yu, 2014; Pham-Thanh et al., 2022; Truong et al., 2021). For example, highly pathogenic avian influenza (HPAI) outbreaks have caused the death of millions of poultry in 2003–08, due to the disease itself or control efforts, with an economic cost estimated at US$200 for this period. The frequent detection of the virus in live bird markets suggest that the disease still affects poultry production and therefore the livelihood of farmers (Burgos et al., 2008; Cuc et al., 2020). Understanding the drivers of zoonotic disease dynamics requires an interdisciplinary approach to analyze jointly the biological, environmental and the socio-economic and political factors potentially shaping disease transmission. The role of environmental factors, such as local geography, humidity, temperature, and seasonality are often emphasized by epidemiological studies (Park and Glass, 2007; Lipsitch and Viboud, 2009; Thai et al., 2015). Other studies have investigated the impact of other variables on the occurrence of poultry related health hazards, including poultry farm management (e.g. stocking density and biosecurity) (Desvaux et al., 2011; Conan et al., 2012; Nguyen et al., 2015; Delabouglise et al., 2019), the management of poultry on marketing sites, cold chain capacity and consumption preferences (Fournier, 2009; Lachat et al., 2009; Marisa, 2010; Sealy et al., 2019; Soares Magalhães et al., 2010). Consequently, improving biosecurity was identified by the Vietnamese government and the Food and Agriculture Organization of the United Nations as a key strategy to prevent introduction and spread of infectious diseases in the future (FAO, 2020: Cuc et al., 2020), which can help improved productivity and profitability of farms (Truong et al., 2021).

A joint analysis of climatic and socio-economic factors has also revealed how these variables shape the complex spatiotemporal dynamics of avian influenza viruses (Delabouglise et al., 2017). However, to date, research conducted in Vietnam often only focuses on a single segment of the production and distribution networks (PDN) and fails to provide a holistic view on the network as whole. Thus, our ability to assess the influence of multiple actors within the PDN, the power and incentives structures within, and ultimately how disease risks are created along PDN are limited. Consequently, there is currently insufficient available information on the structure of the poultry food systems in Vietnam for planning and policy purposes. Given the rapid growth of the sector and the continuous threat of diseases, it seems essential to assess the way in which the structure of the chicken PDN may promote the generation of major disease risks and affect its recovery from shocks (e.g. large HPAI outbreaks) that may have food security and economic consequences. Developing such an understanding is critical to guide the design of interventions including alterations of the PDN configuration aiming to minimize disease risks. This study aims to characterize the chicken PDN in Vietnam and collect and discuss stakeholders' perceptions of major structural factors associated with disease risk generation and mitigation.

Our analysis builds on value chain framework to understand public health risks. This framework is considered a valuable approach in evaluating and reducing risks in chicken production and consumption (Alarcon et al., 2017, 2021; Antoine-Moussiaux et al., 2017; Carron et al., 2017; FAO, 2011). Employing a value chain approach helps researchers, on one side, to map and understand the production and marketing systems and the operations involved. This then allows identification of potential points where pathogens can enter the network, amplify and disseminate, including the cross-contamination of products. It can help assessing the level of human and poultry exposure to given pathogens along the PDN. For example, it can indicate the type of consumers exposed to a specific commodity that is distributed via a particular high-risk chain within the network, or the type of stakeholders involved in the generation of this risk. Characterizing the structure of the PDN can generate insights about its governance, i.e. the level of coordination and power asymmetry along the chains, through understanding of the institutions involved and their interactions, existing rules (formal, private and cultural norms), incentives, barriers to entry and the value extracted by the different stakeholders involved (Alarcon et al., 2021). The governance can contribute to a better understanding of existing risk behaviors and the complexity for implementation and coordinating disease control policies. This approach has been used to identify and explain the possible critical control points for pathogen control along poultry food systems, and understand behaviors of different stakeholders involved (Alarcon et al., 2017; Aslam et al., 2020; Carron et al., 2017; Hennessey et al., 2021; Indrawan et al., 2018; Truong et al., 2021; Mubamba et al., 2018; Taylor et al., 2010) . For example, Indrawan et al. (2018) investigated the governance of poultry value chain in Indonesia to explain implementation of HPAI control measures, and suggest more effective intervention. Value chain analysis can then provide the basis for an in-depth assessment of the risks associated with the network, or be combined with other tools, such as social network analysis, to identify nodes that may act as risk hot spots and inform disease surveillance (Mubamba et al., 2018). Yet, while analyzing the value chain is helpful, the notion of "*chain*" implies that products and services are a result of a series of linear activities at national or international level (Farnworth, 2011), which has been criticized to be narrow. Thus, in this research we then use the term "*production and distribution network*" (PDN) to emphasize the complex network of activities carried out by different stakeholders (Hennessey et al., 2021) and the importance of actors' functions as well as their capability, visibility, voice, and market share that helps to understand the barriers and challenges in the collaborations needed for effective actions in the management of animal health. Furthermore, understanding the way in which the network configuration may vary, depending on the different types of poultry and poultry products considered and the type of institutions and environment involved, can generate a finer understanding of the process underlying disease risk generation and targets for risk mitigation interventions.

2. Materials and methodology

2.1. Data collection

Data was collected via literature review and interviews with key informants (KIs). The literature review conducted was done to develop an overview of chicken production in Vietnam, the distribution of chicken commodities, their consumption and exportation. Five types of key informants, representing various stakeholder groups, were recruited as shown in Table 1. These were selected based on their high level expertise and knowledge of the overall network, segment or the network or specific nodes within the network. Hence, we selected group

Table 1
Key informant interviews (KIIs).

KI types	Position	Number of KIIs	Province
Type 1: National and local governmental stakeholders	Senior officer Dept of Animal Health; Dept of Livestock Production; Dept of Agrotrade	3	Hanoi
	Senior officer Sub-Dept of Animal Health; Sub-dept of Livestock Production	2	Hai Duong
Type 2: Stakeholders from the private sector	Manager of Integrated company on coloured chicken	1	Bac Ninh
	Manager of Integrated company on both coloured and white chicken	1	Bac Ninh
	Private veterinarian at a poultry company	2	Hanoi
Type 3: Representatives of workers/producers	Representatives of farmer association	1	Hai Duong
	Owner of laying hen farm	1	Hai Duong
	Owner of coloured chicken farm	3	Hai Duong
	Owner of white chicken farm	2	Hai Duong
	Owner of Hatchery/incubator	2	Hai Duong
Type 4: Representatives of distributors	Owner of slaughter house	3	Hai Duong
	Coloured chicken trader	2	Hai Duong
	White chicken trader	2	Hanoi
	Egg trader	2	Hai Duong
Type 5: Representatives of regional/national research and educational institutions	Senior researcher in animal sciences	1	Hanoi
	Senior researcher in veterinary science	1	Hanoi
Total		**29**	

representatives and government officers who are used to work with multiple stakeholders along the PDN and are familiar about the diversity of people within the network or nodes (e.g. farms). Particular PDN actors (traders, farmers, etc.) with extensive experience were also interviewed to further understand the PDN and validate responses obtained by other key informants. The key informants were identified through the authors' contact network and using a snowball approach. When a new element was identified in the network (such as a new actor, product, or location), key informants were asked to recommend other informants knowledgeable about it. Two rounds of key informant interviews were conducted in October-December 2019 and in September-December 2020 in Hanoi, Bac Ninh and Hai Duong provinces where key informants' workplaces were located. The second round of interviews allowed us to address knowledge gaps identified through the analysis of the first-round data. A total of 29 KIs interviews were conducted.

An interview guide was developed by the authors in English for each type of KIs. These interview guides were then translated in Vietnamese. The guide was divided in four sections to collect data on: 1) the role of key informants; 2) the structure of the PDN and the types of stakeholders involved; 3) informants' perceptions on the nodes (defined here as a particular point in the network where poultry inputs, live poultry or meat are being sold, moved, raised or processed) and behaviors that may generate disease risk affecting the system; and 4) their experiences on the challenges that stakeholders face for the control of poultry diseases or health hazards. The first author and other Vietnamese authors conducted the interviews and translated the transcripts to English.

To map the chicken PDN, the interviewer drew a flowchart diagram of a particular subset of the PDN based on instructions from the KI. In the process of creating the diagram, the KI was asked to describe the actors involved, the PDN nodes, the type and number of commodities, and how these varied spatially. When possible, KIs were asked to differentiate amongst stakeholders and nodes based not only on the type of activity, but also on other characteristics such as the size of operations (e.g., farm size), level of association or integration, type of commodities involved, and any other factor deemed relevant by the KI. All interviews were conducted in Vietnamese. Interviews took place at the KI's workplace, allowing us to observe farms, slaughterhouses, and markets where Kis of type 3 and 4 operated. Field notes and audio-records of interviews were transcribed.

2.2. Data analysis

All transcriptions were carefully read, coded, and entered in templates. A template was a file with tables used to collate data on the KI information (e.g., position, experience, etc.); structure of the chicken PDN; movements of chickens and chicken products; interactions between stakeholders, factors influencing disease risk, food safety and quality and PDN governance. The flow diagram developed with the KI was also placed in the template. One template was created per KI interview.

Data analysis included two parts. First, the research team combined all collated data to identify the different components of the PDN. KIs were contacted by telephone if there was a need to clarify any information they provided. A flowchart diagram (PDN mapping) detailing the involved actors and representing the movements of chickens or chicken products were developed for each network through discussions among the research team to build a common understanding of the data and minimize subjective bias in their interpretation(Bordier et al., 2018). The PDN was mapped following the protocol developed by Alarcon et al. (2017). For this, the PDN was disaggregated into color chicken, white chicken and egg production networks. The mapping attempted to incorporate the diversity of stakeholders between and within nodes, according to the differentiation given by stakeholders or as identified in the literature. Based on the KI responses, the magnitude of the flow of chickens and products was indicated qualitatively by the size of the arrows, to help visualize the major flows within the system.

A manifest content analysis was conducted using a process of familiarization with the interviews data, and re-coding of the codes entered in the templates. This analytical method is a descriptive approach that is used to categorize the interview data into groups or topics, as described by (Bengtsson, 2016). This analysis attempted to remain close to the statements and words used by the KIs to clearly describe the activities and factors involved in the PDN. All the analysis was done by the first author. The last author reviewed the codes and grouping done for three interviews for validation purpose. The results where then discussed by all authors.

2.3. Ethic

The ethic of this study was approved by the London School of Hygiene & Tropical Medicine, UK (ref.10214 − 1).

3. Results

3.1. Classifications and overview of chicken production in Vietnam

Chicken breeds and farming systems in Vietnam are diverse with various classifications of chicken production units (Burgos et al., 2007).

The current classification adopted by the Vietnamese government is based on the scale of production, differentiating farms into: large-scale (above 300 livestock units where one production unit equals 500 kg of livestock), medium-scale (30–300 units), small-scale (10–30 units) and household farms (less than ten units) (Vietnamese National Assembly, 2018; Vietnam National Assembly, 2020). We use this classification along with the patterns of production collected from interviews to categorize the main chicken types and chicken production systems (Table 2).

Colored chickens refer to indigenous and hybrid breeds and are popular across Vietnam. Hybrid colored broilers are the cross between indigenous cocks (mainly Ho, Choi, Dong Tao and Mia) and exotic hens (such as Luong Phuong, Tam Hoang, Isa brown, JA57, Redbro, Sasso, Kabir and others) (Yitayih et al., 2021) described there being 30 Vietnamese indigenous breeds and 24 hybrid breeds in Vietnam. Colored chickens account for 72% of the total broiler population with the rest composed of white chickens. The production and consumption of colored chickens have been increasing in recent years due to increasing consumer preference and income (Ifft et al., 2009, Department of Livestock Production, 2019). The colored chicken PDN is based on a variety of business models and type of farms, with limited vertical integration. In contrast, white chicken PDN presents a duality between a vertically integrated system and an informal system involving traders and live bird markets. Most white chicken production occurs in large-scale farms producing up to 100,000 birds per cycle in environmentally controlled houses. For egg production, the PDN is mostly dominated by large companies and composed of large-scale households, company-owned or contracted farms that raise 2000–10,000 birds per cycle. The majority of laying hen breeds are exotic to Vietnam, such as Leghorn, Goldline 54, Brown Nick, Hyline, Lohmann Brown, Hisex Brown, ISA Brown, Babcock- 380, Novogen (Novo White and Novo Brown), Isa Warren, I Shaver, Dominant, Egypt, Newhampshire Godollo, Yellow Godollo. A small proportion of the eggs consumed are raised in backyard farms. These are typically small-scale household farms with a flock of several to a dozen local breed hens, kept under free-ranging conditions with on-farm breeding. Eggs may be used for household consumption and/or sold at local markets.

3.2. Chicken production and distribution networks

3.2.1. Colored broiler and spent hen PDN

Fig. 1 shows the colored broiler and spent hen PDN. In Vietnam, spent layers are effectively treated and seen as colored broiler, and hence share the same PDN and have similar prices. For this reason, we present both type of birds together in this section. However, more details on the type of production systems of layer birds are shown later when describing the egg PDN.

Colored chickens for broiler are produced in large-scale farms, contracted or independent household farms. Chickens are raised in cycles and grown for 70–105 days until achieving a body weight of around 2.5 kg. Indigenous chickens were found to be mainly kept in backyard farms, where they are raised as one flock that combines all kinds of chickens across different age groups (reproductive hens, cocks, chicks, and young chickens).

Most large-scale independent and contracted farms buy day of chicks (DOCs) from breeding companies, which in turn import grandparent exotic chickens. These companies normally sell DOCs to farmers through their own agencies located in each province or through independent agencies or traders. However, some companies reported selling some DOCs directly to the farms. Most household and backyard farms buy DOCs or older chicks from household hatchery farms. These household hatchery farms have their own breeding stock or co-own an incubator with others and use it to produce DOCs from to buy fertile eggs they purchase from breeding farms. Some backyard farms incubate their eggs or buy chicks from local markets; however, this type of farm is reducing in number. There is also a very small proportion of farms that buy DOCs from public research institutions. Layers are bought by farms as DOCs or growers from companies or research institutes and raised for egg

Table 2
Typologies within the chicken production and distribution network in Vietnam.

Indicator	Colored chicken	White chicken	Layer
Farms business model	-Predominantly household farms- Backyard	Mostly composed of household and contracted farms	Predominantly company and contracted farms
Production purpose	-Commercial -Home consumption	- Commercial	-Commercial -Home consumption
Breed of chicken	-Indigenous breeds: Ho, Choi, Dong Tao, Mia, -Hybrid breed: Crossing between local breeds and exotic ones (Luong Phuong, Tam Hoang, Isa brown, JA57, Redbro, Sasso, Kabir,)	Arbor Acres (AA); Hubbard	ISA, Ross; Avian; Lohman; Cobb; Hubbard, indigenous breeds
Farms size	Various farm sizes: Large-scale: 2000–10,000 birds, Medium scale:100 to < 2000 birds Small scale: < 100 birds	Large-scale and medium scale from 2000–100,000 birds	-Large-scale: 2000–5000 birds -Small scale: ~10 hens
Type of housing	- Modern close housing and facilities. - Open housing. - Free range	Modern close housing and facilities	-Modern close housing and facilities -Free range
Length of production cycle	70–105 days	35–52 days	16–18 months
DOCs sources	-Hatching households -Hatching companies, - Self-supply	Hatching companies	-Hatching companies -Self-supply
Feed sources	- Self-supply, -Feed companies, -Local animal feed stores -Scavenging	-Feed companies, -Local animal feed stores	-Self-supply, -Feed companies. -Local animal feed stores - Scavenging
Disease management	Various levels of biosecurity from high to low biosecurity	Predominantly high level of biosecurity	Various, from high to low level of biosecurity
Main products	Fresh Broiler chicken	Fresh and frozen broiler chicken	Egg/DOCs/spent hens
Distribution of commodities	Self-consumption, Live bird markets, restaurant	Supermarket, canteen, restaurant	Self-consumption, Live bird markets
Destination of final products	Domestic	Domestic and Export	Domestic and export

Source:(Vietnam National Assembly, 2020, Ministry of Agriculture and Rural Development and Department of Livestock Production, 2021)

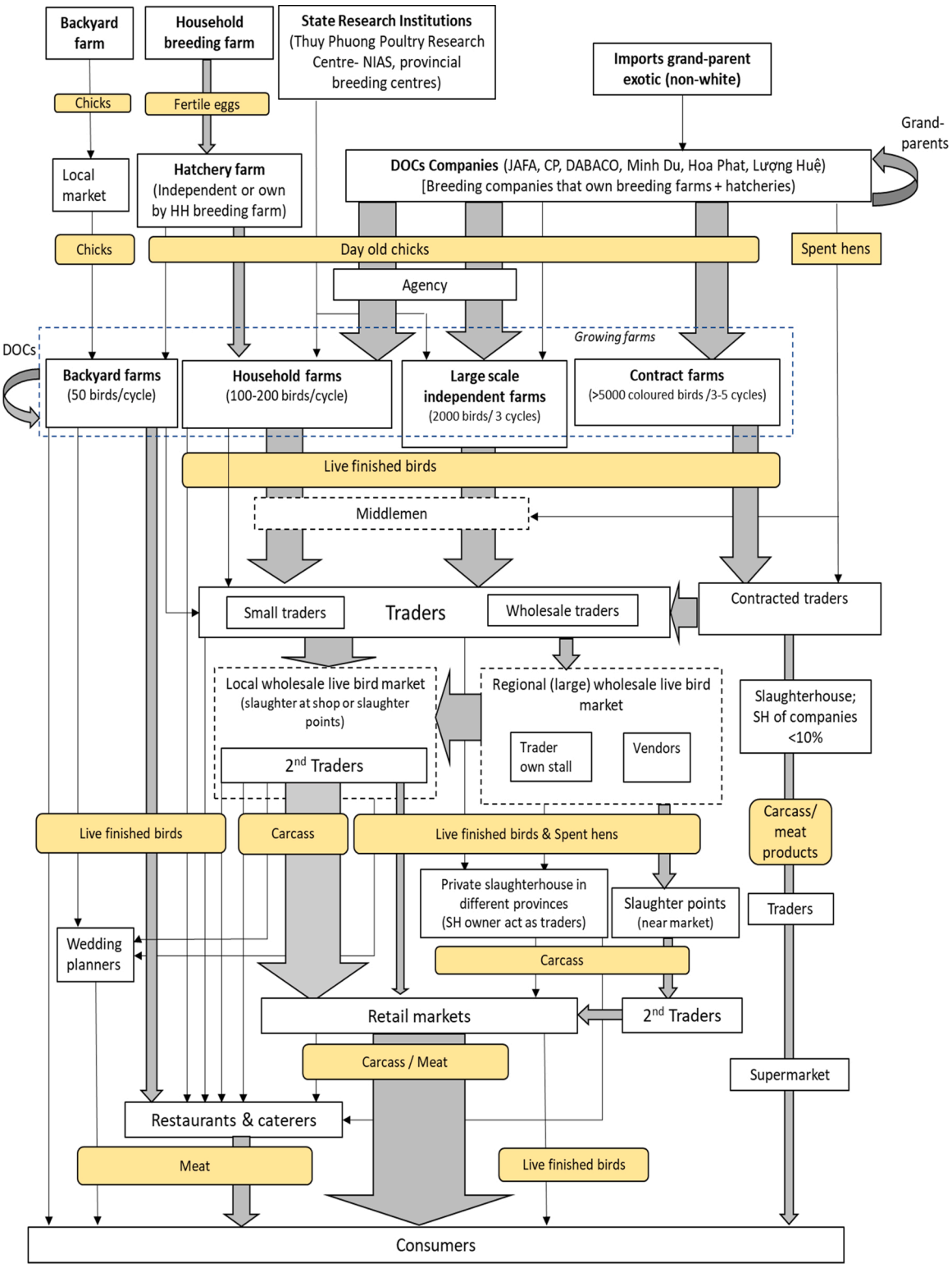

Fig. 1. : Production and distribution network of colored chicken and spent hens. White boxes represent stakeholders in the system, while round orange boxes represent commodities (animals or products). The widths of the arrows represent the relative importance of a given flow in the network.

production. Layers are usually kept up to the age of 16–18 months, when egg production decreases, spent hens are then sold as colored broiler chickens.

At the distribution stage, the sales of live colored broiler from household farms to traders is generally mediated by middlemen. Middlemen are independent actors who help traders collect chickens from farms and have information about the market price, the quality, and number of chickens of each farm in the region. Traders pay middlemen for their service and sell birds to other traders in local wholesale live bird markets (LBMs) where birds are slaughtered at the back of a shop and sold to retailers or final consumers. Chickens are classified into 3 types based on their quality:

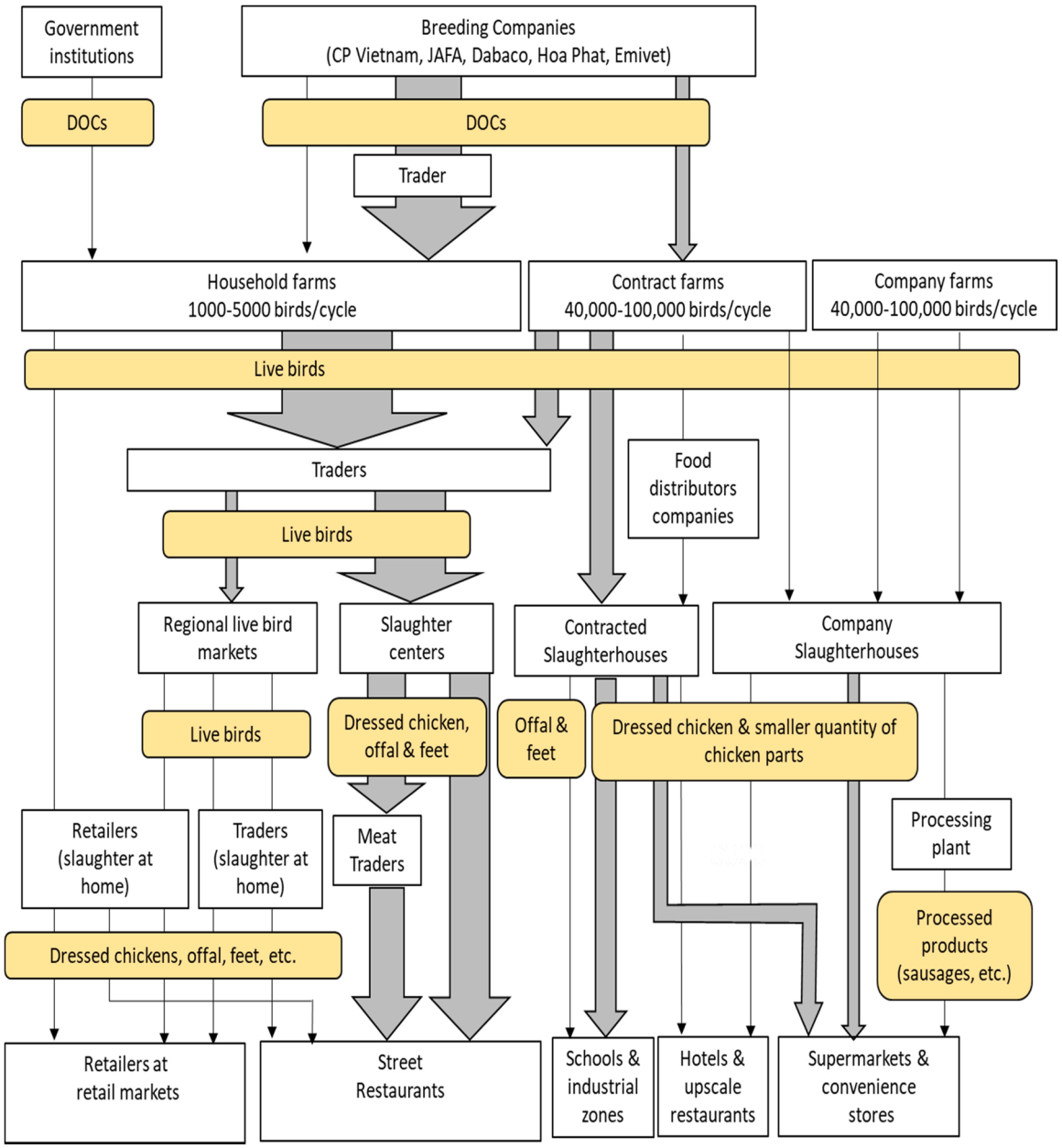

Fig. 2. White chicken production and distribution network. White boxes represent stakeholders in the system, while round orange boxes represent commodities (animals or products). The widths of the arrows represent the relative importance of a given flow in the network.

- Type 1- Feather chicken (gà lông): These are chicken with beautiful and smooth feather. The color of the feather is typical for its breed, have beautiful comb, and reaches require standard weight (2.5 kg). This type has the highest market value.
- Type 2 - the feet chicken (gà chân): this chicken reaches the standard weight but has either no feather, ruffle or ragged feather or the feather is broken and has no comb.
- Type 3 – discarded or "ugly" chicken (gà loại): This chicken does not reach the standard weight, presents signs of malnutrition and has no feather. This category includes sick chickens, with some traders specialising in the trade of such birds. These have the lowest market value.

Retailers can also buy live birds directly from provincial-level wholesale LBMs. Examples of such markets are Tien Mon market in Bac Giang province and Kim Thanh market in Hai Duong province. Birds are then culled at the slaughterhouses at the market and sold to customers (e.g., wedding planners, event organizers, small restaurants, and consumers.

Regional-level wholesale LBMs operate larger scale, trading up to 100–120 tons of bird meat per day (Ha Vy market in Hanoi and Tan Yen market in Bac Giang province). Most chickens are sold and transported to local LBMs on the same day they enter in the regional wholesale LBMs. Other chickens are kept in stalls overnight then sold and transported to retail markets where they are slaughtered at point of sale to customers. Slaughtering facilities and practices greatly differed depending on markets. For instance, many informal slaughtering facilities are set up in houses located in the vicinity of Ha Vy market. While retailers in most markets provide slaughtering services at the back of their shops, such practices are often prohibited in LBMs located city centers (especially Hanoi) as where live birds are banned. Retailers operating in Hai Duong province can get birds slaughtered in a dedicated slaughterhouse outside the LBMs.

Only an estimated 10% of birds produced on contracted farms are

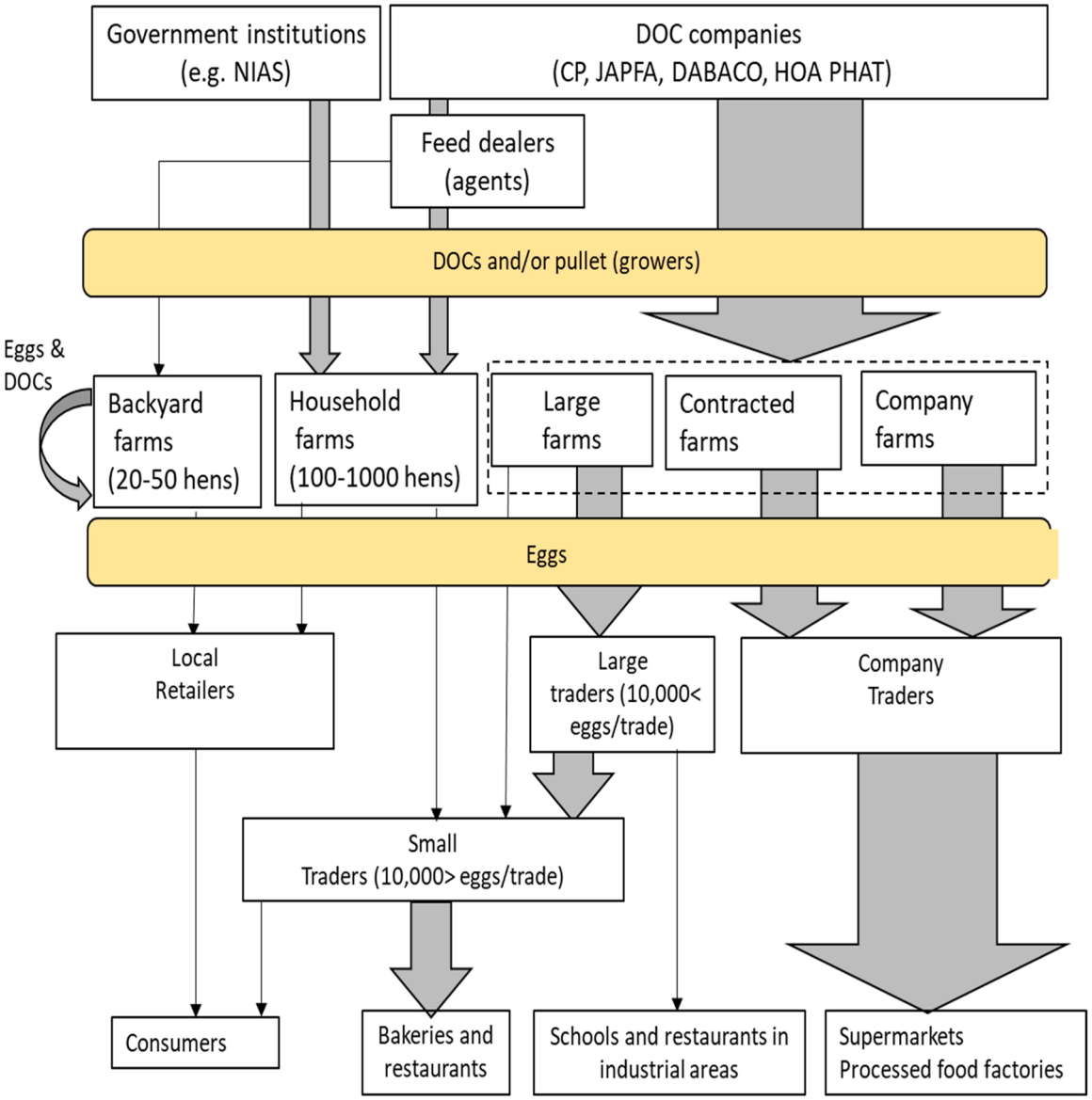

Fig. 3. : Egg production and distribution network. White boxes represent stakeholders in the system, while round orange boxes represent commodities (animals or products). The widths of the arrows represent the relative importance of a given flow in the network.

slaughtered in companies' own slaughterhouses and distributed to supermarkets. The majority of birds are sold to traders working for the integrators, who then sell birds on to other traders at local, provincial or regional LBMs. A small proportion of chickens are sold directly from farms to restaurants and caterers. Similarly, a small proportion of chickens are bought directly from backyard farms by consumers who then slaughter chickens at home.

Spent hens are sold to traders. Contrary to colored broilers, middlemen do not mediate the transaction. Spent hens are then sold in LBMs, mostly at provincial and regional levels, since spent hens are favored by restaurants, which are numerous in urban centers, to prepare Pho (a popular soup dish in Vietnam). In Ha Vy market, there is a dedicated section supplying spent hens to retailers who then slaughter the birds and sell meat to restaurants and consumers in Hanoi. The distribution and price of spent hens is the same to that of colored broilers. Sometimes the price of spent hens is even higher as the demand for spent hens is high, but supply is low.

3.2.2. White broiler PDN

Large companies such as Japfa Comfeed, CP Vietnam and Emivest supply a large number of white chickens to Vietnam (Fig. 2). Three of these are part of large international companies that are managed by foreign capital; the Japfa group is based in Singapore; Charoen Pokphand Foods Public Company Limited, owner of CP Vietnam, is based in Thailand; Leong Hup Group, owner of Emivest, is based in Malaysia. These companies have their own farms and operate with contracted farmers. Some farmers also raise white broilers independently, i.e., without contractual arrangements with these companies.

Batch sizes in this PDN vary from a thousand heads per cycle in household farms to up to 100,000 heads per cycle in contracted farms. Almost all white broilers are raised under industrial conditions: modern housing with air ventilation, fan, automatic drinking tap and troughs, closed houses, and industrial feed. Chickens kept in houses have the same age (one batch), but farmers may have different batches in different sheds. White broilers are raised for 35–52 days and then sold to traders in one to two days. Once vacated, houses are cleaned, disinfected, and kept empty for one to two weeks before starting a new batch. Four to six cycles are produced per house each year. Contracted farms were reported to have better environmentally controlled houses and biosecurity practices (sanitation, diseases control, feed, housing

conditions and others) compared to independent household farms.

Contrary to colored broiler farms, most white broiler farms, household or contracted, are considered large scale. Most independent household farms buy DOCs produced by breeding companies through DOC traders, who may also act as feed dealers. Few household farms buy DOCs directly from breeding companies or government research institutions. Almost all chickens in household farms are sold to traders. In the contracted farms, companies provide DOCs and other production inputs and services to their contracted farms. Contracted farms sell their chickens to back to the large companies at an agreed price. On occasion where contract farms produce more than companies' requirements, they can sell surplus chicken to independent traders. Company traders have contracts with food providers who in turn have contracts with private slaughterhouses to provide slaughtering services and the transport of dressed chicken and chicken parts to schools and industrial zones. Some food providers also have contracts with hotels or upscale restaurants who also receive the dressed chicken from contracted slaughterhouses. Some breeding companies own farms, slaughterhouses and processing plants and supply processed chicken products to supermarket and convenience stores (Japfa and CP for example). Interviewed company officials reported a wide variation in the fraction of white chickens produced on a company's owned and contracted farms that are then slaughtered at the company's slaughterhouses.

Most white broilers from household farms are transported to slaughter centers where birds are slaughtered by traders. A small proportion of white broilers are transported to regional wholesale LBMs and purchased by retail traders who slaughter those chickens at their home. Chicken products (i.e. dressed chickens, offal, and feet) are then supplied to other retailers sold to consumers in retail markets or street restaurants. Some retailers also buy white broilers directly from farms.

3.2.3. Egg PDN

Large laying farms buy DOCs or growers directly from breeding companies such as CP Vietnam, Dabaco, Japfa or Hoa Phat directly (Fig. 3). While CP Vietnam and Japfa are owned by foreign companies, Dabaco and Hoa Phat are Vietnamese companies. All these companies also provide DOCs and growers to small farms through agents, who may also be feed dealers. Some small laying farms buy DOCs and growers from government research institutions. Most eggs sold to consumers are produced in farms contracted by these companies. Company traders collect eggs from contracted farms and sell them to supermarkets. Most eggs are sold to large-scale traders who trade about 100,000 egg per day. In addition to chicken eggs, these large-scale traders collect duck and quail eggs (either normal or balut) and other types of special indigenous chicken eggs. Large-scale traders sell eggs mostly to small-scale traders, but also to restaurants, including canteens in industrial zones and schools. Small-scale traders can thus be supplied with different types of eggs, allowing them to meet the diverse demand of final consumers shopping at the retail markets where they operate. They also buy eggs directly from small household farms, which may raise laying hens and ducks for both normal and balut eggs. Backyard farms raise chickens for meat and egg for their own consumption and occasional sales at local markets. Spent hens from laying farms are sold to traders at a similar price to colored broilers (see colored broiler and spent hens PDN).

3.3. Manifest content analysis findings

In this sub-section, we identify the underlying socio-economic factors that shape the poultry PDN described above. In doing so, we also discuss the implications for public health and factors influencing stakeholder behaviors relevant to poultry disease control.

3.3.1. Factors influencing the breeds, business operations and production types

Producers determine which chicken breeds to raise based on meat or egg productivity, consumer preferences and production costs, including measures to control poultry diseases. While Vietnamese indigenous chicken breeds are preferred by wealthier consumers – especially free-range local chickens (Ifft et al., 2009) – and are more resistant to diseases than exotic breeds, their productivity is low. On the other hand, cross breeds have higher productivity and therefore are preferred by commercial farms. Breeds produced by companies are generally considered high quality because of superior poultry genetics (introduced through grandparents and parent birds), their own hatching farms and incubators, and careful selection of their DOCs. On the other hand, household incubators can provide chicks cheaply. However, the chicks produced by household incubators display variation in breeds (i.e., diverse, or mixed breeds) and quality (i.e., variation in health of DOCs), and suffer high loss rate. The scale of production is an important factor impacting on breed selection, particularly as there is more pressure to avoid losses as the scale increases.

Related to production operation and production types, there are different levels of stakeholder specialization along the PDN. While some stakeholders concentrate on only one type of chicken and chicken product, others deal with multiple types of chickens and chicken products, and, at times, with other poultry species as well. For instance, in producing and trading live birds, some producers and traders specialize in colored chicken or in white chicken only. Other producers produce colored chicken, duck, and pigs, and many retailers trade colored chicken, duck, pigeon, and quail. Another pattern of specialization and diversification is that some stakeholders specialize in a single activity in a specific node of the PDN, while others diversify their businesses in one, several or all nodes of PDN. For instance, a producer can also be a feed and drug agent and companies involved in producing and supplying DOCs also supply feed and technical advises for farm. Contract farming arrangements between companies and contracted farms state the responsibilities of companies and farms. Drug dealers are as the first source of health advice for many independent producers who consider them to have local knowledge on infectious diseases. Chicken retailers also provide the slaughtering services.

3.3.2. Chicken demand and consumer preferences

While it is well established that chicken production has increased in Vietnam due to socio-economic changes (Delabouglise et al., 2017; Yitayih et al., 2021), our data show how consumer demand differs with consumer characteristics, chicken breeds and seasons. Wealthier consumers tend to prefer indigenous free- ranged colored chickens while poorer consumers can only afford white chickens produced in commercial farms (Ifft et al., 2009). However, most colored chickens sold as indigenous free-ranged are not raised in backyard farms, but are hybrid chickens or spent hens raised in commercial farms, with many consumers being unaware or not knowing the type of chicken consumed.

While consumers generally prefer fresh (non-refrigerated) low weigh chicken (1.2 kg), as these can be eaten in a day, their preference for different breeds of colored chickens depends on the purpose of the purchase. For instance, hot pot restaurants preferentially purchase small hens with large thighs because it is assumed that hens are better than cock for hot pot. Restaurants offering "*Pho*" – a popular noodle soup dish in Vietnam – on the other hand, prefer spent hens with thick skin and flavorful meat. These are also preferred for weddings, conferences and by hotels. Consumers look for specific local breed chickens and cocks for religious ceremonies. Balut – eggs with embryos and mostly derive from quails and ducks – are sold to beer restaurants, with the demand increasing during warm summer months.

> "I buy hen for the hot pot restaurants. Normally a hen weights about 1.3–1.5 kg which is the common weigh of a hen for hot pot. The hot pot restaurants prefer the hen with large thighs and small ones because the clients want to have a whole chicken but not a part of chicken" (A female big trader in Hai Duong province)

During autumn and winter (from August to January) which is also the wedding season in Vietnam, demand for chicken is higher than in

summer. During the main festivals, including Tet- the Vietnamese New Year, usually held in February– the demand for eggs and chickens, especially colored chickens, nearly doubles. This rising demand for chickens implies that the demand for DOCs and other production inputs also increases prior to these periods. Key wholesale markets, such as Ha Vy, a regional wholesale market in northern Vietnam, see the number of traded chickens doubling in the month preceding Tet. Demand for white broiler chickens decreases by around 20% during school holidays (June through August) and Tet, as schools and canteens in industrial zones which mostly serve white broilers as they are cheaper than colored broiler, are fully or partially closed.

These seasonal changes in demand were quoted to be one of the reasons for the volatility in the price of chicken products, alongside poultry disease outbreaks, and changing government policies regarding the imports of chickens and chicken products. Some reported that the price of chickens can vary by 40% above and below its average value within days. This was considered to be a major challenge for producers as some of the fluctuations are perceived as unpredictable, making it difficult to optimize the planning of production cycles.

3.3.3. Health risks along the PDN

PDN stakeholders adopted different strategies, resources, and rationales to manage poultry diseases. Hatchery farms (i.e., household farms with incubators) for colored chickens reported to disinfect fertile eggs before incubation and to vaccinate DOCs (vaccines mentioned were Marek, Newcastle and Gumboro disease) before transporting them to farms. Incubators are then fumigated with potassium permanganate and disinfectant is applied. At farms operated or contracted by large-scale companies, chickens, mostly white broilers, are raised in closed systems with high level of biosecurity and companies use extensive diagnostic tests to detect diseases that may affect their chickens. These farms follow standard procedures, including all-in and all-out systems in houses. Vaccination was reported to occur in breeding companies and layer farms, but not in broiler farms. Household farms have some procedures that are similar to those implemented in large-scale farms (i.e. all-in-all-out, vaccination schedule) but colored chickens are often raised in open housing surrounded by fences. The level of biosecurity in these farms are reported to be lower, with producers making decisions based on their personal experiences rather than on standard procedures set by contracting companies. Many of such farms took advantage of existing pig house, vacated due to the epidemics of African Swine Fever, for raising chickens. Household farms were also reported to not use fans and ventilator systems to cool housing during the summer, and to give low-quality feed made of restaurant leftovers. The presence of these small farms was then seen as a risk by some stakeholders. The high density of household farms was considered as a major factor in the transmission of diseases and increases in mortality. Furthermore, the quick, sale of chickens for a low price from clinically affected flocks was reported as a strategy to limit financial losses. Some farmers avoid treating chickens due to the high cost of veterinary services and drugs, and the expectation that treatments are ineffective. This practice was identified as a public health risk, as it could further promote disease transmission. Farm manure in both closed and open housing systems and in the LBMs is collected and used or sold as fertilizer, with some household farms using it to raise earthworms for fishing. Chicken faeces are collected at slaughterhouses and used to feed animals (e.g. fish). One slaughterhouse owner reported to use feathers as fertilizer for fruit trees by slaughterhouse owners or their neighbours. Dead and sick birds and broken eggs are used as feed for dogs, fish, or crocodile in nearby farms. This type of waste management was also considered a disease risk practice by stakeholders.

An important public health risk reported by KIs was the extensive use of antibiotics and other medicines in both small- and large-scale farms. Even though most farmers were reported to be aware of the danger of antibiotic misuse, the fragile health environment of farmed chicken populations means that antibiotics are considered necessary to ensure efficient and affordable production.

> "A light dose of antibiotics is used once a month for layers, but when the layer starts laying egg, the antibiotics is used less" [a layer farmer in Hai Duong province]

> "Cannot stop antibiotic use, but can only limit it, we keep advising but the climate doesn't allow it" [a manager of a breeding company]

However, some breeding companies reported to use antibiotic only for therapeutic purpose, and not for disease prevention.

The type of breed was also mentioned as a factor influencing antibiotic usage. While some stakeholders believed that indigenous breeds are more resistant to diseases because they are better adapted to local environment (i.e., suitable for open housing), others perceived that they pose a higher disease risk due to uncertainty about the type of pathogens that may infect them.

Disease risk management at the distribution nodes of the network were also mentioned. When transporting chickens from farms to LBMs or restaurants, large traders reported cleaning and disinfecting their vehicles and cages. Ice cubes are used to cool chickens during transportation in the summer. Yet, a high mortality rate of chickens was still reported due to high temperatures and a high density of birds in cages during transport. Small traders use motorcycles to transport the birds, and the cleaning of their vehicle and equipment may be irregular. One KI considered that this represents an important risk for disease transmission as it may promote the survival of pathogens. Similarly, the lack of hand washing by some traders was considered a risk. Indeed, government officers estimated that transport by traders of large numbers of chickens to LBMs or small slaughterhouses under insufficient hygiene conditions was the most important factor promoting disease transmission.

The mixing of chickens from different origins was reported as a common practice during their transport and in LBMs. Large traders collect chickens from different producers, while many small traders collect chickens from different stalls in markets. Such practices were considered as promoting pathogen transmission and dissemination among marketed chickens.

> "The big trader every day gather chicken from 40 different households. They are more likely to have the virus infected" [a government officer]

Furthermore, traders were considered as key actors in the dissemination of diseases across the country, given their pivotal role in the PDN.

> "Trading and distributing are the stages that causes the disease risks because the traders are in contact with the farms, and also with all kinds of actors in other stage from the slaughterhouse to the consumer" [a government officer]

On the other hand, hygiene measures implemented in industrial and semi-industrial slaughterhouses (the higher level of automatization processing chains with large number of slaughtered chicken) were considered to be applied satisfactorily. In these slaughterhouses, the cleanliness of slaughtering areas and tools is regularly monitored by the State Veterinary office. In contrast, there is a lack of monitoring and regulation of the way chickens are slaughtered and processed in markets, retail shops, representing, according to KIs, an important system risk.

> "At the industrial and semi-industrial slaughterhouses, the sampling is taken to control viruses, especially avian influenza viruses to monitor the slaughterhouse activities [a government officer from Sub-DAH]

3.3.4. Government regulations which influence PDN stakeholder behaviours

Government policies have focused on increasing livestock productivity (Yitayih et al., 2021) and the promotion of food security and safety

(Nguyen-Viet et al., 2017). Regarding policies specific to the poultry sector, our informants have mainly mentioned health certification as a disease prevention and control policy. Health certification is provided by the Department of Animal Health to the different PDN actors if they adhere to state regulations. It is a requirement to produce and trade chickens. For instance, traders transporting chickens between provinces must report their shipment to the relevant veterinary station for inspection and examination and must hold a quarantine certificate from the place of origin. All hatcheries must have implemented quarantine, control, and inspection. Yet, health certification is not consistently adhered to through all the PDN, creating an informal sector in the country. For instance, many traders buying chickens from multiple provinces only apply for one health certificate whereas several certificates should be required. One reason for PDN actors bypassing certification, is the fact that many household farms are not officially registered. On the other hand, large-scale farms are registered and able to implement government regulations more consistently than household farms.

One of the main challenges reported by KIs to the effective implementation of disease prevention and control activities is the changes made to the administrative system in 2017. The district veterinary, animal husbandry and agricultural departments are now combined in a unique administrative entity in charge of providing all agricultural services, including veterinary services. This change was perceived to have influenced the effectiveness of poultry disease prevention and control, as veterinary officers are now requested to carry out many administrative and business tasks and have less time to work on disease prevention and control activities.

> "The changes in Vet administrative system creates the complex administrative procedure in providing the health certificate and the task dividing within the unit. The limitations of management lead to the ineffectiveness for disease control, like to issue a health certificate, it is ok for the inner province, but it will be the problem for the inter-provinces" [an officer from the Department of Animal Health]

3.3.5. Economic considerations of PDN actors and their behaviours

Transaction costs determine the level of profit within the PDN. Our data indicate that the larger businesses benefit from lower transaction costs. For instance, large poultry grower farms are able to obtain 5% discounts from breeding companies when purchasing large volume of DOCs and feed. The cost of slaughtering services also follows this economic of scale rule, where the large abattoirs can provide a 33% discount in slaughtering fee to traders asking for the slaughtering of a large number of chickens. Similarly, large-scale incubators purchasing $>$ 15,000 eggs within 2 days were reported to benefit from a 15% discount price compared to the price paid by small-scale incubator.

Mode of payment is variable among PDN stakeholders, but the use of informal credit, as a form of late payment, was often mentioned by KIs. At the production level, feed dealers are usually paid by farmers on credit, while feed mills require immediate payment. Breeding farms usually require immediate payment, because of the risk that farmers may lose some birds during the production cycle. Large and medium scale farms that lack financial capital, are allowed to wait until they sell chickens to pay feed dealers back, but they will incur a higher price than farmers paying immediately. When selling chickens, most farmers receive payment at the time of the transaction. If traders have a good relationship with farmers, traders may make a partial payment – about 60–70% of the total purchase price – when collecting the chickens and pay the rest a few days later. These agreements are always oral and mostly between household farmers and middlemen, who are the local intermediaries facilitating transactions with traders. Contracted farms receive payment from the contracting companies once chickens are sold. Traders who buy chickens from contracted farms have a formal contract with the company. They have paid the companies 50–70% of the agreed price a day before collecting the chickens, and the rest upon collection. Retailers and slaughterhouses reported purchasing chickens on credit, particularly when being supplied by companies' traders.

One key finding emerging from the data was the perception that the poultry system in Vietnam has not yet been fully developed, and hence is not well organized and contains several inefficiencies. Some stakeholders indicated that there are inadequate slaughtering models, with slaughterhouses being under-used, and that maintaining the cold chain required for marketing fresh meat is a major challenge. The feed supply system for colored bird was believed to be inadequate, as current industrial feed are thought to be unsuitable for these birds. A white broiler producer commented that product quality is uneven and generally poor, due to the low quality of breeds used by some farmers. The high volatility of finished chicken prices implies that the PDN cannot have robust and stable mechanisms of supply and distribution. This is combined with a perception that consumers preferences are highly variable, in particular with respect to chicken traits such as feather color, the types of comb and feet skin. Producers have difficulties to adapt to these changes. The breeds, amongst other factors, determine the chicken production costs in Vietnam, which is considered higher than in other countries. This was believed to lead to increases in imports of chicken, causing uneven chicken prices at markets. This affects the stability of the PDN, making it more vulnerable to international market variations and disruptions and to import policies (Yitayih et al., 2021). Furthermore, the current conditions under which the PDN operate, including the abovementioned high density of farms, was believed to generate disease risks, of which the financial impact may drive many farmers to stop their activity, as they are financially vulnerable. This contributes to PDN instability.

> "When people saw the benefit, they raised chicken. Then there was a gumboro epidemic that killed half of the herd, people were scared, they didn't raise them anymore. From then on, only my family cares of raising chicken" [a laying poultry farmer]

The population of household farms and backyard farms was reported to be numerous, operating on small profits, and highly heterogenous in terms of practices and compliance with regulations, which could generate further instability of chicken supply. The number of small farms was however believed to be declining, as they struggle to compete with large farms. In contrast, companies, through vertical integration, were seen to have more stable networks. These companies ensure that prices of DOCs and feed sold to farmers remain stable and provide farmers with support on technical advises on husbandry practices. As they have contracts with, or even own supermarkets, as well as slaughterhouses and processing plants, companies can also ensure the stability of the prices of finished chickens raised on their farms. Consequently, there is a high demand from farmers to be contracted by these companies.

> "Company provides price stability to farmers, but these have to contribute capital and profits are then shared" [a director of breeding company]

These large companies have almost exclusive control of some commodities, such as brown eggs or frozen chickens. These were also reported to have an easy access to industrial feed, at the expense of smaller producers who get higher prices for this.

4. Discussion

The study shows that there are major differences in governance and power dynamics between different networks, which have implications for disease control. Those networks operated through traders and live bird markets presents much lower coordination capacity and increased level of power symmetry than the networks organized by large integrated companies. The color broiler PDN is the most uncoordinated network, operating largely on informal processes in a market and relational type of chains (Gereffi et al., 2005) and where relationship with

traders is central for access to market. Consequently, the control of diseases along such networks becomes challenging as a large proportion of stakeholders are unregistered (with difficulty to monitor and implement surveillance programs), there is a lack of capacity to implement adequate traceability schemes (given lack of contracts). Moreover, the low investment model operated across the network means reduced biosecurity investments by stakeholders, lack of adequate infrastructure (such as slaughterhouses and cold chain) and the use of low-quality inputs (e.g. feed). This network however produces an important commodity and source of livelihood, given that it accounts for 72% of all broiler chickens produced in Vietnam, and their consumption increases in festive seasons. On the other hand, the white broiler and egg networks present a better coordination capacity, given the large scales of operations and the partake of large companies, supported through large foreign investment funds, and contract farming. Yet, a significant part of the white broiler chain operates through household farms and informal processes. Policies that can help establish better network coordination are required to allow effective disease control strategies to be implemented.

The mapping of the Vietnam chicken PDN shows the complex patterns of interactions among the different stakeholders along the networks. This study addresses the realities of overlapping and diversifying roles of stakeholders and provides a clear framework of the PDN which is a fundamental basis for any future research and policy. Moreover, the findings shed further understanding of some key factors governing the system and generating potential disease risks. The diversification of stakeholders, their business sizes, their patterns of production and management have been reported here to play a role on the generation of system risks for animal and human health. It is also reported the examples of such nodes which are the potential roles for household farms and independent traders in disease transmission (Nguyen et al., 2015), the importance of live bird markets in the colored broiler PDN (Phan et al., 2013; Nguyen et al., 2014; Sealy et al., 2019), the informal slaughter of chickens in some parts of the PDN and the management of sick birds (Carrique-Mas et al., 2019; Delabouglise et al., 2020). The identifications of nodes of epidemiological importance and of some of the factors influencing the configurations of the PDN will enable future detailed ethnographic research to unravel the social, economic, and cultural processes underlying zoonotic risk generation, and biological studies to assess the transmission, persistence, and evolution of poultry-origin zoonotic health hazards.

In this study, it was reported that some farmers sell sick birds to avoid financial losses. These birds could represent a risk of disease transmission throughout the network when they are transported and sold, but also represent a risk of foodborne disease to consumers. A study conducted in Northern Vietnam characterized the network of sick birds and found that, for bird reaching 90–105 days old, when disease occurred or there is a danger of getting a disease from a nearby flock, about 66% of farmers will choose to sell the whole batch to traders at a 20–70% discount price (Mai et al., 2017). Furthermore, it was suggested that some traders specialize on selling of sick birds. The risk generated by these complex networks of stakeholders may even be amplified by certain consumers eating habits and the lack public health awareness (Pramuwidyatama et al., 2022). For example, there is a general preference for consuming small local chicken (e.g., Ri and Mia breeds, or at the hot pot restaurants). Consumers who do not have knowledge about the quality of the birds might mistake sick birds for small, healthy birds. Conditions are met for such poor practices to occur, representing a public health risk. There is a need for further research that can help identify the implementation of incentives and policies to avoid the trading of sick birds.

Another key factor that requires attention is the reported instability of prices and uncertain profits, that may push farmers to reduce cost of production at the expenses of disease risk mitigation investments. The reported variability in compliance to regulations, particularly from small farmers, is another point of concern, as this may disincentivize other farmers from following these regulations. Small farmers were thus considered by KIs as promoting disease risk generation along the PDN, contrasting with more efficient, economic, and regulated large businesses. Small stakeholders have generally been considered to play a crucial role in food security and poverty alleviation in Low- and Middle-Income Countries (Wong et al., 2017). Although such roles were also emphasized by KIs in this study, some interviews indicated that large white broiler farmers are able to supply cheaper meat, while colored chicken produced by small farmers is preferred by richer consumers. However, several KIs perceived that Vietnam may be experiencing a shift toward larger integrated businesses, which may have a significant impact on the disease risk landscape in the country. Although large farms seemed to be better managed, they can represent a major risk of disease emergence if biosecurity measures are suboptimal. Observational epidemiological studies combined with economic and behavioral research should be conducted to assess the risks generated by the wide spectrum of farming systems in Vietnam and inform the design of suitable disease risk mitigation interventions.

KIs thought that slaughtering facilities at the wet markets did not meet food safety requirements. Furthermore, the mixing of large number of birds originating from multiple sources in LBMs promote the amplification and transmission of infectious agents, such as avian influenza viruses (Nguyen et al., 2014). A study found that the odds of birds being positive to avian influenza was 45 times higher in LBMs compared to commercial farms (Trung le et al., 2022). Another study showed that some traders practices increase the risk of avian influenza transmission, and LBM retailers (those buying from middlemen and selling small quantities to consumers) had highest odds of infection (Sealy et al., 2019). We recommend conducting further risk assessment studies to assess the potential of LBMs to generate disease risks along the PDN; to develop studies to understand people's risk behaviors and changes in consumer habits; and to conduct economic analysis on the feasibility and impact of policies aiming at improving disease management. In Vietnam, these markets play a major role in the distribution of the colored broilers and, to a lesser extent, of white broilers. Given their importance, further work in characterizing these is also required. Networks involving markets also involve numerous small independent stakeholders. The regulation of these networks hence can represent an important challenge for the government. On the other hand, the livelihoods of many people rely on these networks, and hence their enforcement and regulation require careful consideration.

Interestingly, KIs' perceptions of disease risks associated with colored broilers vary. Some consider that the colored chicken in open housing system is strong and more resistant to disease, while others consider that farms producing chicken in open houses may increase the probability of these flocks being exposed to pathogens (Trung et al., 2017) from wild bird populations and the wider environment (Henning et al., 2011). Overall, biosecurity in household and small farms was considered lower than in large farms. Furthermore, the density of such farms in some areas was also seen as a biosecurity issue that affected all farm types. A study conducted in Asia have shown that clustered poultry farms do not show better economic performance, but that these have a detriment impact to the environment (Wang et al., 2015). There is however a lack of studies that provide insight on the biosecurity of Vietnamese poultry farms and other PDN stakeholders. A study on 142, mostly contracted, farms in Vietnam, showed that these have low biosecurity scores (with a score of 22 out of 42), with deficiencies in the control of visitors, cleaning, disinfection and protection measures of workers (Wang et al., 2015). One small study of 35 farms, indicates that farms had good disease management practices, but required improvement on the removal of manure and sick birds, and on cleaning and disinfection practices on farm (Cuc et al., 2020). A study in Indonesia, identified that biosecurity measures can be variable between different business models, with some contract models (farming for a fee) associated with lower biosecurity compared to other farm models (Indrawan et al., 2020). Chain governance has also been found to be a key factor

influencing biosecurity up-take in that country (Indrawan et al., 2018; Pramuwidyatama et al., 2022). Our study indicates that this PDN operated through integrated networks were seen to use better infrastructure and biosecurity practices than those operated via other networks. Given the importance of biosecurity for disease control, the existing gap in literature and the linkage of biosecurity practices to different business and value chain models, further research in these areas should be prioritized.

Consumers' preferences may also influence application of adequate production practices and drive the generation of risks practices. The reported consumer preference for fresh and cheap meat, may reduce incentive to adequate cold chain up-take and infrastructure, leading to lower hygiene standards and practices (such as backyard slaughtering of birds). A study conducted on Hanoi consumers' showed that avian influenza influenced, for a short period of time, consumer patterns and risk behaviours, such as increase cooking or the use of salt water to clean the meat (Figuié and Fournier, 2008). That study indicates that consumers' perceived 'industrial chicken' to be more dangerous due to breeding, flock size and use of contaminated feed. It was suggested that the experience with avian influenza helped improve safety standards in many integrated and contracted farms (Figué and Desvaux, 2015). The impact of avian influenza on consumer behaviour was also reported in other countries in the region, where trust channels and product characteristics (such as freshness) were associated to changes in consumption (Indrawan et al., 2018). However, there is yet little evidence of the impact that consumers perceptions may have on Vietnamese PDN stakeholders' practices, and further research in this area is needed. By targeting consumers, policies aimed at promoting consumers' awareness of food safety may incentivize stakeholders to implement risk mitigation interventions. Such measures may be particularly relevant during festivals, during which the surge in production and trade to meet high consumer demand may further promote disease spread (Delabouglise et al., 2017). Future risk assessment studies should consider the seasonal importance of such festive periods on the consumption and production of poultry.

This study presents several limitations. It is important to note that the findings identified are based on participant perceptions. To minimize selection bias, our participants were carefully selected to represent different nodes, and to ensure that they had sufficient experience, and therefore knowledge, about the PDN. The interview guides were used with key informants at different levels of the PDN, enabling the cross-checking and triangulation of the information obtained. The flows of chickens, meat and eggs along the PDN are difficult to estimate quantitatively, and only personal opinions are reported due to lack of reliable data. Similarly, there is a lack of data on number of farms and network stakeholders, as current statistics only report the number of chickens per farm size category. One reason for this may be the lack of formal registration of small and household farms, and other stakeholders. Quantitative and observational studies will be required to validate the findings and generate accurate estimates on the amount of chickens and products sold through the PDN. Another limitation was the small time available with some KIIs, such as group leaders or traders. The resulting PDN should be seen as a useful framework to understand the network structure, and as baseline to inform future research and policy development. However, it should not be regarded as a complete and full representation of the network as some actors (e.g. regulators, financial actors, etc.) and small network subsets (e.g. those operated by traders specialize on sick birds) are omitted. While potential errors may have been generated through the translation of the interview guides and transcripts, these were likely to be limited as interviews and data analysis were led by Vietnamese authors experienced with the poultry industry and proficient in both languages.

5. Conclusion

The study provides an overview of the structure of the colored broiler, white broiler, and egg PDNs. Our findings show that the PDN associated with colored broiler is mostly composed of small independent stakeholders, although some vertical integration does exist. Most products are distributed by traders directly to retailers, who slaughter birds in the market or near their shop. White broilers present a duality between a vertically integrated system and an informal system involving traders and LBMs, but most birds are produced by large-scale household farms. The egg PDN is increasingly dominated by large integrated companies. Key informants thought that small-scale farms represent a high risk of disease transmission and emergence, given their high density in some areas, poor husbandry practices, lack of access to good quality feed, low biosecurity, and low adherence to government regulations. By mixing birds from different geographical origins and farming systems, traders' vehicles, slaughterhouses, and LBMs are thought to be hotpots of disease transmission. Findings from these studies can be used to plan future studies to assess the risk of diseases in the poultry PDN in Vietnam.

Funding source

This study was funded by the UKRI GCRF One Health Poultry Hub (Grant No. B/S011269/1), one of twelve interdisciplinary research hubs funded under the UK government's Global Challenge Research Fund Interdisciplinary Research Hub initiative. The funders were not involved in the conduct of the research or preparation of this paper.

CRediT authorship contribution statement

NTD, GF, PA and AE designed the research and developed guides for data collection; VDT and NVD arranged the key informant interviews; NTD, VDT, AE, NVD, HAT, LTTH, NVD, NVD collected data; NTD, PA, PTTH and AE performed the analysis, discussed the results and validate the data; NTD, PA, AE, NTMK, NVD wrote the paper; GF and VDT contributed to writing by providing inputs to versions of the preprint. All authors provided revisions to the final version of the manuscript.

Declaration of Competing Interest

All the authors listed on this manuscript declared no conflict of interest.

Acknowledgements

The authors would like to acknowledge the contributions made by our colleagues in Vietnam for their support during this study, special thanks to the staffs in Vietnam National Institute of Veterinary Research, Pham Thi Ngoc, Daan Vink, Flavie Goutard and Marisa Peyre for hosting and organizing the stakeholder workshop which are valuable for the information and data validation of this research. We thank Mathew Hennessey at Royal Veterinary College for his carefully English proofreading work. The authors would like to acknowledge the contributions made by all stakeholder that participated in this study. We are also grateful to Prof. Tony Barnett (RVC) for his help in the design of the study.

Appendix A. Supporting information

Supplementary data associated with this article can be found in the online version at doi:10.1016/j.prevetmed.2023.105906.

References

Alarcon, P., Dominguez-Salas, P., Fèvre, E.M., Rushton, J., 2021. The importance of a food systems approach to low and middle income countries and emerging economies: a review of theories and its relevance for disease control and malnutrition. Front. Sustain. Food Syst. 5, 92.

Alarcon, P., Fèvre, E.M., Murungi, M.K., Muinde, P., Akoko, J., Dominguez-Salas, P., Kiambi, S., Ahmed, S., Häsler, B., Rushton, J., 2017. Mapping of beef, sheep and goat food systems in Nairobi - a framework for policy making and the identification of structural vulnerabilities and deficiencies. Agric. Syst. 152, 1–17.

Antoine-Moussiaux, N., Peyre, M., Bonnet, P., Bebay, C., Bengoumi, M., Tripodi, A., 2017. The value chain approach in one health: conceptual framing and focus on present applications and challenges. Front. Vet. Sci. 4, 206.

Aslam, H.B., Alarcon, P., Yaqub, T., Iqbal, M., Häsler, B., 2020. A value chain approach to characterize the chicken sub-sector in Pakistan. Front. Vet. Sci. 7, 361-361.

Bengtsson, M., 2016. How to plan and perform a qualitative study using content analysis. NursingPlus Open 2, 8–14.

Department of Livestock Production, 2019. Overview of poultry production in Vietnam (P8): The evolution of poultry products - "Price of poultry product in our country has non-stop changing". J. Vietnam Anim. Prod.

FAO, 2020. FAOSTAT Statistical Database: Crop and Livestock Products, Vietnam. Food and Agricultural Organization of the United Nations, Rome.

Bordier, M., Binot, A., Pauchard, Q., Nguyen, D.T., Trung, T.N., Fortané, N., Goutard, F. L., 2018. Antibiotic resistance in Vietnam: moving towards a One Health surveillance system. BMC Public Health 18 (1), 1136.

Burgos, S., Hong Hanh, P.T., Roland-Holst, D., Burgos, S.A., 2007. Characterization of poultry production systems in Vietnam. Int. J. Poult. Sci. 6 (10), 709–712.

Burgos, S.,Hinrichs, J., Otte, J., Roland-Holst, D. 2008. *Poultry, HPAI and Livelihoods in Viet Nam—A Review*. Food and Agriculture Organization of the United Nations, Rome. Mekong Team Working Paper No. 2.

Carrique-Mas, J., Van, N.T.B., Cuong, N.V., Truong, B.D., Kiet, B.T., Thanh, P.T.H., Lon, N.N., Giao, V.T.Q., Hien, V.B., Padungtod, P., Choisy, M., Setyawan, E., Rushton, J., Thwaites, G., 2019. Mortality, disease and associated antimicrobial use in commercial small-scale chicken flocks in the Mekong Delta of Vietnam. Prev. Vet. Med. 165, 15–22.

Carron, M., Alarcon, P., Karani, M., Muinde, P., Akoko, J., Onono, J., Fèvre, E.M., Häsler, B., Rushton, J., 2017. The broiler meat system in Nairobi, Kenya: using a value chain framework to understand animal and product flows, governance and sanitary risks. Prev. Vet. Med. 147, 90–99.

Conan, A., Goutard, F.L., Sorn, S., Vong, S., 2012. Biosecurity measures for backyard poultry in developing countries: a systematic review. BMC Vet. Res. 8 (1), 240.

Cuc, N.T.K., Dinh, N.C., Quyen, N.T.L., Tuan, H.A., 2020. Biosecurity level practices in pig and poultry production in Vietnam. Adv. Anim. Vet. Sci. 8 (10), 1068–1074.

Delabouglise, A., Nguyen-Van-Yen, B., Thanh, N.T.L., Xuyen, H.T.A., Tuyet, P.N., Lam, H.M., Boni, M.F., 2019. Poultry population dynamics and mortality risks in smallholder farms of the Mekong river delta region. BMC Vet. Res. 15 (1), 205.

Delabouglise, A., Thanh, N.T.L., Xuyen, H.T.A., Nguyen-Van-Yen, B., Tuyet, P.N., Lam, H.M., Boni, M.F., 2020. Poultry farmer response to disease outbreaks in smallholder farming systems in southern Vietnam. Elife 9.

Delabouglise, A., Choisy, M., Phan, T.D., Antoine-Moussiaux, N., Peyre, M., Vu, T.D., Pfeiffer, D.U., Fournié, G., 2017. Economic factors influencing zoonotic disease dynamics: demand for poultry meat and seasonal transmission of avian influenza in Vietnam. Sci. Rep. 7 (1), 5905.

Department of Animal Health, 2018. Implementing prevention and control animal diseases in autumn-winter season and prevention of African swine fever in Vietnam. Conference organized on the 14th Sept. 2018 by the Department of Animal Health, Hanoi, Vietnam.

Department of Livestock Production, 2019. Overview of Poultry Production and the Development Guide. Department of Livestock Production. Hanoi, Vietnam.

Desvaux, S., Grosbois, V., Pham, T.T.H., Fenwick, S., Tollis, S., Pham, N.H., Tran, A., Roger, F., 2011. Risk factors of highly pathogenic avian influenza H5N1 occurrence at the village and farm levels in the red river delta region in Vietnam. Transbound. Emerg. Dis. 58 (6), 492–502.

FAO, 2011. A value chain approach to animal diseases risk management: Technical foundations and practical framework for field application. In: Animal Production and Health Guidelines, 4. Food and Agricultural Organization of the United Nations, Rome, p. 135.

Farnworth, C.R., 2011. Gender-aware value chain development. UN Women Expert Group Meeting: Enabling Rural Women's Economic Empowerment: Institutions, Opportunities and Participation. Accra, Ghana.[Accessed on the 29 March 2023 at https://www.un.org/womenwatch/daw/csw/csw56/egm/Farnworth-EP-1-EGM-RW-Sep-2011.pdf.

Figué, M., Desvaux, S., 2015. Managing Global Risks: Vietnamese Poultry Farmers and Avian Flu. Socio-Ecological Dimensions of Infectious Diseases in Southeast Asia. 2015 Apr 1:257–73. doi: 10.1007/978-981-287-527-3_15.

Figuié, M., Fournier, T., 2008. Avian Influenza in Vietnam: Chicken-Hearted Consumers? Risk Anal. 28 (2), 441–451.

Gereffi, G., Humphrey, J., Sturgeon, T., 2005. The governance of global value chains. Rev. Int. Polit. Econ. 12 (1), 78–104.

Hennessey, M., Fournié, G., Hoque, M.A., Biswas, P.K., Alarcon, P., Ebata, A., Mahmud, R., Hasan, M., Barnett, T., 2021. Intensification of fragility: Poultry production and distribution in Bangladesh and its implications for disease risk. Prev. Vet. Med. 191, 105367.

Henning, J., Henning, K.A., Morton, J.M., Long, N.T., Ha, N.T., Vu Le, T., Vu, P.P., Hoa, D.M., Meers, J., 2011. Highly pathogenic avian influenza (H5N1) in ducks and in-contact chickens in backyard and smallholder commercial duck farms in Viet Nam. Prev. Vet. Med. 101 (3–4), 229–240.

Ifft, J., Roland-Holst D., Zilberman, D., 2009. Impact of quality characteristics on demand for chicken in Viet Nam. ARE Update 12(4): 9-11. University of California Giannini Foundation of Agricultural Economics [accessible at https://giannini.ucop.edu/filer/file/1453327751/16805/].

Indrawan D., Rich K.M., Van Horne P., Daryanto A., Hogeveen H. Linking supply chain governance and biosecurity in the context of HPAI control in Western Java: a value chain perspective 5 2018 94.

Indrawan, D., Tacken, G., Hogeveen, H., 2018. What drives the choice of poultry market channel and the change of purchase behavior due to highly pathogenic avian influenza outbreaks? Poult. Sci. 97 (10), 3652–3660.

Lachat, C., Khanh Le, N.B., Khan, N.C., Dung, N.Q., Nguyen Do, V.A., Roberfroid, D., Kolsteren, P., 2009. Eating out of home in Vietnamese adolescents: socioeconomic factors and dietary associations. Am. J. Clin. Nutr. 90 (6), 1648–1655.

Lipsitch, M., Viboud, C., 2009. Influenza seasonality: Lifting the fog. Proc. Natl. Acad. Sci. U.S.A. 106 (10), 3645.

Mai, H.N., Phuong, N.T., Tien, N.D., Ton, V.D., Peyre, M. (2017). Diversified chicken farming systems and trading networks in Hai Duong Province, Northern Vietnam. Proceeding of the International conference on animal production in South-East Asia. Hanoi, Vietnam. Pages 38-47.

Maki, J.J., Klima, C.L., Sylte, M.J., Looft, T., 2019. The microbial pecking order: utilization of intestinal microbiota for poultry health. Microorganisms 7 (10), 376.

Marisa, V.D.S., 2010. Poultry and poultry products - risks for human health. Poultry Development Review. Food and Agricultural Organization of the United Nations, Rome, pp. 1–21.

Ministry of Agriculture and Rural Development and Department of Livestock Production Report on the situation of animal production in 2021 and the solution to develop animal production in quarter IV/2021 and early 2022 2021 Hanoi, Department of Livestock Production.

Mubamba, C., Ramsay, G., Abolnik, C., Dautu, G., Gummow B., 2018. Combining value chain and social network analysis as a viable tool for informing targeted disease surveillance in the rural poultry sector of Zambia. Transbound Emerg Dis. 2018, 65 (6):1786-1796.

Nguyen, D.T., Bryant, J.E., Davis, C.T., Nguyen, L.V., Pham, L.T., Loth, L., Inui, K., Nguyen, T., Jang, Y., To, T.L., Nguyen, T.D., Hoang, D.T., Do, H.T., Nguyen, T.T., Newman, S., Jennifer, S., Pham, D.V., 2014. Prevalence and distribution of avian influenza a(H5N1) virus clade variants in live bird markets of Vietnam, 2011-2013. Avian Dis. 58 (4), 599–608.

Nguyen, V.T., Carrique-Mas, J.J., Ngo, T.H., Ho, H.M., Ha, T.T., Campbell, J.I., Nguyen, T.N., Hoang, N.N., Pham, V.M., Wagenaar, J.A., Hardon, A., Thai, Q.H., Schultsz, C., 2015. Prevalence and risk factors for carriage of antimicrobial-resistant Escherichia coli on household and small-scale chicken farms in the Mekong Delta of Vietnam. J. Antimicrob. Chemother. 70 (7), 2144–2152.

Nguyen-Viet, H., Tuyet-Hanh, T.T., Unger, F., Dang-Xuan, S., Grace, D., 2017. Food safety in Vietnam: where we are at and what we can learn from international experiences. Infect. Dis. Poverty 6 (1), 39.

Pan, D., Yu, Z., 2014. Intestinal microbiome of poultry and its interaction with host and diet. Gut Microbes 5 (1), 108–119.

Park, A.W., Glass, K., 2007. Dynamic patterns of avian and human influenza in east and southeast Asia. Lancet Infect. Dis. 7 (8), 543–548.

Pham-Thanh, L., Nhu, T.V., Nguyen, T.V., Tran, K.V., Nguyen, K.C., Nguyen, H.T., Ngo Thi, H., Padungtod, P., 2022. Zoonotic pathogens and diseases detected in Vietnam, 2020–2021. One Health 14, 100398.

Phan, M.Q., Henry, W., Bui, C.B., Do, D.H., Hoang, N.V., Thu, N.T., Nguyen, T.T., Le, T. D., Diep, T.Q., Inui, K., Weaver, J., Carrique-Mas, J., 2013. Detection of HPAI H5N1 viruses in ducks sampled from live bird markets in Vietnam. Epidemiol. Infect. 141 (3), 601–611.

Pramuwidyatama, M.G., Indrawan, D., Saatkamp, H.W., Hogeveen, H., 2022. Smallholder Broiler Farmers' Characteristics to Uptake Measures Against Highly Pathogenic Avian Influenza in Western Java. Front Vet Sci 9, 727006.

Sealy, J.E., Fournie, G., Trang, P.H., Dang, N.H., Sadeyen, J.R., Thanh, T.L., Van Doorn, H.R., Bryant, J.E., Iqbal, M., 2019. Poultry trading behaviours in Vietnamese live bird markets as risk factors for avian influenza infection in chickens. Transbound. Emerg. Dis. 66 (6), 2507–2516.

Sealy, J.E., Fournie, G., Trang, P.H., Dang, N.H., Sadeyen, J.-R., Thanh, T.L., Van Doorn, H.R., Bryant, J.E., Iqbal, M., 2019. Poultry trading behaviours in Vietnamese live bird markets as risk factors for avian influenza infection in chickens. Transbound. Emerg. Dis. 66 (6), 2507–2516.

Soares Magalhães, R.J., Ortiz-Pelaez, A., Thi, K.L., Dinh, Q.H., Otte, J., Pfeiffer, D.U., 2010. Associations between attributes of live poultry trade and HPAI H5N1 outbreaks: a descriptive and network analysis study in northern Vietnam. BMC Vet. Res. 6, 10.

T. Fournier Coping with new food-related risks / Autour de la grippe aviaire au Viet Nam 2009 Anthropology of food [Online].

T. Phan Dang B. Duquesne P. Lebailly T. Vu Dinh Poultry supply chains and challenge facing the poultry smallholders in Hanoi suburban Vietnam's Socio-Economic Development 63 2013 64 80.

Taylor, N., Pinto J., Rushton J., 2010. Linking value chain analysis with epidemiological risk assessment in order to identify efficient disease control interventions–focusing on poultry value chains and H5N1 HPAI, A working paper released December 2008 and revised January 2010. FAO AGAL, Rome.

Thai, P.Q., Choisy, M., Duong, T.N., Thiem, V.D., Yen, N.T., Hien, N.T., Weiss, D.J., Boni, M.F., Horby, P., 2015. Seasonality of absolute humidity explains seasonality of influenza-like illness in Vietnam. Epidemics 13, 65–73.

Trung, N.V., Matamoros, S., Carrique-Mas, J.J., Nghia, N.H., Nhung, N.T., Chieu, T.T., Mai, H.H., Van Rooijen, W., Campbell, J., Wagenaar, J.A., Hardon, A., Mai, N.T., Hieu, T.Q., Thwaites, G., De Jong, M.D., Schultsz, C., Hoa, N.T., 2017. Zoonotic transmission of mcr-1 colistin resistance gene from small-scale poultry farms, Vietnam. Emerg. Infect. Dis. 23 (3), 529–532.

Trung Le, K., A Stevenson, M., Isoda, N., Thanh Nguyen, L., Chu, D.-H., Ngoc Nguyen, T., Van Nguyen, L., Ngoc Tien, T., Thanh Le, T., Matsuno, K., Okamatsu, M., Sakoda, Y.,

2022. A systematic approach to illuminate a new hot spot of avian influenza virus circulation in South Vietnam, 2016-2017. Transbound Emerg. Dis. 69 (4), 831–844. https://doi.org/10.1111/tbed.14380.

Truong, D.B., Cuong, N.V., Doan, P.H., Dung, N.T.T., Kiet, B.T., Rushton, J., Carrique-Mas, J., 2021. Small-scale commercial chicken production: A risky business for farmers in the Mekong Delta of Vietnam. Prev Vet Med 195, 105470.

Vietnam National Assembly (2020). Degree Guide the detailed implementation of Law on Animal Husbandry. 13/2020/ND-CP. Vietnam National Assembly. Hanoi.

Vietnamese National Assembly (2018). Law on Animal Husbandry. No.32/2018/QH14 National Assembly. Hanoi,Vietnam [Access on 03.04.2023 at https://www.economica.vn/Content/files/LAW%20%26%20REG/Law%20on%20Animal%20Husbandry%202018.pdf].

Wang, L., Basuno, E., Nguyen, T., Aengwanich, W., Ilham, N., Li, X., 2015. An ecohealth assessment of poultry production clusters (PPCs) for the livelihood and biosecurity improvement of small poultry producers in Asia. Infect. Dis. Poverty 4, 6.

Wong, J.T., De Bruyn, J., Bagnol, B., Grieve, H., Li, M., Pym, R., Alders, R.G., 2017. Small-scale poultry and food security in resource-poor settings: a review. Glob. Food Secur. 15, 43–52.

Yitayih, M., Geremew, K., Esatu, W., Worku, S., Getachew, F., Nguyen Viet Don, Ngo Thi Kim Cuc, Unger, F., Dessie, T., 2021. Poultry production, marketing and consumption in Vietnam: A review of literature. ILRI Research Report 80.