



Intensification of fragility: Poultry production and distribution in Bangladesh and its implications for disease risk

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ABSTRACT

Poultry production is a valuable source of nutritious food and income and is considered a crucial part of global development. This is especially important for countries such as Bangladesh where levels of hunger and childhood stunting remain high. However, in many low- and middle-income countries poultry production remains dominated by small to medium scale enterprises operating with poor farm biosecurity associated with poultry and zoonotic disease risks. We aimed to characterize the structure of poultry production in Bangladesh in order to identify the underlying structural factors and resulting practices which create risk environments for emergence, persistence and transmission of infectious diseases.

Using the concept of a *production and distribution network* (PDN), we conducted a review of the literature, 27 in-depth interviews with key-informants and stakeholders, and 20 structured interviews with poultry distributors to map the ways which poultry are raised, distributed and marketed in Bangladesh. Findings indicate that the PDN can be considered in the context of four major sub-networks, based on the types of chickens; broadly indigenous, cross-bred, exotic broiler, and layer chickens. These sub-networks do not exist in isolation; their transactional nodes - actors and sites - are dynamic and numerous interactions occur within and between the PDN.

Our findings suggest that the growth in small and medium scale poultry enterprises is conducted within 'fragile' enterprises by inexperienced and poorly supported producers, many of whom lack capacity for the level of system upgrading needed to mitigate disease risk. Efforts could be taken to address the structural underlying factors identified, such as the poor bargaining power of producers and lack of access to independent credit and indemnity schemes, as a way to reduce the fragility of the PDN and increase its resilience to disease threats.

This knowledge on the PDN structure and function provide the essential basis to better study the generation, mitigation and consequences of disease risks associated to livestock, including the analysis of potential hotspots for disease emergence and transmission.

1. Introduction

Poultry are a valuable source of protein (FAO, 2013; Miller and Welch, 2013) and provide opportunities for poverty alleviation, gender

empowerment (Paul et al., 2013; Wong et al., 2017), and improved maternal and child nutrition (Alders et al., 2018). Consequently, in low- and middle-income countries (LMICs hereafter) poultry production is considered a crucial part of global development, contributing to the

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achievement of several sustainable development goals¹ (UN, 2015), and has become the fastest growing livestock sector worldwide (FAOSTAT, 2017; Mottet and Tempio, 2017).

In Bangladesh, despite sustained economic growth and nutritional improvements over last two decades, the prevalence of hunger and childhood stunting remain high - 26.1 % and 31 % respectively (GHI, 2019; NIPORT and ICF, 2019). While poultry consumption in the country has increased dramatically over the last 30 years current consumption - 6.3–8.5 kg/person/year (LightCastle, 2020; WPSA, 2020) - remains lower than the world average (14.7 kg/person/year) and far behind that of many high-income countries (OECD and FAO, 2020). According to FAO production data, the Bangladesh poultry sector has been growing at a rate between 3 and 5% per year since 2007 though production is still only able to meet around two thirds of meat and egg demand (Hamid et al., 2016). Thus, safeguarding the development of the poultry sector is considered important to improve the nutritional status and economic development of Bangladeshi people.

In many high-income countries, technological advances, organisational innovations, genetic selection, and access to global supply chains have resulted in vertically integrated operations dominating the poultry market (DEFRA, 2010). However, in many LMICs where rapid intensification is still ongoing, small to medium scale enterprises remain major contributors to the sector often operating with poor farm biosecurity (Wong et al., 2017). Prior to the late 1980s, poultry production in Bangladesh consisted mainly of backyard production with native chickens. During the 1990s the country saw the introduction and rise of commercial production, supported by private and public investment (FAO, 2015; Sheel and Sen, 2013). However, this type of growth and intensification has not occurred without risk for disease transmission; transitioning systems characterised by poor biosecurity and frequent contact with live bird markets have been associated with numerous highly pathogenic avian influenza (HPAI hereafter) reassortment events (Dhingra et al., 2018). Of particular concern is the zoonotic pathogen HPAI H5N1. Since its emergence in 1996 in China, H5N1 has spread across Asia and to the rest of the world (WHO, 2012) and following an epidemic in 2007, became endemic in Bangladesh and forced the closure of an estimated 60 % of the country's poultry farms (FAO, 2015; Jones et al., 2012; Kock et al., 2012). Engagement with HPAI H5N1 requires sustained global effort and investment; it has been argued that reducing disease occurrence will increase the productivity and profitability of poultry for poor people, as well as reducing the risk of new variants being transmitted to and between humans (Lewis, 2011; Lewis et al., 1996).

In this paper, we extend ideas taken from previous value chain analysis (Ahmed et al., 2012; Alam et al., 2013; Alarcon et al., 2017; Amin et al., 2012; Buckley and Strange, 2015; Ebata et al., 2018; FAO, 2011; Gibbon and Ponte, 2005; Goletti et al., 1995; Kaplinsky, 2000; Kaplinsky and Morris, 2001), largely concerned with distributional regulatory and efficiency questions, to the concept of *production and distribution network* (PDN hereafter). We do this to explore the social, economic, and cultural structures within which poultry are produced, traded, and consumed. Here social and economic processes and structure, such as relations of patronage, indebtedness, trust, loyalty, political relations, gender relations create the risk environments (Barnett and Blaikie, 1992; Barnett and Whiteside, 2006) in which changes in the pathogen may occur, and the mutated pathogen be transmitted between poultry, from poultry to humans, and ultimately between humans – thus having epidemic or even pandemic potential. We aimed to describe the poultry PDN in Bangladesh in order to identify the underlying structural factors and resulting behaviours and practices which may favour poultry and zoonotic disease risk environments. The study forms a critical initial component in a much larger interdisciplinary study of the situation in

Bangladesh, India, Sri Lanka, and Vietnam using data collected in a One Health framework drawn from virology, microbiology, pharmacology, epidemiology, genomics and a range of social sciences².

2. Methods

2.1. Data collection

An initial literature review was conducted to gather data on poultry production and distribution in Bangladesh. Information extracted from the literature review was used to draw preliminary PDN maps for each of the poultry systems, identify current knowledge gaps, and generate *a priori* interview guides for the semi-structured in-depth interviews. These guides covered the following topics; (1) role of the key informants in the PDN, (2) mapping of the network, and (3) the governance of the network (Supp. 1). Informants were asked to map the poultry PDN and identify actors, sites and major flows of commodities present in the network.

Chattogram and Dhaka, the two largest cities in Bangladesh, were selected as study sites for data collection as they are focal points for the movement of poultry from across the country into the many network endpoints located in the cities (Moyen et al., 2018). Twenty-seven in-depth interviews were conducted with key-informants (KIs hereafter) - defined as individuals with a suspected high-level knowledge of the system - and poultry stakeholders. Interviewees originated from Chattogram (n = 12) and Dhaka (n = 15), and from the following sectors: private commercial (n = 7), academic (n = 5), government (n = 5), non-governmental organisations (n = 6), and independent farming, poultry distribution and sale (n = 4). KIs were identified through experts known to the authors and then via a purposive snowballing technique. Interviewees were provided with a study information sheet (Supp. 2), interviews conducted in English or Bangla, and where participants gave consent, voice recorded. Researchers fluent in Bangla and English, who were also embedded in the study, acted as facilitators and translators.

Additional data were obtained from 20 poultry distributors – known locally as middlemen – from Chattogram (n = 10) and Dhaka (n = 10) using structured questionnaires. Middlemen were defined as PDN actors who moved poultry from farms to market. The structured questionnaire covered the following topics, (1) role of the middlemen in the PDN, (2) type of poultry the middlemen dealt with, and (3) the infrastructure - vehicles and cages - needed to distribute poultry through the PDN (Supp. 3). Middlemen were randomly selected from a sampling frame developed in a previous study (Moyen et al., 2020).

All electronic files and quotes relating to participants were given a code to protect anonymity and to prevent participant identification. The codes used consist of three parts: a unique number for the interview, a city code (CG for Chattogram and DK for Dhaka), and the sector from which the interviewee came.

2.2. Data analysis

Interview audio files were listened to by the interviewer and data extracted into an *a priori* template in Word (Microsoft® ver. 16.46) and verbatim quotes extracted into the data management software NVivo (QRS International ver. 12.6.0.959). Subsequently, two types of analyses were performed: PDN mapping and thematic analysis.

PDN mapping: diagrams consisting of nodes - actors and/or sites - and connection between nodes were produced based on the templates, the literature review and the flowcharts created by interviewed participants.

Thematic analysis: data extracted from the templates were coded using an inductive approach following a protocol developed from Braun and Clarke (2006) and Castleberry and Nolen (2018) (Supp. 4). Coded

¹ Sustainable development goals: 1 (no poverty), 2 (zero hunger), 5 (gender equality), and 12 (responsible consumption and production)

² One Health Poultry Hub <https://www.onehealthpoultry.org>

data were put into context through a process of reassembly to generate themes and allow interpretation. Middlemen telephone questionnaire data were entered into Excel (Microsoft® ver. 16.38) (Supp. 5).

2.3. Data validation

The final set of PDN maps and remaining knowledge gaps were presented to seven of the previous key informants during a One Health conference in Dhaka in November 2019 and to 35 participants at a multi-stakeholder workshop held in Dhaka in Jan 2020. This process allowed validation of the PDN maps based on stakeholder agreement or through the correction of inaccuracies.

2.4. Ethics

The ethics of this study were approved by the Institute of Epidemiology, Disease Control & Research, Bangladesh (ref. IEDCR/IRB/2016/06) and the London School of Hygiene & Tropical Medicine, UK (ref. 10214–1).

3. Results

3.1. Typology of chickens

The literature on Bangladesh poultry production referred to four chicken types; *deshi* [*Bangla* for 'local'], cross-bred *Sonali* [*Bangla* for 'golden'], exotic broilers, and exotic layers; which existed within four rearing systems; backyard, semi-scavenging, intensive broiler, and intensive layer. A summary of chicken types is provided in Table 1.

From the results of our interviews we categorised the production of poultry in Bangladesh into four main systems (Fig. 1); (1) backyard production of *deshi* chickens used for meat and eggs, (2) commercial production of *Sonali* chickens for meat, (3) commercial production of imported exotic birds for meat, and (4) commercial production of imported exotic birds for eggs. Detailed PDN maps for the *Sonali* and exotic broiler systems are presented in this manuscript, while the *deshi* and exotic layer maps can be found in the supplementary material.

Contrary to the existing literature, we did not find evidence of semi-scavenging systems of backyard *Sonali*, or *Sonali* poultry being used primarily for egg production. The absence of two networks described in the literature were discussed with several KIs who explained that these systems were associated with government and NGO promoted *Sonali*

production in the 1990s but had become increasingly uncommon over the last decade.

3.2. Production

Backyard systems, producing mainly *deshi* chickens for meat and eggs, have a low-level reliance on inputs - feed, medicines, labour, and infrastructure - with households either keeping a small self-maintaining flock or periodically obtaining new stock from neighbours or markets. Birds predominately scavenge for food and may be fed household refuse and crop by-products. While it was reported that some vaccine coverage - mainly for Newcastle disease - is provided to backyard birds by government livestock services, supply chain and human resource issues appeared to limit vaccine coverage in this sub-sector. Producers consume or sell birds and eggs when they were available, needed, or in excess, utilising the services of local traders (Das et al., 2008; Shanta et al., 2017). The *deshi* PDN map is provided in Supp. 6.

In contrast, the production of *Sonali*, broiler, and layer poultry were heavily reliant on inputs, albeit to differing degrees. *Sonali* producers needed to purchase day-old chicks from either government breeding farms, of which there were few and supply unreliable, or from private independent breeding farms predominately located in the north-east of the country (Fig. 2). Due to the unregulated nature of the private breeding farms, there were reports of diminishing quality of *Sonali* genetics. However, the ability to raise *Sonali* to adulthood and produce laying and breeding birds was seen as an advantage, allowing producers to weather poor markets and produce their own replacement stock:

"If the market has demand, the profit margin is high, the [farmer] sell all [*Sonali*] to the field. If the market is down, they think that "no I am not interested in selling, I just rear them for my own" 27_DK_Corporate poultry employee

Conversely, the genetics of exotic broiler and layer stock are so highly regulated and controlled by a small number of companies, that the systems remain reliant on imports of day-old chicks from other countries. Imported chicks enter a system of nationally and internationally owned grand-parent and parent stock farms which are used to propagate the imported genetics to produce enough broiler and layer day-old chicks to satisfy national demand (Fig. 3). In addition, *Sonali*, exotic broiler, and exotic layer systems are also heavily reliant on commercial feed to support production, with specialist feeds existing for all three sub-sectors.

Table 1

Summary of chicken types identified in Bangladesh from existing literature and their associated production characteristics.

Type of chicken	Characteristics	Associated farming systems identified from literature	Current market price (March 2021)	Annual production estimates (million birds per year)	Standing stock estimates (million birds)	Sources
<i>deshi</i> [<i>local</i>]	26-week production cycle for meat; eggs pale blue	Backyard production	Meat: 450–460 BDT/kg Egg: 12 BDT/egg	–	168–224 [80–95% of 26 million rural households keeping 8–9 chickens]	(Bhuiyan et al., 2005; FAO, 2015, 2008; Rimi et al., 2016; Siddiky, 2017; Sultana et al., 2012)
cross-bred <i>Sonali</i> [<i>golden</i>],	Cross-bred from Rhode Island Red males and Egyptian Fayoumi females 12-week production cycle for meat; eggs pale blue	Backyard production Semi-scavenging Intensive (meat and egg)	Meat: 280–300 BDT/kg Egg: 10 BDT/egg	140 over 4–5 production cycles	30	(Bhuiyan et al., 2005; FAO, 2015; Hamid et al., 2016; Siddiky, 2017; personal comm. Brum 2019)
Exotic broiler	Imported industrial breeds such as Hybro-PN, Hubbard classic, Ross, Cobb 500 28-31 day production cycle for meat	Intensive	Meat 150–160 BDT/kg	500 over 6–7 production cycle	75	Key-informant information Unpublished research data (personal comm. Brum 2019) FAO, 2008
Exotic layer	Imported industrial breeds such as Hisex white & brown, Arbor Acres, ISA brown. 650 day production cycle, 300-320 eggs per/year Eggs white or brown	Intensive	Egg: 7.5–8 BDT/egg Spent hen meat: 200 BDT/kg	50	90	Hamid et al. (2016) Reports of the weekly day-old chick production numbers (Bangladesh Breeders Association 2019)

BDT = Bangladeshi taka (1 USD = 84.8 BDT April 2021).

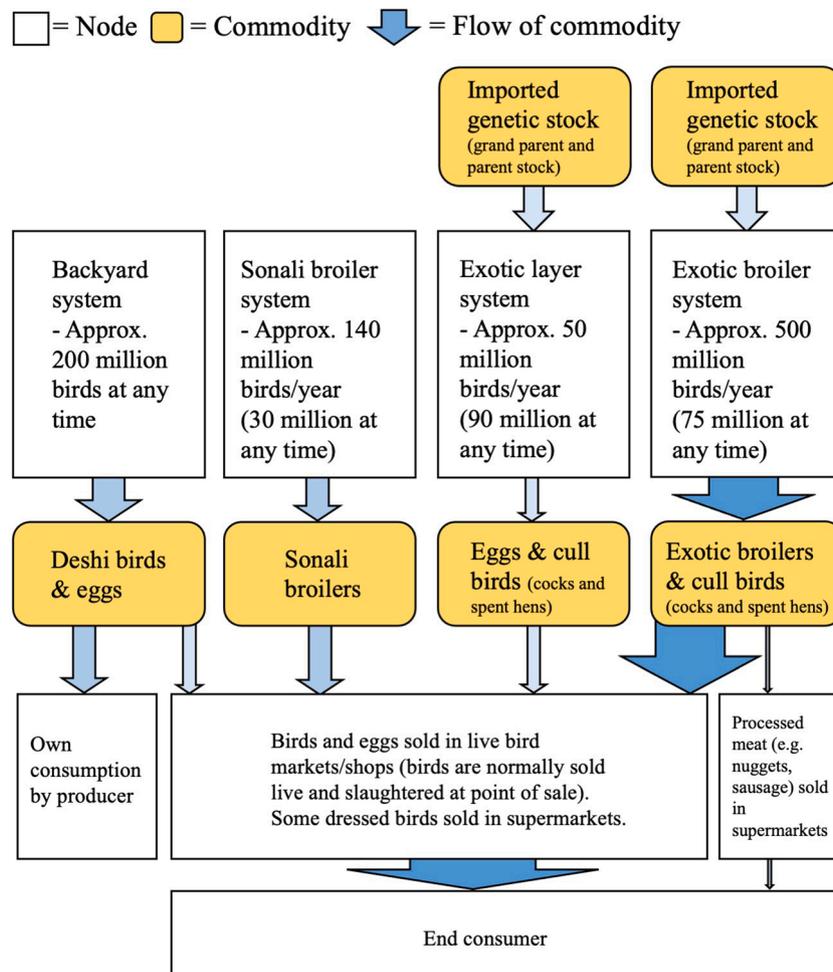


Fig. 1. Overview of the four main poultry production systems in Bangladesh. Arrow width and shading density indicates the relative quantity of commodities flowing through the production and distribution network.

The rapid growth rate of broilers was seen to have some disadvantages as market ready birds needed to be sold quickly in order to avoid the negative impacts of additional feed costs:

“In case of farmers, what they realise is that they cannot keep broiler for a long time, in case the market price is low, so they want to keep for more days, in case of broiler they eat more and they do not make a profit.” 24_DK_Corporate poultry employee

Conversely, it was reported that Sonali producers were not limited to such a short window in which to sell their poultry, with one informant reporting that older Sonali poultry attained more colourful plumage and more closely resembled deshi phenotypes which are preferred by consumers and thus receive a higher market price (Hamid et al., 2016).

“In case of Sonali they take less [food]. And the market for the birds is different, some markets prefer the larger bird, some the smaller bird, so when the Sonali get to 60, 70, 80 days they become more nice, they are colourful, attractive, bright.” 25_DK_NGO employee

The production of Sonali and exotic broiler chickens for meat was dominated by independent small (less than 500 birds) to medium (500–2500 birds) sized enterprises, where producers were reliant on feed dealers to provide day-old chicks and feed, mostly through trade credit. In these systems, there appeared to be a low level of infrastructural specificity needed to produce birds allowing relatively easy market access and for producers to capitalise on market changes by switching between Sonali and broiler production:

“There are very few farmers who rear just Sonali, most of them rear both, so it depends on the market price, one month they rear broiler, the next they rear Sonali.” 25_DK_NGO employee

Within the exotic broiler production system, a small proportion of birds are produced by company owned or contract grower farms in order to supply the growing processed poultry sector. Similarly, within the layer system, production was reportedly dominated by independent layer farms, reliant on feed dealers to supply chicks and feed via credit, with a smaller proportion of eggs being produced by company owned farms. The layer PDN map is provided in Supp. 7.

3.3. Distribution

Live birds - deshi, Sonali, broiler, and cull birds from layer systems - and eggs are moved from producers and either sold at local bazaars/markets or transported into distant urban and peri-urban live bird markets (LBM hereafter). Middlemen played a pivotal role during this stage of the PDN, being responsible for collecting live birds and eggs from farms or households and moving them through the distribution network, either all the way to market, or to intermediary middlemen. Most middlemen transported only one type of bird at a time, in commercial trucks with capacities of 1500 kg–2600 kg poultry. Middlemen dealing with Sonali and exotic broilers had to visit several farms a day, with some needing to visit six to eight to fulfil a shipment. By contrast, one middleman described the piecemeal collection of deshi poultry which are predominately moved using public transport:

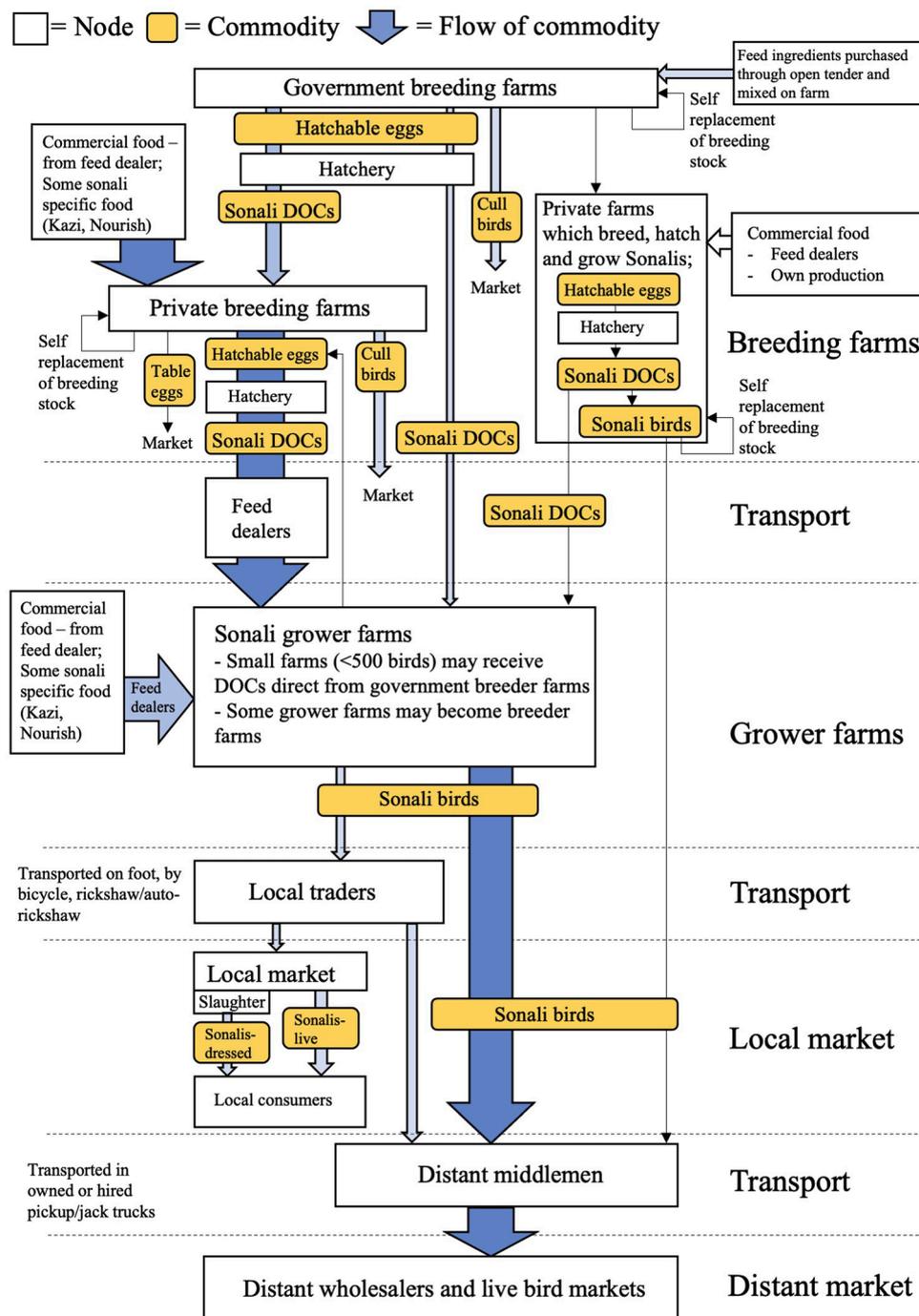


Fig. 2. Sonali broiler production and distribution network in Bangladesh. Arrow width and shading density indicates the relative quantity of commodities flowing through the production and distribution network.

“There are many types of middleman involved in this process. I contact with the first middleman to tell them my demand, then they communicate with other middleman and he collects deshi poultry from different households [that are] freely roaming the area. Then they accumulate a number of deshi in storeroom and then middleman one or middleman two supply us through rooftop of the local bus or public transportation” 37_CG_Poultry middleman

Further details of the middlemen interviews can be found in Supp. 5.

Routes of poultry into market were dependent on the nature of the relationship between the producer and their input supplier; those producers who utilised trade credit to secure access to inputs were bound to distribute poultry and eggs through their creditors - often a feed dealer -

rather than dealing directly with end markets or middlemen. Conversely, producers who were able to purchase their inputs in cash could choose whether to trade with or without the assistance of feed dealers.

Poultry enter LBMs predominately through wholesalers and are mostly kept in cages with birds of the same type before sale and slaughter. However, despite being in single type cages, many stalls kept different chicken types in close proximity to each other. Wholesalers sell chickens onto various retailers; market stallholders, live bird shops, mobile vendors/street hawkers, and more recently supermarkets, who then sell to end consumers (Fig. 4). Most consumers prefer to buy live birds and have them slaughtered at point of sale, thus providing an

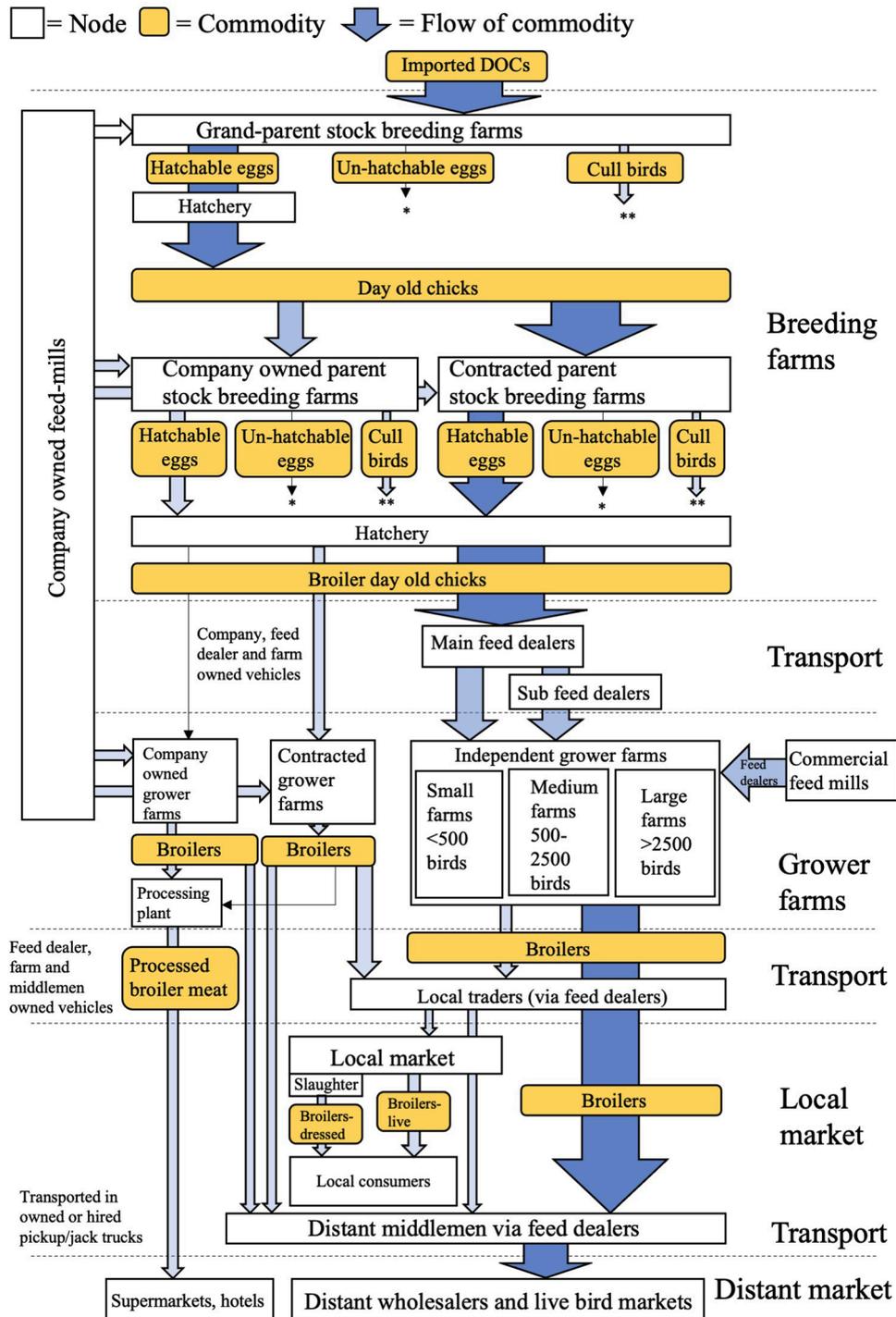


Fig. 3. Exotic broiler production and distribution network in Bangladesh. Arrow width and shading density indicates the relative quantity of commodities flowing through the production and distribution network.* Eaten by farm workers or sold locally; ** Moved to market via middlemen.

opportunity to make a judgement about the quality of the bird and the appropriateness of slaughter:

“There are actually three main issues, one is the customer wants to buy the poultry with open eyes, “I want to make sure that this poultry is healthy.” Number two, they want to make sure it is halal. Number three is that the price is right, it is higher in the supermarket.” 8_CG_NGO employee

3.4. Thematic analysis

Thematic analysis of interview data produced themes which help to explain how the PDN functions. Many of these themes are interconnected and were combined to produce dominant major themes (Fig. 5).

3.4.1. Unregulated networks

Several actors discussed the lack of capacity of the veterinary sector and government regulatory authority to effectively enforce legislation within the PDN. For example, a lack of negative incentives/fines and

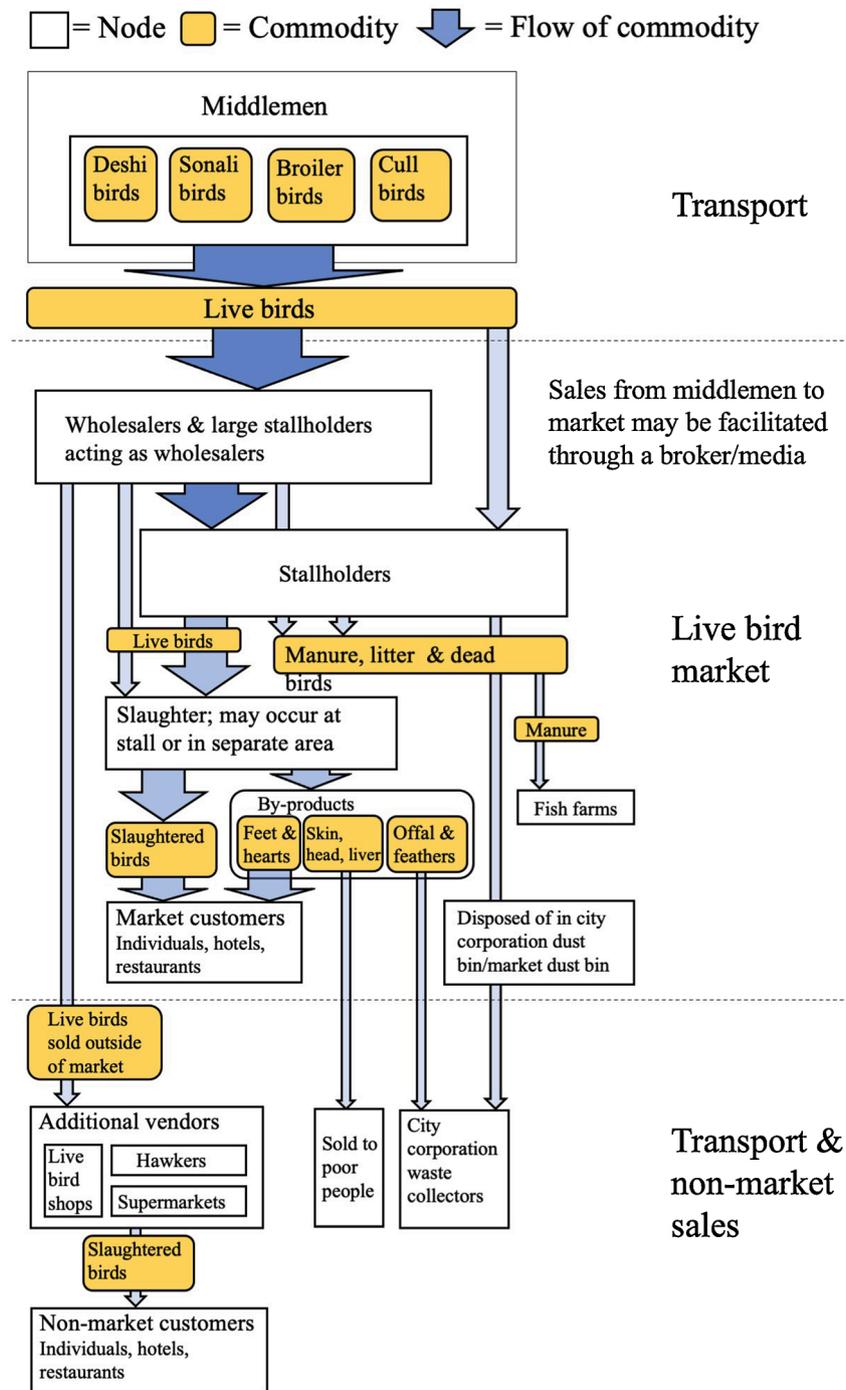


Fig. 4. Poultry live bird markets in Bangladesh. Arrow width and shading density indicates the relative quantity of commodities flowing through the production and distribution network.

compensation for culling diseased birds during outbreaks of HPAI created a situation where producers sold sick birds into the network in order to avoid losses:

“There are ups and downs in the market price almost every day, I try to sell at the best price. If we keep the birds for two or one days, then the price may increase and so he keeps it in the farm. But if he thinks there is chance of disease and the death, then they will sell at a loss. If they keep it for another two days, then there could be disease or death of the bird they will sell it at a lower price.” 4_CG_Feed dealer

Within LBMs, mandatory ‘rest days’, where markets are instructed to close and be empty of live birds for one day a week, are not observed due

to concerns over lost business, a lack of clarity over how to manage unsold birds, and an absence of regulatory enforcement.

3.4.2. Occupying network niches

It appeared that many opportunities exist for actors to occupy niche roles in the PDN to earn a living. At the production level such niche roles included, de-beakers, vaccinators, manure collectors, and at the distribution level numerous middlemen, bird and egg collectors, and brokers/media. While some of these actors were only connected to the PDN through virtual networks, others such as de-beakers, vaccinators, collectors, and middlemen were highly mobile, moving between several farms each day.

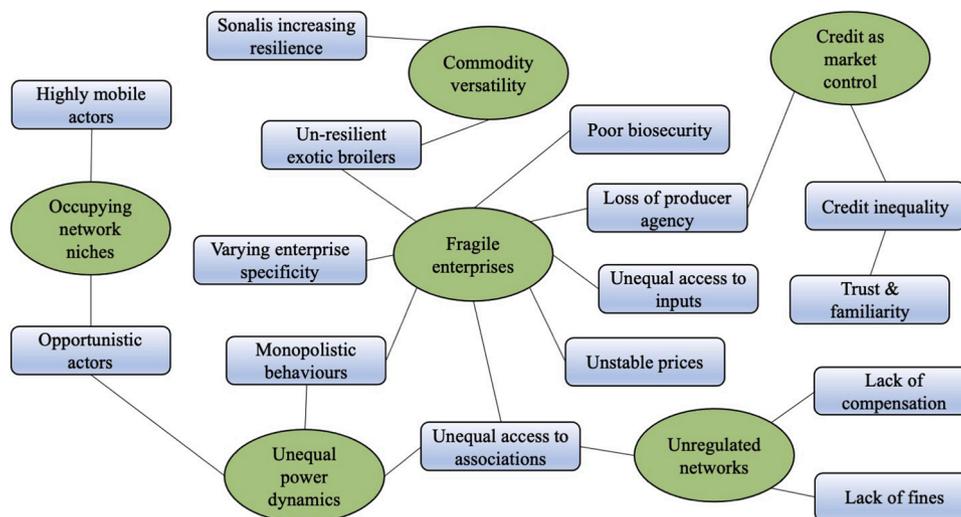


Fig. 5. Overview of themes and sub-themes identified within the Bangladeshi poultry production and distribution networks. Key; Major themes presented in oval boxes; minor themes presented in rectangular boxes.

3.4.3. Credit as market control

Many actors describe how capital poor farmers in the Sonali and exotic broiler subnetworks are forced to rely on trade credit from their suppliers to gain access to inputs, inadvertently placing themselves within a captive market where they are bound to trade with their creditors:

“If the small farmers take the feed and day-old chicks in credit, then they are bound to sell back to the feed dealer. Some farmers are independent, they have more cash, they can buy in cash, they sometimes sell directly to the supermarkets and the customer. But this is very rare.” 13_DK_NGO employee

Credit transactions were also present within poultry distribution, with some middlemen and traders acquiring commodities from feed dealers on short term credit. However, access to credit was not always equitable, being preferentially granted to local and familiar actors:

“We know the local salesmen... If we know them, then sometimes we will give them short term credit. If we don't know them, then we will do full cash. The farmer who I am not familiar with, is around ten percent, we deal in cash.” 4_CG_Feed dealer

3.4.4. Unequal power dynamics

Unlike large-scale broiler and layer enterprises - represented by the Bangladesh Breeders Association and the Layers Association - small and medium scale producers did not have access to professional organisations. This was seen as a barrier for producers, limiting their bargaining power within the PDN.

“The big farmers have more control over the market and also they are investing more, so they have a mentality to grab all market. They want to control the whole market. Sometimes when the small farmers are coming, they bring down the price, so they cannot sell. Sometimes they want to crush the small farmers. This is also a kind of syndicate. It is a kind of corporate culture.” 19_DK_NGO employee

Some PDN actors alluded to informal syndicates operated by middlemen and feed dealers. These syndicates were considered to exert control over farmer's distribution of poultry and were a barrier of entry to new middlemen and feed dealers entering the network.

3.4.5. Fragile enterprises

Our findings suggest that entry of new businesses into small and medium scale broiler production is relatively easy due to the low level of

investment and infrastructure needed to establish an enterprise. However, these infrastructurally poor enterprises, often operating with a low level of biosecurity, may be owned by producers with little to no technical training or knowledge who rely on other network actors to provide poultry services.

Price fluctuations of inputs such as feed and day-old chicks, and outputs was seen to add to the fragility of small producers, who faced uncertainty created by rapidly changing prices.

“Some of the big companies are engulfing the poultry industries. Small businessmen suffer. There is no regulation over the price of sale, I never know if after buying for 145 or 155 [taka per kg] that I will be able to sell for 145, it is uncertain. If the big company make a loss of one taka per kg it is ok for them, but if I do, then I am not interested in the poultry industry. It is an uncertain business.” 5_CG_Middleman

3.4.6. Commodity versatility

The presence of two major broiler types within the PDN warrants particular consideration. Exotic broiler breeds, selected for their fast muscle growth rates require a high level of input - vaccines, feed, biosecurity and antibiotics - to support production. While there is potential for a return on investment for producers who can satisfy these input requirements, those who cannot risk worsening their vulnerability. In addition, in the Bangladeshi market which favours darker poultry meat, exotic broilers suffer a low market preference:

“How the bird has developed for the western market has actually made the bird less desirable in the Asian market where there isn't a demand for large breast meat and it is difficult to keep the birds healthy at the rates that they grow, so the quality of the commercial broiler meat is very low, even the industry complains and they prefer to eat the Sonali, that's what everyone is eating on a daily basis. So, it's just instructive that it's the consumer that is ultimately going to drive where production systems go.” 21_DK_NGO employee

Conversely, the Sonali broiler, though taking twice as long to reach market age, is perceived by some producers to be a hardier bird, demands a greater market price, and can be sold within a wider window of time allowing producers to ride out short term market fluctuations. Additionally, unlike broilers, Sonalis can be raised into adulthood and potentially be used as breeding birds, increasing the commodity versatility of this breed and allowing producers opportunity for enterprise diversification:

“In case of farmers, what they realise is that they cannot keep broiler for a long time, in case the market price is low, so they want to keep for more days, in case of broiler they eat more and they do not make a profit, in case of Sonali they take less. And the market for the birds is different, some markets prefer the larger bird, some the smaller bird, so when the Sonali get to 60, 70, 80 days they become more nice, they are colourful, attractive, bright.” 25_DK_NGO employee

However, to our knowledge, only one large company is formally engaged with the Sonali system and has invested in a Sonali breeding programme. Consequently the growth in the sector has predominately been through small scale domestic breeding enterprises. It remains unclear whether the lack of corporate engagement with the Sonali sector is due to an underestimation of its relevance, uncertainty around breeding - ownership and maintenance of genetics - or the influence of domestic or foreign institutional power attempting to maintain the status quo of

exotic broiler production.

4. Discussion

The results presented in the mapping exercise and through thematic analysis describe the poultry PDN in Bangladesh, both in terms of its components – nodes and connections – and the underlying structural qualities. We argue that the current way in which the PDN operates is subject to underlying structural forces which create practices and behaviours that increase the risk of poultry and zoonotic diseases along the PDN (Fig. 6).

A combination of narrow profit margins and a lack of robust regulation appear to create an environment where sick poultry are sold into the market to prevent economic losses. This practice likely promotes disease transmission among poultry and between poultry and humans along the PDN (Zhou et al., 2009) and has been reported in Bangladesh

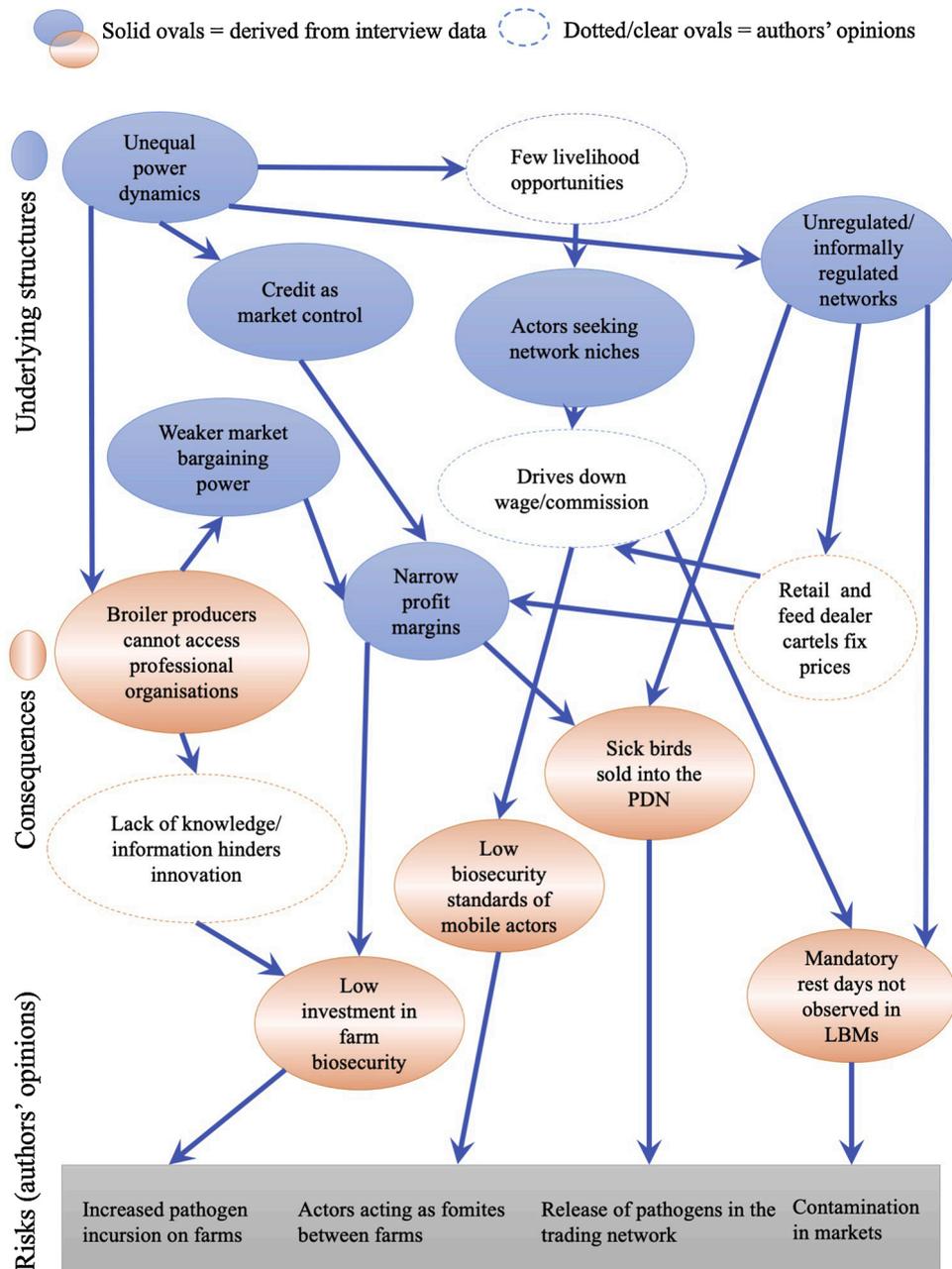


Fig. 6. Interactions between the Bangladeshi poultry production and distribution network structures, the resulting consequences and creation of disease risk environments.

(Høg et al., 2018) and Vietnam (Delabougliose et al., 2020). After the 2007 H5N1 HPAI outbreak, a compensation scheme was set up in Bangladesh supported by the World Bank to stamp out HPAI. The scheme was scrapped after the removal of external funding as it was considered unsustainable due to frequent outbreaks and suspected overreporting of disease (Chattopadhyay et al., 2018). While a thorough discussion of compensation schemes goes beyond the scope of this paper, it could be prudent for countries with endemic HPAI to re-evaluate the role of passive surveillance compensation schemes in national disease control programmes. For example, indemnity schemes could be developed with varying compensation rates depending on the participation of farmers in disease prevention programmes.

Concerningly, regulatory authorities are unable to ensure adherence to mandatory rest days designed to limit pathogen build up in LBMs. Further work is needed at the level of the LBMs to establish how to overcome barriers of compliance with mandatory rest days and to identify what incentives and disincentives could be effective in the absence of regulatory enforcement.

The mobility of actors operating within network niches increased the interconnectivity of an already highly connected PDN, and through their roles as pathogen vectors these actors may increase the opportunity for disease introduction and transmission. This is concerning given the reports of poor biosecurity practices in small and medium scale broiler farms by our participants and reflected in a study of Bangladeshi layer farms by Rahman et al. (2017), who found an absence of foot baths, hand washing facilities, and biosecurity awareness in most farms. While farmers may benefit from biosecurity training to mitigate disease risks by upgrading their infrastructure, investments are constrained by major structural factors, such as a lack of capital or access to independent credit. Indeed, a growing body of social science literature highlights weaknesses in the 'knowledge deficit model' of behavioural change (Tompson and Chandler, 2021), where individual's behaviour can be modified simply by providing information to fill a knowledge gap. Consequently, failures to address underlying structures are likely to result in information provision being ineffective in inducing behavioural change.

Small and medium scale poultry enterprises may benefit from access to professional organisations/associations which could be used to disseminate information – such as market prices of inputs and outputs – and knowledge on poultry production and biosecurity. Collective efforts may result in improved market bargaining power for producers, improving profit margins and creating capacity for system upgrading. In a study of poultry farming in Kenya, Kithendu (2017), describes how co-operatives allowed members to engage with information, knowledge, and innovative technologies, though noting that a limiting factor in the adoption of technology was lack of sufficient income. Readdressing the unequal power dynamics operating in the PDN may help to reduce the dominance of production inputs - feed, day-old chicks, vaccinations - by higher capital enterprises.

The commonly identified trade credit relationships in the small and medium scale enterprises appear to restrict producer agency and limit their market freedom. As a result, credit reliant producers can be subjugated by the numerous PDN patrons who seek to maximise economic rent appropriation. Producers exist on slender profit margins, precluding system upgrading and an escape from the control of trade credit. This finding was consistent with another study of small-scale poultry production in Bangladesh where reliance on trade credit results in the credit supplier – most often feed dealers - being the main influencer of farmer's decisions (Masud et al., 2020). Similarly, in their study of grain trading in Bangladesh, Crow (2001) described how trade credit relationships can cause 'interlocked transactions' characterised by price-fixing and trade-tying contracts. Microcredit schemes may help to alleviate the control exerted by trade-credit relationships and have been used successfully in the Vietnamese poultry sector to allow farmers to invest in biosecurity schemes such as vaccinations and restructuring poultry pens (Cristalli and Capua, 2007).

If growth in the Sonali poultry sector continues at the same rates seen before the outbreak of COVID-19, it is possible that within the next ten years this sector may become a dominant force in the PDN. Should investigations establish whether Sonali broilers are indeed more disease resilient than exotic broiler breeds then the growth of this sector may be beneficial in helping to improve the innate resilience of the PDN. Given the control exerted over the exotic broiler and layer sectors by multinational companies, it seems unlikely that the Sonali sector will continue to remain overlooked by scale operators who may seek to strengthen the influence of foreign institutional power in the PDN.

Inevitably, the qualitative nature of this study produced narratives about the PDN from the perspective of the snowballed selection of the interviewees. It can only be seen as a guide to these 'objects of study', more detailed ethnographic and quantitative follow up would doubtless produce a different picture, even a different set of narratives. This later work will be done using ethnographic methods (Connors, 1992; Herman and Bentley, 1992; Jenkins and Howard, 1992; Marcus, 1995; Nichter, 1991) and reported on in subsequent publications.

The accounts outlined here contain both emic and etic perspectives, but they are also 'truths' in two senses: they make sense as related by knowledgeable people who are deeply familiar with the poultry sector and reflect this lived experience and also by other more personal and political agendas. The other 'truth' reflects the researcher's interpretation and to a degree are exogenous to many actors within the PDN structures and indeed Bangladesh. As Moore (2005) says – and the point has long been recognised with social and cultural anthropology, this can only provide a version of the 'truth' which is partial and subjective. Consequently, alternative 'truths/realities' are bound to exist. These we were either unable to capture or, due to inherent issues of observer validation and enchantment (Gellner, 1959), unable to adequately formulate. We attempted to compensate for these limitations and biases by gathering accounts from numerous points within the PDN in an attempt to saturate and triangulate the data. Against these remarks, we should note that almost all our interviewees were male - as were most the research team - and thus the narrative of this paper reflects this. In particular we suspect that the absence of an explicit gender and age perspective may have resulted in neglect of the role of women and household juniors in the analysis. Neither did we explicitly investigate the distribution of financial and political (in the broadest sense) power in the PDN. Any future research about the PDN should take care to focus on these questions which are omitted from consideration in this paper.

5. Conclusion

The PDN maps presented in this paper demonstrate the complexity of poultry production in Bangladesh. They highlight the major flows of commodities through the networks and resulting disease risk environments. Analysis of the PDN suggests the majority of production occurs within fragile enterprises, operated by inexperienced and poorly supported actors many of whom lack capacity for the level of system upgrading needed to mitigate disease risk and navigate the instability of volatile markets. If this is indeed the key dynamic in the Bangladesh poultry sector, then given the way that the PDN as constituted creates multiple risk environments it is possible that the development of small and medium-scale poultry production may by its very nature lead to increased disease risk which is beyond regulation. Efforts could be taken to address the structural underlying factors identified as a way to reduce the fragility of the PDN and increase its resilience to disease threats. These findings are not only relevant to poultry production and distribution in Bangladesh but may help to inform our understanding of challenges posed by the rapidly growing poultry sector in other LMICs with similar structural concerns.

Author contributions

GF, MdAH, PB, PA, AE, TB conceived and designed the analysis;

MdAH, RM, MHasan arranged interviews to collect data; MH, RM, MHasan collected data; MH, GF, PA, AE, TB performed the analysis; MdAH organised a stakeholder workshop to validate data; MH, GF, TB wrote the paper, and MdAH, PB, PA, AE, RM, MHasan contributed to writing by providing inputs to versions of the preprint. All authors provided revisions to the final version of the manuscript.

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Declaration of Competing Interest

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

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Appendix A. Supplementary data

Supplementary material related to this article can be found, in the online version, at doi:<https://doi.org/10.1016/j.prevetmed.2021.10.5367>.

References

- Ahmed, N., Young, J.A., Dey, M.M., Muir, J.F., 2012. From production to consumption: a case study of tilapia marketing systems in Bangladesh. *Aquac. Int.* 20, 51–70.
- Alam, G.M.M., Khatun, M.N., Rahman, K.T., 2013. Marketing channel and consumer preference of poultry products in rural areas of Bangladesh. 8th International Poultry Show and Seminar.
- Alarcón, P., Fèvre, E.M., Murungi, M.K., Muinde, P., Akoko, J., Dominguez-Salas, P., Kiambi, S., Ahmed, S., Häslér, 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. <https://doi.org/10.1016/j.agsy.2016.12.005>.
- Alders, R.G., Dumas, S.E., Rukambile, E., Magoke, G., Maulaga, W., Jong, J., Costa, R., 2018. Family poultry: multiple roles, systems, challenges, and options for sustainable contributions to household nutrition security through a planetary health lens. *Matern. Child Nutr.* 14, e12668 <https://doi.org/10.1111/mcn.12668>.
- Amin, V.A., Islam, M.R., Hossain, M., 2012. Marketing channel of dried marine fish in the southeastern coastal belt of Bangladesh. *Middle-East J. Sci. Res.* 12, 301–306.
- Barnett, T., Blaikie, P., 1992. *AIDS in Africa: its Present and Future Impact*. Belhaven Press, London and Guildford Press, New York LB - Hopelessness.
- Barnett, T., Whiteside, A., 2006. *AIDS in the 21st Century: Disease and Globalisation*, 2nd ed. Palgrave Macmillan, London.
- Bhuiyan, A.K.F.H., Bhuiyan, M., Deb, G., 2005. Indigenous chicken genetic resources in Bangladesh: current status and future outlook. *Anim. Genet. Resour. Inf.* <https://doi.org/10.1017/S101423390001899>.
- Braun, V., Clarke, V., 2006. Using thematic analysis in psychology. *Qual. Res. Psychol.* 3, 77–101. <https://doi.org/10.1191/1478088706qp063oa>.
- Buckley, P., Strange, R., 2015. The Governance of the Global Factory: location and control of world economic activity. *Acad. Manag. Perspect.* 29, 237–249.
- Castleberry, A., Nolen, A., 2018. Thematic analysis of qualitative research data: is it as easy as it sounds? *Curr. Pharm. Teach. Learn.* 10, 807–815. <https://doi.org/10.1016/j.cptl.2018.03.019>.
- Chattopadhyay, K., Fournié, G., Abul Kalam, M., Biswas, P.K., Hoque, A., Debnath, N.C., Rahman, M., Pfeiffer, D.U., Harper, D., Heymann, D.L., 2018. A qualitative stakeholder analysis of avian influenza policy in Bangladesh. *Ecohealth* 15, 63–71. <https://doi.org/10.1007/s10393-017-1285-2>.
- Connors, M.M., 1992. Risk perception, risk-taking and risk management among intravenous-drug-users - implications for AIDS prevention. *Soc. Sci. Med.* 34, 591–601.
- Cristalli, A., Capua, I., 2007. Practical problems in controlling H5N1 high pathogenicity avian influenza at village level in Vietnam and introduction of biosecurity measures. *Avian Dis.* 51, 461–462. <https://doi.org/10.1637/7564-033106R.1>.
- Crow, Ben, 2001. *Markets, Class and Social Change: Trading Networks and Poverty in Rural South Asia*. Palgrave, London.
- Das, S.C., Chowdhury, S.D., Khatun, M.A., Nishibori, M., Isobe, N., Yoshimura, Y., 2008. Poultry production profile and expected future projection in Bangladesh. *Worlds Poultry Sci. J.* 64, 99–118. <https://doi.org/10.1017/S0043933907001754>.
- DEFRA, 2010. *Poultry in the United Kingdom*.
- Delabouglise, A., Le Thanh, N.T., Ai Xuyen, H.T., Nguyen-Van-Yen, B., Tuyet, P.N., Lam, H.M., Boni, M.F., 2020. Poultry farmer response to disease outbreaks in smallholder farming systems. *bioRxiv* 2020. <https://doi.org/10.1101/2020.05.19.104059>, 05.19.104059.
- Dhingra, M.S., Artois, J., Dellicour, S., Lemey, P., Dauphin, G., Von Dobschuetz, S., Van Boeckel, T.P., Castellan, D.M., Morzaria, S., Gilbert, M., 2018. Geographical and historical patterns in the emergences of novel highly pathogenic avian influenza (HPAI) H5 and H7 viruses in poultry. *Front. Vet. Sci.* 5, 84. <https://doi.org/10.3389/fvets.2018.00084>.
- Ebata, A., MacGregor, H., Loevinsohn, M., Win, K.S., Tucker, A.W., 2018. Value Chain Governance and Its Influence on Livestock Diseases: a Case of Pig Farming in Myanmar.
- FAO, 2008. *Poultry Sector Country Review Bangladesh Fao Animal Production and Health Division Emergency Centre For Transboundary Animal Diseases Socio Economics, Production And Biodiversity Unit*.
- FAO, 2011. *A Value Chain Approach to Animal Diseases Risk Management - Technical Foundations and Practical Framework for Field Application*. Rome.
- FAO, 2013. *Poultry Development Review*.
- FAO, 2015. *Comparative Performance of Sonali Chickens, Commercial Broilers, Layers and Local Non-descript (Deshi) Chickens in Selected Areas of Bangladesh*. FAO.
- FAOSTAT, 2017. *Faostat*.
- Gellner, E., 1959. *Words and Things*. Penguin, London.
- GHI, 2019. *A Closer Look at Hunger and Undernutrition in Bangladesh - Country Case Studies [WWW Document]*.
- Gibbon, P., Ponte, S., 2005. *Trading Down Africa, Value Chains, and The Global Economy*. Temple University Press.
- Goletti, F., Ahmed, R., Farid, N., 1995. Structural determinants of market integration: the case of rice markets in Bangladesh. *Dev. Econ.* 33, 196–198. <https://doi.org/10.1111/j.1746-1049.1995.tb00713.x>.
- Hamid, M.A., Rahman, M.A., Ahmed, S., Hossain, K.M., 2016. Status of poultry industry in Bangladesh and the role of private sector for its development. *Asian J. Poultry Sci.* <https://doi.org/10.3923/ajpsaj.2017.1.13>.
- Herman, E., Bentley, M.E., 1992. *Manuals for ethnographic data collection: experience and issues*. *Soc. Sci. Med.* 35, 1369–1378.
- Høg, E., Fournié, G., Hoque, M.A., Mahmud, R., Pfeiffer, D.U., Barnett, T., 2018. Competing biosecurity and risk rationalities in the Chittagong poultry commodity chain. *Biosocieties*. <https://doi.org/10.1057/s41292-018-0131-2>.
- Jenkins, C., Howard, P., 1992. The use of ethnography and structured observations in the study of risk factors for the transmission of diarrhea in highland Papua New Guinea. *Med. Anthropol.* 15, 1–16.
- Jones, K., Herrero, M., Kruska, R., Said, M., Iapar, L., Grace, D., Mutua, F., Akuku, I., Brierley, L., Nguyen, B.T., Ochungo, P., Ogutu, F., Pham, D.P., 2012. Mapping of Poverty and Likely Zoonoses Hotspots.
- Kaplinsky, R., 2000. *Spreading the Gains From Globalisation: What Can Be Learned From Value Chain Analysis?*
- Kaplinsky, R., Morris, M., 2001. *A Handbook for Value Chain Research*, 113.
- Kithendu, J., 2017. *The Role of Co-operative on Farmers' Adoption of Poultry Farming Innovations in Kwale, Kenya: an Application of Roger's Diffusion of Innovation*. Chandaria School of Business.
- Kock, R., Croft, S., Dixon, M., Fletcher, C., Good, L., Guzman, J., Heymann, D.L., Liyanage, R., Mckeever, D.J., McNamee, R., Peeling, R.W., Moran, M., Pfeiffer, D.U., Waage, J.K., Wu, L., 2012. *Prioritising the Need for New Diagnostics, Medicine, Vaccines and Management Practices of Zoonoses Which Have Significant Impact in the Developing World*.
- Lewis, D., 2011. *Bangladesh: politics, economy and civil society, Bangladesh: politics*. *Econ. Civil Soc.* <https://doi.org/10.1017/CBO9781139017138>.
- Lewis, D., Wood, G.D., Gregory, R., 1996. *Trading the Silver Seed: Local Knowledge and Market Moralities in Aquacultural Development*. University Press, Dhaka, Bangladesh.
- LightCastle, 2020. *Structured Poultry Industry Growing in Size - LightCastle Partners [WWW Document]*.
- Marcus, G., 1995. *Ethnography in/of the world system: the emergence of multi-sited ethnography*. *Annu. Rev. Anthropol.* 24, 95.
- Masud, A., Al, Rousham, E.K., Islam, M.A., Alam, M.-U., Rahman, M., Mamun, A., Al, Sarker, S., Asaduzzaman, M., Unicomb, L., 2020. Drivers of antibiotic use in poultry production in Bangladesh: dependencies and dynamics of a patron-client relationship. *Front. Vet. Sci.* 7, 78. <https://doi.org/10.3389/fvets.2020.00078>.
- Miller, D.D., Welch, R.M., 2013. Food system strategies for preventing micronutrient malnutrition. *Food Policy* 42, 115–128. <https://doi.org/10.1016/j.foodpol.2013.06.008>.
- Moore, H., 2005. *The truths of Anthropology*. *Camb. Anthropol.* 25, 52–58.
- Mottet, A., Tempio, G., 2017. *Global poultry production: current state and future outlook and challenges*. *Worlds Poultry Sci. J.* 73, 245–256. <https://doi.org/10.1017/S0043933917000071>.
- Moyen, N., Ahmed, G., Gupta, S., Tenzin, T., Khan, R., Khan, T., Debnath, N., Yamage, M., Pfeiffer, D.U., Fournie, G., 2018. A large-scale study of a poultry trading

- network in Bangladesh: implications for control and surveillance of avian influenza viruses. *BMC Vet. Res.* 14, 12. <https://doi.org/10.1186/s12917-018-1331-5>.
- Moyen, N., Hoque, M.A., Hasan, M., Sarkar, S., Biswas, P., Hossain, M., Henning, J., Mangtani, P., Meerjady, F., Rahman, M., Debnath, N., Giasuddin, M., Barnett, T., Pfeiffer, D., Fournie, G., 2020. Avian Influenza Transmission Risk among Live Bird Trading Networks. Submitted.
- Nichter, M., 1991. Use of social science research to improve epidemiologic studies of and interventions for diarrhea and dysentery. *Rev. Infect. Dis.* 13, S265–71.
- NIPORT, ICF, 2019. Bangladesh Demographic and Health Survey 2017-18: Key Indicators. Dhaka, Bangladesh, and Rockville, Maryland, USA..
- OECD, FAO, 2020. OECD-FAO Agricultural Outlook 2020-2029, OECD-FAO Agricultural Outlook. OECD. <https://doi.org/10.1787/1112c23b-en>.
- Paul, M., Baritau, V., Wongnarkpet, S., Poolkhet, C., Thanapongtharm, W., Roger, F., Bonnet, P., Ducrot, C., 2013. Practices associated with highly Pathogenic Avian Influenza spread in traditional poultry marketing chains: social and economic perspectives. *Acta Trop.* 126, 43–53. <https://doi.org/10.1016/j.actatropica.2013.01.008>.
- Rahman, M.M., Badhy, S., Islam, M., Osmani, M., Chowdhury, E.H., Das, P., Islam, M.R., 2017. A Baseline Survey on Biosecurity Practices of Layer Farmers in Bhaluka and Sakhipur Upazila of Bangladesh.
- Rimi, N.A., Sultana, R., Ishtiak-Ahmed, K., Rahman, M.Z., Hasin, M., Islam, M.S., Azziz-Baumgartner, E., Nahar, N., Gurley, E.S., Luby, S.P., 2016. Understanding the failure of a behavior change intervention to reduce risk behaviors for avian influenza transmission among backyard poultry raisers in rural Bangladesh: a focused ethnography. *BMC Public Health* 16, 858. <https://doi.org/10.1186/s12889-016-3543-6>.
- Shanta, I.S., Hasnat, M.A., Zeidner, N., Gurley, E.S., Azziz-Baumgartner, E., Sharker, M. A.Y., Hossain, K., Khan, S.U., Haider, N., Bhuyan, A.A., Hossain, M.A., Luby, S.P., 2017. Raising backyard poultry in rural Bangladesh: financial and nutritional benefits, but persistent risky practices. *Transbound. Emerg. Dis.* 64, 1454–1464. <https://doi.org/10.1111/tbed.12536>.
- Sheel, S.K., Sen, B.K., 2013. Poultry contract farming in Bangladesh with special reference to aftab bahumukhi farm limited (ABFL). *J. Bus. Stud.* XXXIV.
- Siddiky, N.A., 2017. Backyard Poultry Production Systems in SAARC Member States South Asian Association for Regional Cooperation, pp. 39–58.
- Sultana, R., Nahar, N., Rimi, N., Azad, S., Islam, S., Gurley, E.P., Luby, S., 2012. Backyard Poultry Raising in Bangladesh: a Valued Resource for the Villagers and a Setting for Zoonotic Transmission of Avian Influenza. A Qualitative Study, Rural and Remote Health..
- Tompson, A.C., Chandler, C.I.R., 2021. Addressing Antibiotic Use: Insights from Social Science Around the World. A Report Collated With Social Scientists of the Antimicrobials in Society Hub. London. <https://doi.org/10.17037/PUBS.04659562>.
- UN, 2015. Sustainable Development Goals: Sustainable Development Knowledge Platform [WWW Document]. URL <https://sustainabledevelopment.un.org/?menu=1300> (accessed 4.14.20)..
- WHO, 2012. H5N1 Avian Influenza: Timeline of Major Events.
- 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 Sec.* 15, 43–52. <https://doi.org/10.1016/j.gfs.2017.04.003>.
- WPSA, 2020. Poultry at a Glance – World's Poultry Science Association (WPSA) [WWW Document]. URL <https://wpsa-bb.com/poultry-at-a-glance/> (accessed 4.14.20)..
- Zhou, L., Liao, Q., Dong, L., Huai, Y., Bai, T., Xiang, N., Shu, Y., Liu, W., Wang, S., Qin, P., Wang, M., Xing, X., Lv, J., Chen, R.Y., Feng, Z., Yang, W., Uyeki, T.M., Yu, H., 2009. Risk factors for human illness with avian influenza A (H5N1) virus infection in China. *J. Infect. Dis.* 199, 1726–1734. <https://doi.org/10.1086/599206>.