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Transformation of the feed supply segment of the aquaculture value chain in Bangladesh

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ABSTRACT

The rapid growth of aquaculture in Bangladesh over the past three decades has been facilitated by increasing supplementary feed use and increasing numbers of feed suppliers, but little is known about the organization and behavior of the feed supply segment of aquaculture value chain. We conducted a comprehensive survey with 79 feed suppliers of two types: 'dealers' linked to feed companies ($n = 34$) and independent retailers ($n = 45$), in the seven main aquaculture producing districts of southern Bangladesh in 2021 to address this knowledge gap. We found the following. (1) Over the past 10 years, the number of traders increased 70% and the volume of feed traded almost doubled. (2) Feed supply is shifting from traditional agricultural byproducts to formulated feeds (47% of total feed), and floating feeds as a subset of those (54% of formulated feed), contributing to increasing farm productivity. (3) The formulated fish feed market in Bangladesh is diverse, but quite concentrated. Feed suppliers sold formulated feed produced by 35 companies, with eight companies accounting for 74% of sales. (4) Feed handling practices are efficient. Traders sell feeds quickly (average turnover time 10 days) and storage practices are adequate to maintain quality. (5) No traders reported experiencing any waste or loss of feed during their most recent completed transaction, and only 5% of traders reported losing a small portion of feed (1.7%) during transport. (6) The average profit margin earned by feed suppliers is a modest 6.2%. (7) Feed trading creates substantial employment: 43,937 full time equivalent (FTE) jobs in the seven surveyed districts. In sum, the feed supply segment of the aquaculture value chain in southern Bangladesh is dynamic, well-developed, and relatively competitive and efficient. This finding is contrary to the conventional wisdom, which often portrays the sector as inefficient and beset by problems.

1. Introduction

Recent research on agrifood value chains has called for greater attention to the role of traders and input suppliers in facilitating farm commercialization and raising farm productivity (e.g., Barrett et al., 2022; Liverpool-Tasie et al., 2020). The literature on aquaculture value chains is growing (e.g., Bush et al., 2019), but includes little detailed coverage of the upstream segments of the value chain supplying inputs to farms (Bremer et al., 2016; Haque et al., 2021). This is an important gap because intensification of aquaculture through increasing levels of feed use, in particular formulated feeds, is one of the most important trends in aquaculture globally (e.g., Boyd and McNevin, 2022; Naylor et al., 2021; Bush et al., 2019; El-Sayed et al., 2015).

This trend is apparent in Bangladesh, where use of both formulated and non-formulated fish feeds is increasing quickly (Mahmud and Nazrul, 2013; Hasan and Arthur, 2015; Bosu et al., 2016), contributing to large increases in aquaculture output, which jumped from 124,000 tons in 1984 to 2.64 million tons in 2021 (Hernandez et al., 2018; DoF, 2022). Increasing feed use has also contributed to increases in aquaculture productivity, which rose from an average of 2580 kg/ha in 2000 to 5129 kg/ha in 2021 for pond farms (DoF, 2022). Feed use is therefore associated with the growth of aquaculture production at both the extensive and the intensive margins.

Feed accounts for the largest share of production costs in most commercial pond-based aquaculture systems, ranging from 52 to 80% or operating costs for pond farms in Bangladesh (e.g., Ahmed et al., 2010;

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Alam, 2011; Ali et al., 2018a; Jahan et al., 2015). Feed traders serve as intermediaries between feed manufacturers and farmers. They therefore play an increasingly important role in facilitating adoption of fish feeds by aquaculture farms.

The structure (e.g., numbers, size, and geographical location of traders, and degree of market concentration), conduct (e.g., trader services to clients, such as product storage, feed delivery to farms, or credit provision), and performance (e.g., rates of feed loss and waste, trader profit margins, inclusiveness, competitiveness) of the feed supply segment of the value chain therefore all play an increasingly important role in determining the productivity and profitability of aquaculture.

Most prior studies on the fish feed sector, both internationally and in Bangladesh, have focused on feed formulation and production, and the nutritional composition, quantity quality, price, and use of feeds and feed ingredients (Tacon, 2020; Hasan and Arthur, 2015; Mamun-Ur-Rashid et al., 2013; Mahmud and Nazrul, 2013; Kader et al., 2005), but contain little information on feed trading and distribution. Hernandez et al. (2018) trace the evolving structure of the feed segment of the aquaculture value chain in Bangladesh, based on a meso-scale survey of key informants, but provide few details of the microeconomic behavior of feed supply businesses. A handful of value chain studies have addressed aquaculture feed supply and distribution and utilization more comprehensively, for Vietnam (Hasan and Shipton, 2021), Egypt (Macfadyen et al., 2012; El-Sayed et al., 2015), Kyrgyz Republic (Islam and Hasan, 2020) and Kenya (Munguti et al., 2021), but even these pay relatively limited attention to the role of feed dealers and retailers. Moreover, even where studies include coverage of feed suppliers, they typically do not use robust sampling techniques, making it difficult to generalize results (e.g., Sabur et al., 2010; Islam et al., 2022).

Where the literature has addressed fish feed traders in Bangladesh, it often includes the following characterizations: First, feed traders are reported to make contractual agreements with feed manufacturers to obtain sole distributorship rights (so caller 'dealerships') to trade in a particular geographical area but are locked into selling only feed from the company providing the contract (Islam et al., 2022). Second, feed traders provide in-kind credit to farmers, allowing them to 'capture' these clients, who are then obliged to use feed provided by the traders, despite it often being of poor quality (Islam et al., 2020; Islam et al., 2021). Third, the performance of the feed supply chain is often characterized as poor. Improper storage and handling of feeds is said to reduce their quality, and transport and delivery services are said to be inadequate, with cases of late or no delivery reported (Hasan and Arthur, 2015; Islam et al., 2022). Fourth, feed distribution is often characterized as inefficient due to large numbers of small intermediaries, resulting in high marketing margins, which increase feed prices for farmers (Islam et al., 2022). This view often gives rise to recommendations aimed at 'cutting out the middleman' by linking feed manufacturers directly to farmers (Islam et al., 2022).

More positively, feed traders may help to reduce feed transaction costs for customers by providing transportation services (Sarwer, 2021). The feed trading segments of value chain are also thought to generate substantial employment (Mahmud and Nazrul, 2013), but there has been little quantitative evaluation of the scale of this.

Considering the above context, we conducted a survey to address the lack of information on feed trading in Bangladesh. We distinguished between two distinct types of feed supplier: (1) 'Dealers' who are dedicated agents for specific feed mills, serving primarily as a conduit for retail sales to farmers; (2) Independent retailers who do not engage in relational contacts with feed mills, and specialize more in selling agricultural processing by-products as feeds.

The remainder of the paper is organized as follows. First, we analyze the ***structure*** of the feed supplier segment of the aquaculture value chain in the seven main aquaculture producing districts in southern Bangladesh. Structure includes numbers of dealers and independent retailers, scale of operations, and geographical location, and trader socio-demographic characteristics and asset ownership. Second, we analyze trader ***conduct***, with reference to the types and quantities of feeds traded, procurement and marketing behavior, utilization of working capital and credit, and service provision to clients. Third, we analyze value chain ***performance*** with respect to employment generation, the impacts of COVID-19 on business operations, rates of feed loss and waste, and business profitability. This approach to value chain analysis is consistent with that set out in the 2019 special issue of *Aquaculture* on emerging trends in aquaculture value chain research (Bush et al., 2019), and other foundational work on agrifood value chains (e.g., Reardon et al., 2012). Fourth, we triangulate information on feed use and utilization of in-kind credit for feed purchases, using data from a representative survey of aquaculture farms conducted in the same seven districts. The final section concludes.

2. Materials and methods

2.1. Study area and types of trader

This study was conducted in the seven main aquaculture producing districts of southern Bangladesh (Fig. 1). These districts accounted for 43% of national aquaculture area, and 24% of national aquaculture production, and 88% and 80% of aquaculture area and production for southern Bangladesh in 2021 (DOF, 2022).

Species farmed in this zone include a mix of fish (mainly Indian major carps, tilapia, and brackish water species), shrimp (mainly black tiger shrimp, *Penaeus monodon*) and giant freshwater prawn (*Macrobrachium rosenbergii*). Crustaceans are grown primarily in polyculture with fish, mainly for export, and in many cases integrated other agricultural crops such as rice or vegetables (Jahan et al., 2015). Fish are produced for the domestic market.

Two distinct categories of feed supply business were identified during pre-survey scoping visits: (1) 'Dealers' function mainly as retailers, but large ones that work directly with mills. They serve as agents for one or more mills, mainly retailing feed to farmers and doing a little wholesaling to other retailers. Dealers have sole distributorship rights to sell a particular mill's feeds to farmers and retailers in given area, and may receive commission or other financial incentives from feed mills if they are able to fulfil sales targets. (2) Retailers are smaller on average than dealers, are not linked to feed mills through relational contracts, and specialize more in sales of non-formulated feeds. They mainly sell to farmers, although a small portion also sell feed to other retailers.

2.2. Survey methods and data

Data were collected between May and August in 2021 from a survey of 79 feed suppliers (34 dealers and 45 feed retailers). This study was part of larger 'stacked survey' of multiple aquaculture value chain segments, including 721 farms, conducted in the same districts. The stacked survey approach facilitates collection of more comprehensive and accurate data than conventional approaches to value chain research, which often rely on small, non-representative and/or qualitative samples across fewer value chain nodes (Reardon et al., 2012).

The 2021 survey was the second round of an earlier survey conducted in 2013. For the 2013 survey, the seven districts were initially selected purposively based on their importance for aquaculture production. All *upazila* (sub-districts) with non-negligible aquaculture production were selected for inclusion in the initial sample frame, then selected randomly by probability proportional to size (PPS), yielding 13 upazila for inclusion in the final sample. In each selected upazila, all *mouza* (the smallest administrative unit reported in the Bangladesh agricultural census), underwent a second stage of trimming to eliminate those with fewer than 20 aquaculture farms, as reported in the national agricultural census of 2008. Two to three mouza were then selected randomly from each upazila for inclusion in the farm survey. In all selected mouza, 20 aquaculture farms were selected randomly for interview from a list compiled during a pre-survey farm census. A census

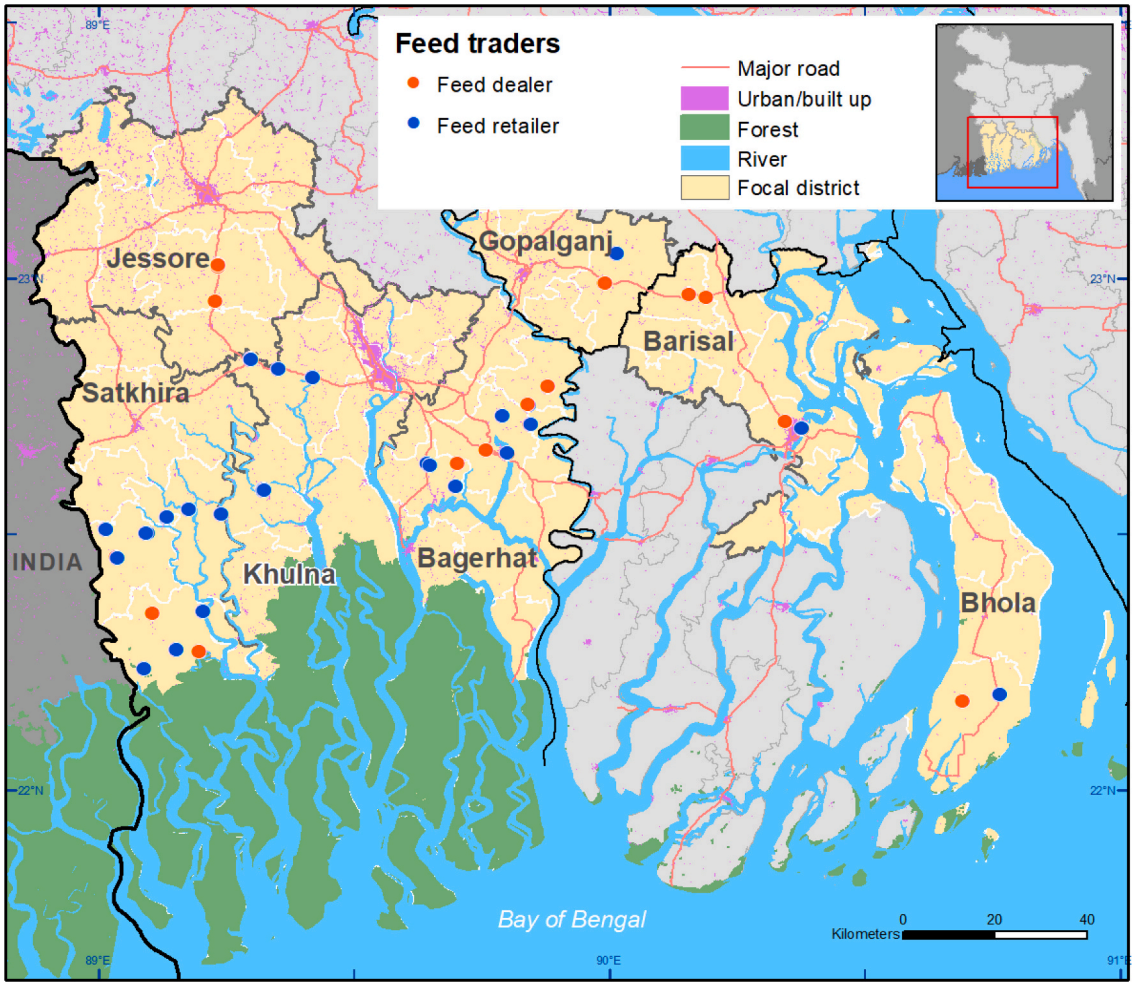

Fig. 1. Map of location of surveys traders in southern Bangladesh.

of feed traders was also conducted all 13 upazilas in the farm household sample, and respondents were randomly selected from the census list for interview.

In 2021 we replicated this sampling approach by conducting a new listing of feed suppliers in every upazila surveyed in 2013. All feed suppliers surveyed in 2013 who were identified as still operating in 2021 (43%) were resurveyed. Respondents included in the 2013 survey whose businesses had closed, or who were unavailable to participate in the resurvey were replaced at random from the 2021 census list. A similar procedure was followed for selection of aquaculture farms.

Interviews were conducted face to face by trained enumerators using a structured questionnaire implemented using a tablet. The 79 feed suppliers surveyed in 2021 represented 25% of dealers and 14% of retailers operating in the 13 surveyed upazila, based on data from an unpublished census of feed traders in southern Bangladesh compiled by the Bangladesh Aquaculture and Nutrition Activity project, implemented by WorldFish.

Survey weights were calculated during analysis by dividing the total number of feed dealers and retailers listed in each upazila by the number sampled, and used to adjust for over or under sampling, where applicable. In addition to individual surveys with feed suppliers about their microeconomic behavior, we conducted 15 key informant interviews with feed mill representatives, feed formulation consultants, and experienced feed traders to collect meso-scale information on changes in the number and scale of feed trading operations in the surveyed areas over the last 10 years.

We surveyed 721 fish farmers in 2021, categorized during analysis into four groups based on the combination of species cultured. These are: fish only (FO; $N = 284$), prawn + fish (PF; $N = 165$), prawn + shrimp + fish (PSF; $N = 211$), and shrimp + fish (SF; $N = 65$). We present data on feed procurement and use by these farmers in the final section of the paper.

We estimated the number of full time equivalent (FTE) jobs created by feed supply businesses in the seven survey districts by multiplying the mean labor days per unit of feed sold by feed dealers and retailers by average formulated and non-formulated feed use per ha derived from the farm survey, multiplied by the total area of aquaculture farms in surveyed districts, as reported by DOF (2022). Profit margins earned on feed suppliers' most recent transactions were calculated by subtracting the feed purchase price and operating costs from the sales value, and dividing by the sales value.

3. Results and discussion

3.1. Trader and business characteristics

All surveyed feed suppliers were men, except for one woman retailer, with a mean age of 43 years (Table 1). The average level of formal education was much higher than the national average (11 years, versus 6) (World Economics, 2022). Traders had long experience operating feed trading enterprises (12 years) and this did not differ significantly ($p \geq 0.05$) between dealers and retailers (Table 1).

All surveyed feed suppliers had obtained a trade licenses from local government to operate their businesses, as required by law (Table 1).

Table 1
Demographic and basic information of feed traders.

Variables	Trader category		
	Dealer	Retailer	Overall
Average age (years)	45	40	43
Average schooling (years)	11	11	11
Experience of fish feed trading (years)	12	11	12
Received training on feed marketing (%)	58	47	53
Training received from (%)			
Feed and chemical companies	60	55	57
Department of Fisheries (DOF)	40	50	45
Non-government organization (NGO)	40	40	40
Other organizations	15	15	15
Member of trading association (%)	29	47	37
Primary occupations (%)			
Fish feed and input trading	71	78	74
Fish farming	13	7	11
Other trading	6	12	9
Government/NGO job	9	0	5
Poultry and livestock farming	0	3	1
Business ownership (%)			
Single	88	85	87
joint	12	15	13
Received certification/license (%)	100	100	100
Department of Fisheries	70	57	64
Local government	100	100	100
Other assets/businesses			
Household own land (%)	100	98	99
Household own land area (ha)	1.1	0.73	0.93
Household practiced crop farming (%)	50	48	49
Household practiced aquaculture (%)	65	57	62
Household aquaculture area (ha)	2.3	2.1	2.2
Business scale & composition			
Average working capital (USD/year)	42,120	10,593	28,141
Average volume of feed traded (ton/year)	305	130	182
Formulated feed share in total feed traded (%)	76	18	47
Selling poultry/livestock feed (% of traders)	76	76	76
Selling aquaculture medicines (% of traders)	71	84	78
Sold fish and/or crustacean (% of traders)	1.6	1.1	1.2

Two-thirds had also obtained a license from the DOF in accordance with the 'Fish Feed and Animal Feed Act 2010', the main legislation governing fish feed marketing in Bangladesh. More dealers (70%) took DOF licenses than retailers (57%), as dealers are larger on average and tend to operate in urban or peri-urban areas frequently visited by DOF officials, whereas implementation was less strict in remoter areas where some retailers remained unlicensed.

Fifty-eight percent of dealers and 47% of retailers have participated in short training courses on feed marketing, with most provided by feed and chemical companies (57%), the Department of Fisheries (DOF) (45%), and non-governmental organizations (NGOs) (40%). Feed trading was the primary occupation of most survey respondents (74%), indicating a high level of specialization in feed trading. Around 76% of respondents also sold poultry and/or livestock feed in addition to aquafeeds, reflecting the co-development and simultaneous growth of the animal feed and aquaculture feed sectors (Table 1).

Beyond feeds, 71% of dealers and 84% of retailers traded aquaculture medicines. Feed products and chemical products are bought and sold separately (i.e., not tied or distributed as a package), but suppliers encourage farmers to use both, and may provide leaflets with information about both types of products. Farmers may visit feed shops when they encounter disease or water quality problems to ask for advice, and receive recommendations on chemical products to address their problems (Ali et al., 2018b).

Many respondents had multiple sources of household income beyond feed supply. Sixty-two percent farmed fish and/or crustaceans, and 49% cultivated agricultural crops, reflecting the rural location of many traders, and perhaps indicating that many were originally successful farmers prior to establishing feed supply enterprises. Most feed traders (87%) operated their business alone and the remainder jointly with 2 or 3 partners. Traders sometimes took partners from other locations to reach new clients, and to increase their working capital.

Survey respondents all sold feed manufactured or processed by larger mills, and none produced their own feed. Dealers specialize in trading formulated feeds (76% of their total traded feed volume), whereas retailers specialize more in sales of unformulated feeds (i.e., agricultural processing byproducts, such as broken rice, rice bran, and oilcake), which account for 82% of their sales.

Dealers' operations are significantly larger on average ($p \leq 0.05$) than those of retailers, both in terms of volumes traded (305 t/year vs 130 t/year) and working capital (USD 42,120/year vs USD 10,593/year) (Table 1). This difference in scale likely reflects a progression where feed manufacturers select larger and more successful retailers to serve as dealers.

3.2. The changing structure of the feed trading segment of the value chain

Feed supply businesses have proliferated over the past decade. Estimates from our meso-scale interviews suggest the number of feed suppliers grew by 69% since 2010. Retailers grew more quickly over this period (73%) than dealers (49%). Growing numbers of feed suppliers reflect the growth of aquaculture at both the extensive margin (via horizontal expansion) and intensive margin (by increased rates of supplementary feeding on-farm), respectively, with the latter trend likely of greater magnitude over the past decade. The intensification of aquaculture has increased demand for feed, which has induced demand for traders to distribute feed (Hernandez et al., 2018; Ali et al., 2022). Similarly, improving access to feeds associated with increasing numbers of feed traders is likely to have induced feed adoption by farms.

The first trader in the sample started business in 1992, but the majority (65%) started between 2008 and 2019, reflecting the relatively recent growth of feed use (Fig. 2). Business establishment over this period was perhaps linked to the diffusion of feed trading into more rural areas where most retailers are located, but also reflects concurrent growth in demand for non-formulated feeds along with formulated ones, and a high degree of complementarity between the two, rather than outright substitution.

3.3. Trader assets

All respondents operated from shops at fixed premises. Most shops are located in upazila or union (the administrative sub-unit below upazila) level markets, alongside a variety of other retail businesses (e.g., groceries, clothes, agricultural inputs). Typically, dealers are in upazila level markets, while retailers operate at both the upazila and union level, and occasionally at village level. In some cases, feed shops are found in small clusters, with several businesses co-located in the same market.

Most feed supply shops (61%) are rented. Moreover, 66% of dealers and 51% of retailers maintain warehouses. Average shop and warehouse sizes are small (27 m^2 and 35 m^2 respectively), and slightly larger for dealers than for retailers (Table 2). Most business premises are well-constructed. About 88% of shops and 97% of warehouses are buildings or tin shaded buildings, reflecting their permanent position in markets, the need for security to prevent theft, and protection from the weather (Table 2). Key informant interviews indicated that shop infrastructure has generally improved over the last 10 years, with many earthen floors converted to cement or concrete, requiring significant capital investment.

Feed suppliers maintain adequate feed storage systems and have rapid turnover of stock. Around 98% of dealers and 87% of retailers stored feed in shops and warehouses with cement floors, on wooden or bamboo platforms that facilitate air circulation. Storage of feeds for long periods can cause declining quality due to damp, rancidity, molds, and pests (Sarwer, 2021). However, respondents stored feed for just 10 days on average. The duration was similar for dealers and retailers and for

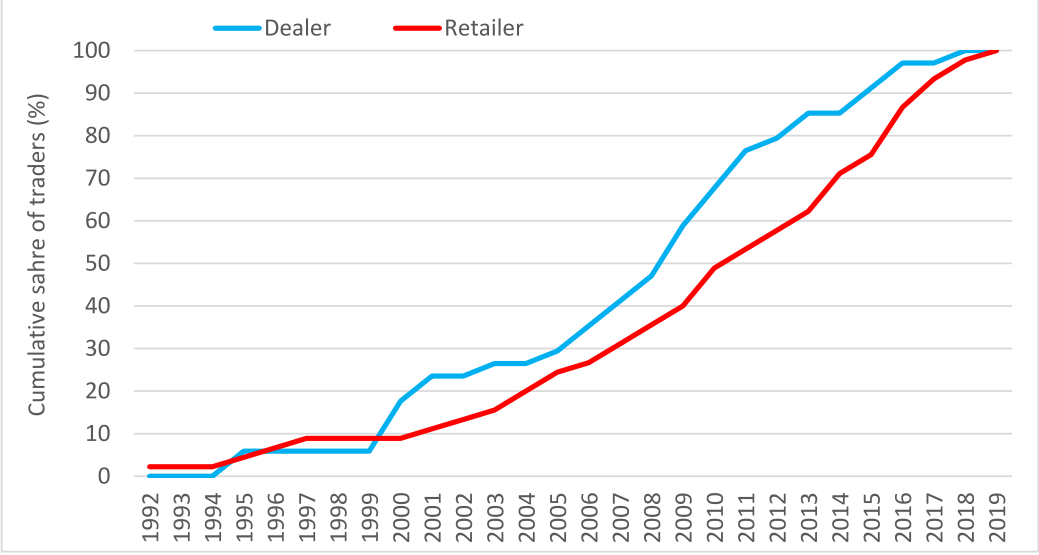

Fig. 2. Cumulative share of feed dealer and retailer businesses established by year, 1992–2019.

Table 2
List of assets used by feed suppliers.

Variables	Trader category		
	Dealer	Retailer	Overall
Shops			
Traders operating shop with fixed premises (%)	100	100	100
Shop ownership (%)			
Rented	63	59	61
Owned	37	41	39
Shop floor space (m^2)	31	23	27
Shop physical condition (%)			
Building	48	48	48
Tin shaded building	37	43	40
Tin shaded room	15	8	12
Warehouses			
Traders with warehouse facilities (%)	66	51	59
Warehouse ownership (%)			
Rented	90	84	88
Owned	10	16	12
Warehouse floor space (m^2)	38	31	35
Warehouse physical condition (%)			
Building	61	38	52
Tin shaded building	39	55	45
Tin shaded room	0	7	3
Feed stored on wooden/bamboo platforms (%)	98	87	93
Equipment (% of traders owning)			
Furniture's	100	100	100
Mobile phone	100	98	99
Calculator	91	93	92
Weighing scales	60	98	77
Shovel	29	78	51
CCTV camera	22	5	14
Others	14	12	13
Television/radio	4	0	2
Mean value of equipment in USD	621	357	504

formulated and non-formulated feeds. This finding suggests that the downstream segment of the feed distribution system is efficient, with swift turnover providing little opportunity for feed quality to deteriorate.

Traders own a variety of equipment, including furniture, scales, calculators, and mobile phones (Table 2). Twenty-two percent (22% of dealers) owned CCTV cameras, indicating a degree of technological sophistication in maintaining business security, as well as the high value of the stock traded. Virtually all surveyed traders use mobile phones, which facilitate connections between traders and their suppliers and clients and make it possible to provide aftersales support services.

Third-party logistics services (3PLS) firms supplying vehicles and drivers play a vital role in facilitating the trade and distribution of feed. Eighty-two percent of dealers and 96% of retailers used 3PLS to deliver feed to their customers. Dealers mainly receive deliveries of formulated feeds from feed mills, which supply transport (much of it likely also provided by 3PLS firms), and many retailers use 3PLS to collect feed ingredients from rice mills and other suppliers. Vehicle ownership by feed suppliers is limited to small vehicles used for personal transport. Around half of feed dealers and one-third of retailers own motorcycles for personal transportation, but none own any larger vehicles such as trucks (Table 3).

The main means of feed transport used by respondents are small electric and motorized vehicles used to transport feed over short distances; 'engine vans' (motorized flatbed trishaws), used by 42% of respondents, and autorickshaws (17%). Trucks, primarily 5-ton (18%) and 10-ton (16%), are used to move larger volumes of feed. (Table 3). Around half of the feed collected and delivered by feed suppliers during their most recent transaction was transported using 3PLS that they had hired themselves, with much delivery by suppliers and collection by customers likely also reliant on 3PLS. Low levels of vehicle ownership by

Table 3
Ownership and rental of vehicles used for transporting feed.

Variables	Trader category		
	Dealer	Retailer	Overall
% of respondents owning vehicles			
Motorbike	47	33	41
Bicycle	0	12	6
Mean value of owned vehicles (USD)	738	542	651
% using vehicle 3PLS			
10 ton truck	16	15	16
5 ton truck	25	8	18
1 ton truck	2	7	5
Half-ton pick-up	5	14	9
Autorickshaw	21	11	17
Engine Van	34	53	42
Van	10	7	8
Boat	6	3	4
Others	0	3	1
Mean annual outlay on vehicle rentals (USD)	1037	835	948
% of feed collected by traders using 3PLS during last transaction	21	64	46
% of feed delivered by suppliers using 3PLS during last transaction	79	36	54

traders and high dependence on 3PLS reflect the high cost of motor vehicles and likelihood of surplus capacity associated with the ownership of lumpy assets. The wide availability of third-party logistics services (transport rental providers) in the study area helps to overcome these constraints.

3.4. Trader conduct

3.4.1. Seasonality

Almost all feed traders operated their business year-round. However, the season for feed trading was separated into a peak season, coinciding with the peak fish production period from the start of the monsoon season in June until the early dry season in November/December. The lean season runs from December/January until May, from the late dry season until pre-monsoon.

3.4.2. Composition of feed traded

Key informant interviews suggested that the total volume of formulated feeds traded by traders in the surveyed area had almost doubled over the past 10 years due to increasing demand. This finding is consisted with national trends in formulated feed production, which jumped from 0.8 million tons in 2010 to 1.7 million tons in 2020 (Aung Tun Aye, *Personal Communication*).

Surveyed traders sold thirteen types of feed, of which five formulated and seven non-formulated (Table 4). The formulated aquafeed market in Bangladesh is diverse. Respondents traded formulated feeds from 35 feed companies, among which eight companies accounted for 74% of sales.

Dealers and retailers specialize in distribution of formulated and non-formulated feeds, respectively, but all surveyed traders sold formulated feeds. Formulated feeds accounted for 76% of feed volume and 83% of sales value for dealers, and 47% and 56% of the overall volume and value of feed traded by respondents (Table 4).

Floating feed is sold by all traders, and accounts for 55% of formulated feed sales. Key informant interviews suggested that the volume of floating feed traded in the zone surveyed has tripled over the past decade, growing more rapidly than sinking feeds. This finding is consistent with Sarwer (2021), who estimated that floating feed increased from 20% of total national formulated feed production in 2010 to 60% in 2020. This shift has likely contributed to higher levels of farm productivity and efficiency in aquaculture as the digestibility and feed conversion ratio of floating feed is superior to that of sinking feed, ceteris paribus.

Retailers specialize in selling non-formulated feeds. The most important of these are wheat bran, oilcakes, and maize. Unformulated feeds accounted for 82% of the total volume of feeds traded by retailers, and 76% of total retail feed sales value, and 53% and 44% of overall volume and value, respectively. These figures reflect the lower unit value of non-formulated feeds compared to formulated feeds (Table 4).

This finding is consistent with farmers' continued use of non-formulated feeds, particularly in improved traditional shrimp farms and homestead ponds, due in part to the lower unit price of these feeds compared to formulated feeds, and lower investment costs. This result is also in line Jahan et al. (2015) who reported that small-scale farmers operating these types of production system in Bangladesh mainly used non-formulated feeds. Many farmers also combine formulated and non-formulated feeds strategically, switching between them or adjusting the proportions used depending on the stage of the production cycle or prevailing market conditions, to maximize growth rates or reduce outgoings.

The average unit price of formulated feed (USD 66/kg) was almost double that of non-formulated feed (USD 33/kg), reflecting a higher level of processing of the former, and inclusion of ingredients selected to meet the nutritional requirements of fish. The average unit selling price for extruded floating feed (USD 0.54/kg) was 23% higher than that of sinking formulated feed (USD 0.44/kg), reflecting the more sophisticated and energy intensive milling technology used to produce the former, and inclusion of higher levels of soy (Table 5).

Despite being more expensive on a per kilogram basis, floating feeds are more efficient than sinking feed as they are more highly digestible as a result of being heated during the extrusion process, and because farmers can observe their consumption by fish at the water's surface, minimizing potential for overfeeding (Craig, 2017). The nutritionally complete nature of floating and sinking formulated feeds supports higher fish growth than non-formulated feeds. However, the high price of formulated feeds relative to non-formulated feeds mean that many farmers prefer to use the latter, or to combine both varieties of feed strategically, such as by using formulated feed to promote fattening in the weeks prior to harvest (Belton et al., 2011).

As expected, the average buying and selling price of formulated feeds was slightly higher for retailers (USD 0.64/kg and USD 0.68/kg, respectively) than dealers (USD 0.59/kg and USD 0.62/kg,

Table 4
Composition of feed sales by volume and value.

Inputs	Trader category								
	Dealer			Retailer			Overall		
	Volume sold (ton/year)	% of total volume	% of total sales value	Volume sold (ton/year)	% of total volume	% of total sales value	Volume sold (ton/year)	% of total volume	% of total sales value
Fish feed (floating)	142	47	50	7.8	6.0	7.9	48	26	31
Fish feed (sinking)	42	14	12	4.4	3.4	3.7	15	8.5	8.3
Shrimp/prawn feed	24	7.8	8.3	9.6	7.4	9.2	14	7.6	8.7
Starter feed	19	6.4	9.1	1.3	1.0	1.7	6.7	3.7	5.7
Nursery feed	5.4	1.8	3.5	0.7	0.5	1.4	2.1	1.1	2.6
Sub total	**233**	**76**	**83**	**24**	**18**	**24**	**85**	**47**	**56**
Oil cakes	15	4.9	4.6	22	17	22	20	11	13
Wheat bran	23	7.6	5.8	25	19	20	24	13	12
Maize	14	4.6	2.5	27	21	13	23	13	7.4
Wheat products	4.3	1.4	0.9	15	12	10	12	6.7	5.0
Rice bran	3.0	1.0	0.5	9.2	7.1	4.7	7.4	4.1	2.4
Rice products	9.2	3.0	2.0	4.3	3.3	2.9	5.7	3.2	2.4
Pulse products	3.7	1.2	1.0	3.9	3.0	3.1	3.9	2.1	2.0
Sub total	**72**	**24**	**17**	**106**	**82**	**76**	**96**	**53**	**44**
Total	**305**	**100**	**100**	**130**	**100**	**100**	**182**	**100**	**100**

Table 5
Average buying and selling price (USD/kg) and marketing margin (%) of feeds traded.

Inputs	Trader category								
	Dealer			Retailer			Overall		
	Average buying price (USD/kg)	Average selling price (USD/kg)	Average margin (%)	Average buying price (USD/kg)	Average selling price (USD/kg)	Average margin (%)	Average buying price (USD/kg)	Average selling price (USD/kg)	Average margin (%)
Fish feed (floating)	0.52	0.54	3.8	0.53	0.56	5.7	0.52	0.54	3.8
Fish feed (sinking)	0.4	0.42	5.0	0.43	0.46	7.0	0.42	0.44	4.8
Shrimp/prawn feed	0.5	0.52	4.0	0.51	0.54	5.9	0.51	0.54	5.9
Starter feed	0.63	0.65	3.2	0.73	0.78	6.8	0.69	0.73	5.8
Nursery feed	0.91	0.99	8.8	1.04	1.13	8.7	0.99	1.07	8.1
Formulated feed	**0.59**	**0.62**	**5.1**	**0.64**	**0.68**	**6.3**	**0.62**	**0.66**	**6.5**
Wheat bran	0.3	0.32	6.7	0.31	0.34	9.7	0.31	0.33	6.5
Oil cakes	0.44	0.47	6.8	0.46	0.49	6.5	0.45	0.48	6.7
Maize	0.25	0.27	8.0	0.27	0.29	7.4	0.26	0.28	7.7
Wheat products	0.37	0.4	8.1	0.38	0.41	7.9	0.38	0.40	5.3
Rice products	0.3	0.32	6.7	0.32	0.35	9.4	0.31	0.33	6.5
Rice bran	0.21	0.23	9.5	0.21	0.23	9.5	0.21	0.23	9.5
Pulse products	0.37	0.4	8.1	0.39	0.42	7.7	0.38	0.41	7.9
Non-formulated feed	**0.34**	**0.36**	**5.9**	**0.33**	**0.36**	**9.1**	**0.34**	**0.36**	**5.9**
All feed	**0.51**	**0.54**	**5.9**	**0.5**	**0.54**	**8.0**	**0.51**	**0.54**	**5.9**

respectively), reflecting the position of retailers slightly further downstream in the supply chain than dealers, and likely also differences in economies of scale and possibly differences in transport costs linked to location. Mean marketing margins were similar for formulated (6.5%) than non-formulated feeds (5.9%), with retailers earning slightly higher margins than dealers (Table 5).

3.4.3. Feed procurement

As noted above, dealers typically supply formulated feeds purchased from feed mills under agreements that provide sole distributorship rights for a specific area (usually a union). Feed mills sell almost all their feeds (96–98%) though dealers (Mamun-Ur-Rashid et al., 2013). In contrast, retailers sell a wider range of products including non-formulated feeds, obtained from sources such as wholesalers and rice mills.

Dealers procured the great majority of feeds traded from feed mills (82%) and the remainder from non-formulated feed wholesalers. Retailers bought 52% of total feeds traded from wholesalers selling non-formulated feeds, 32% from dealers (mostly formulated feed) and 18% from mills (mainly rice mills or other agricultural processors). Both sets of traders obtain feed from a small number of regular suppliers (2.4 on average), which supply almost all feeds traded (98% of total volume). Dealers procured feed from significantly fewer ($p \leq 0.05$) suppliers than retailers (1.7 and 2.7, respectively) (Table 6).

Dealers sourced about two-thirds of feed from outside of their own districts, and one-third from their own districts. Most of Bangladesh's large aquafeed mills are located in Gazipur, a highly industrialized peri-urban district bordering Dhaka and Mymensingh (Hernandez et al., 2018). Per our key informant interviews (KIIs), several new feed mills were established in areas adjacent to Gazipur over the past decade (southern and western Mymensingh and Narshingdi districts, respectively). Additionally, KIIs revealed that numerous small-scale feed mills have developed in a scattered pattern in aquaculture producing regions throughout Bangladesh. By contrast, retailers sourced only 24% of feeds from other districts, 35% from the same district, and 38% from the same upazila (Table 6).

Most dealers (70%) paid mills in advance for feed, with advances accounting for 90% of the value of feed procured, conditional on paying an advance. Conversely, only 14% of retailers pay advances when buying feed, primarily when they purchase formulated feeds from dealers (Table 6). This difference reflects the status of the feed manufactures as 'lead firms' with the power to set conditions governing the conduct downstream actors. This observation contrasts with analyses of global value chains for aquaculture products that emphasize the role of buyers in importing countries as lead firms (e.g., Islam et al., 2021; Jespersen et al., 2014; Van Der Ven, 2018).

According to key informants, feed mills producing higher value

Table 6
Feed procurement details for the two main feeds traded by each respondent.

Variables	Trader category		
	Dealer	Retailer	Overall
Average number of suppliers	2.0	3.0	2.4
Average number of regular suppliers	1.7	2.7	2.2
Share of inputs from regular suppliers (% of total)	99	97	98
Share of inputs procured by type of supplier (% of total)			
Mills	82	18	54
Dealer (representative of company)	0	32	15
Wholesaler	17	52	31
Importer	1.4	0.3	0.9
Location of suppliers (% of feed procured)			
Same village	0	0	0
Same Union	0	4.2	1.8
Same Upazila	3.0	38	18
Same District	31	35	33
Other district	66	24	47
% of respondents receiving feed as in-kind credit	49	42	46
% of feed (volume) procured as in-kind credit (conditional on receiving in-kind credit)	35	34	35
Average number of suppliers providing in-kind credit (conditional on trader receiving)	1.6[a]	2.6[b]	2.1
% of suppliers delivering feed to shop	70	9	43
% of feed (volume) delivered to shop (conditional on supplier delivering)	99	100	99
% of traders paying suppliers in advance, partially or in full	70	14	45
% of feed purchase value paid to suppliers in advance (conditional on paying in advance)	90	91	90
Main mode of payment to supplier (%)			
Bank transfer	88	19	57
Cash	12	81	43
Mobile money	0	0	0

brands (e.g., CP, Megafeed, Quality, Nourish) normally sell feed using an advance payment modality known as telephonic transfer (TT), whereby dealers confirm their orders by sending money by bank transfer. None of the traders used any mobile financial services (e.g., BKash, Rocket, Nagad etc.) to transfer money, reportedly due to the high service charge per payment (1.8% of the transaction value).

Forty-six percent of respondents reported receiving in-kind credit, primarily when procuring non-formulated feeds from mills or wholesalers, accounting for 35% of the total feed volume, indicative of greater flexibility in the terms offered by suppliers of these feeds, relative to feed manufacturers.

3.4.4. Feed marketing

Feed suppliers sold feeds to large numbers of clients, averaging 96 overall, and similar for dealers and retailers (Table 7). Dealers sold 79% of feed directly to farmers, and the remainder to retailers, whereas 91% of feed sold by retailers went directly to farmers, and only 9% to other retailers, usually in remoter areas. Most clients (59%) were regular customers, who bought feed repeatedly from the same traders, purchasing 66% of all feed sold, similar for both dealers and retailers (Table 7). Most clients lived close to shops where traders were located, with sales to customers in the same upazila accounting for 77% and 91% of dealers' and retailers' sales respectively (Table 7), suggesting that convenience and transport costs are important factors determining farmers' choice of where to buy feed.

Almost all traders (95%) provided feed to farmers in the form of in-kind credit, accounting for 39% of total feed sales, with little difference between dealers and retailers. Most dealers (85%) and less than half of retailers (42%) provided in-kind credit to retailers, also amounting to 39% of feed sales. This level of credit provision is significant, likely serving as lubricant that helps farmers and small retailers overcome capital constraints. Per our KIIs, the duration for which in-kind credit is provided can depend on several factors, including kinship, relationships, trust, and the duration of the production cycle. No traders received any advanced payment from their clients.

Customers normally partially repay advances each time they make a new feed purchase, and clear any remaining balance after the final harvest of their fish. The recovery rate for this kind of delayed payment for feed in Bangladesh has been reported to be high, at 98–99% (Sarwer, 2021). Dealers and retailers both received payment from customers in cash. No respondents reported using mobile financial services to accept payment, due to high service charges.

Table 7
Feed marketing details.

Variables	Trader category		
	Dealer	Retailer	Overall
Average number of clients	92	101	96
Average number of regular clients	57	61	59
Share of feed sold regular client (%)	66	67	66
Distribution of clients (% of feed volume)			
Farmers	79	91	84
Retailers	21	9	16
Location of clients (% of feed volume)			
Same village	2.3	5.9	3.9
Same Union	15	29	21
Same Upazila	60	56	58
Same District	20	12	16
Other district	2.9	1.1	2.1
Provided in-kind credit to farmers (%)	97	92	95
Provided in-kind credit to retailers (%)	85	42	61
Feed sold to farmers as in-kind credit (%)	41	38	39
Feed sold to retailers as in-kind credit (%)	39	39	39
Number of clients receiving in-kind credit	68	78	72
Respondents delivering feed to client (%)	6	1	4
% of feed (volume) delivered to client	15	25	17
Mode of payment- received advanced (%)	0	0	0
% of sales paid in cash	100	100	100

Figure 3a and b depict, respectively, flows of formulated and non-formulated feeds from upstream suppliers to dealers and retailers, and from dealers and retailers to their clients. The main marketing channel for formulated feed is from mills to dealers, (88% of supply), and from dealers to farmers, accounting for 64% of formulated feed traded. Other less prominent marketing channels depicted are: mill – dealer – retailer; dealer – retailer – farmer; and, dealer – retailer – retailer, with all feed originating from mills and ultimately distributed to farmers.

For non-formulated feeds, the main upstream flows are from wholesalers (63% of traded volume) and mills (36%) to retailers (69%) and dealers (31%). Around 93% of combined non-formulated feed sales by retailers and dealers are direct to farmers, with 7% flowing from retailers to retailers.

3.4.5. Services offered by traders to clients

Traders offered a variety of services to their customers. In addition to providing feed as in-kind credit (discussed above), 16% of traders offered feed delivery to clients, and 7% provided uploading services (Table 8). This kind of support may help to develop good relationships between clients and traders, which can ultimately help to increase sales volumes. Beyond feeds, 92% of dealers and 78% of retailers provided technical advice to farmers, on subjects including the application of feed, chemicals, fertilizers, and disease control. However, the quality of this technical information is not known.

Most traders (62%) reported obtaining technical information from feed and chemical companies, followed by the Department of Fisheries (21%), but with little information received from the Department of Agricultural Extension or NGOs (Table 8). Key informant interviews indicated that feed traders sometimes distribute leaflets, booklets, and t-shirts, developed and printed by feed and chemical companies, to farmers to promote their products. Dealers also often support feed mill representatives in organizing farmer field days and promotional seminars to increase sales and build trust with farmers.

3.4.6. Financial management

Feed trading businesses require a large amount of working capital to establish and operate. Average annual working capital is significantly higher ($p \leq 0.05$) for dealers (USD 42,120) than retailers (USD 10,593), reflecting the large scale of operations necessary to secure a dealership position from a feed company, and the high average unit value of formulated feeds traded by dealers. Reinvestment of business earnings accounted for (75%) of working capital, with 7.5% from own savings (Table 9). Own income and savings, not loans, are also the main source of working capital for traders of agricultural crops such as rice and potatoes in Bangladesh and elsewhere in Asia (Reardon et al., 2012).

Never-the-less, almost half of traders borrowed from at least one lender, with borrowing more common among dealers (55%) than retailers (32%). Private banks accounted for 55% of the value of all loans. Microfinance was important for dealers (33% of loan value). Co-operatives or credit associations were important for retailers, supplying 41% of loan value (Table 9). Loans from these institutions are considered easy to access due to their widespread presence in rural areas and simple application procedures (Jahan et al., 2015). The average volume of credit borrowed, conditional on borrowing, was higher ($p \geq 0.05$) for dealers (USD 15,693) than retailers (USD 7975), again reflecting differences in scale.

Ninety percent of dealers and 42% of retailers used land as loan collateral, especially for bank loans, whereas microfinance institutions and credit association did not require collateral. Average interest rates were low at 11% per year, indicative of the widespread availability of formal credit in Bangladesh, the formal nature of the businesses studied, and the collateralization of many loans which offers security to lenders. The main use of loans was for operational expenses, especially procuring feed (reported by 99% of loan recipients).

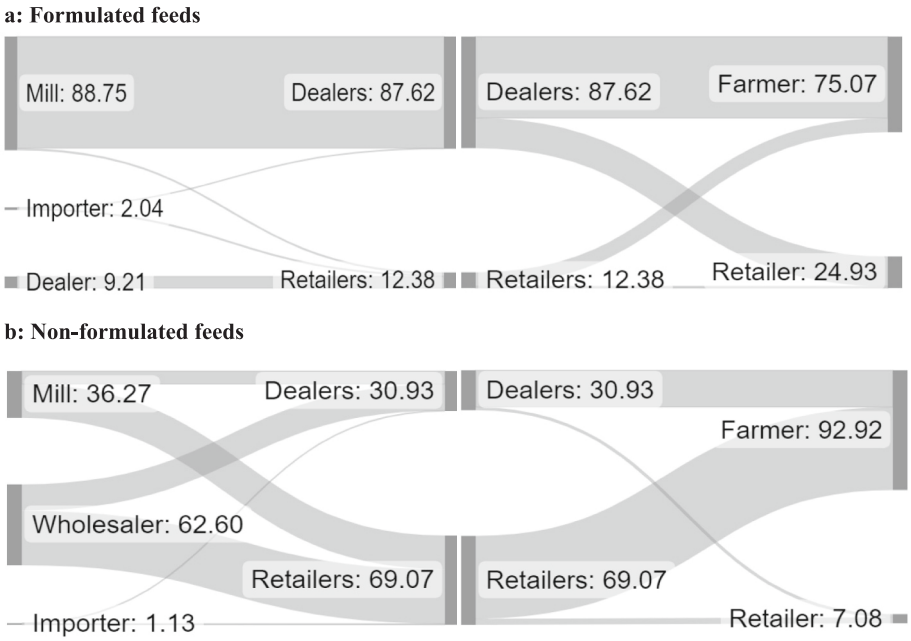

Fig. 3. The supplier-trader and trader-customer marketing channels for: (a) formulated feeds; (b) non-formulated feeds, (% of traded feed).

Table 8
Feed traders' services apart from intermediation.

Variables	Trader category		
	Dealer	Retailer	Overall
Traders provided in-kind credit support to client (%)	97	92	95
Traders provide advice to clients (%)	92	78	86
Traders providing transportation supports to client (%)	16	16	16
Traders provides uploading supports to client (%)	3	11	7
Traders doing packing/packaging (%)	0	2	1
Traders provided advice on subject (conditional %)			
Feed use	92	84	89
Chemical use	62	46	55
Disease control	47	46	47
Fertilizer use	12	35	22
Not specific to any issue	8	16	11
Source of technical information for traders (%)			
Feed and chemical companies	68	58	62
Department of Fisheries	22	19	21
Department of Agricultural Extension	3	6	4
Non-governmental organization	4	5	4

Table 9
Feed traders' access to finance.

Variables	Trader category		
	Dealer	Retailer	Overall
Working capital (USD/Year)	42,120	10,593	28,141
Sources of working capital (% of value)			
Earning from business	70	81	75
Private bank	12	2.3	7.9
Own saving	6.0	9.5	7.5
Microfinance	7.3	3.0	5.4
Upstream traders	2.9	0.5	1.9
Government bank	1.5	1.4	1.5
Cooperatives	0.0	2.6	1.2
% of respondents receiving financial credit	55	32	45
Amount of credit received (USD)	15,693	7975	13,264
Average interest rate/year (%)	11	9.9	11
Sources of credit (%) (conditional on borrowing)			
Private bank	58	47	55
Microfinance	33	5	24
Cooperative/credit association	0	41	13
Government bank	9	0	6
Friends	0	7	2
Purpose of credit use (%)			
Purchasing inputs	100	95	99
Daily living necessities	13	13	13
Renting shop	10	9	10
Employing more staff	6	0	4
Collateral for credit (%)			
Land	90	42	75
Not applicable	10	58	25

3.5. Performance

In this section we evaluate four indicators of performance for the feed supply segment of the aquaculture value chain, namely employment generation (an important indicator of inclusiveness, and economic contributions), impacts of COVID-19 on fish trading (an indicator of value chain resilience to shocks), business profitability (an indicator of economic efficiency, competitiveness, and surplus extraction), and loss and waste (an indicator of process efficiency with implications for food security and environmental outcomes).

3.5.1. Employment generation

Feed trading businesses in southern Bangladesh are predominantly family owned and operated, similar to countries including Cambodia (Joffre et al., 2021), Egypt (El-Sayed et al., 2015), and Vietnam (Hasan and Shipton, 2021). Most work in feed trading is performed by the owner-operator and their family members, who participate in all activities associated with the business, and are particularly involved in managerial, financial, procurement, and sales activities. All dealers and 73% of retailers hire casual workers for loading and unloading feed. Half of traders employ longer term workers, who engage in most activities but to a lesser degree than family labor.

The employment generated by feed businesses in Bangladesh almost exclusively male (99%). Most family workers (90%) are ≥30 years old. This may be explained in part by the large capital requirements needed to start up a feed business which may serve as a barrier to entry for youth. Most casual (84%) and long term, (57%) workers were also ≥30 years in age (Table 10). This finding is in line with Macfadyen et al.'s (2012) observations for the fish value chain in Egypt. However, two

Table 10
Characteristics of labor use by feed trading businesses.

Variables	Trader category		
	Dealer	Retailer	Overall
% of traders using family labor (male)	100	95	98
Average number of male family workers employed (conditional on using)	1.5	1.3	1.4
% of traders using family labor (female)	0.0	2.7	1.2
Average number of female family workers employed (conditional on using)		1.0	1.0
Family labor (person-days/year)	446	470	457
Age of family workers (%)			
≤29 years (youth)	6	14	10
≥ 30 years (non-youth)	94	86	90
Permanent hired male labor used (% of trader)	61	32	48
Number of permanent hired male labor work	1.6	1.3	1.5
Monthly wage rate for permanent hired male worker (USD/month)	98	88	95
Permanent hired female labor used (% of trader)	0	0	0
Permanent hired labor (person-days/year)	566	488	543
Age of permanent hired workers (%)			
≤29 years (youth)	34	65	43
≥ 30 years (non-youth)	66	35	57
% of traders using casual hired labor (male)	100	73	88
Average number of male casual hired workers employed (conditional on using)	3.9	3.2	3.7
Daily wage rate for casual hired male worker (USD/day)	2.47[a]	1.91[b]	2.26
% of traders using casual hired labor (female)	0	0	0
Casual hired labor (person-days/year)	64	56	61
Age of casual hired workers (%)			
≤29 years (youth)	14	20	16
≥ 30 years (non-youth)	86	80	84
Mean number of workers	6.5[a]	4.0[b]	5.4
Mean labor (person-days/year)	857[a]	654[b]	767
Mean labor days per ton of feed sold	9.2[a]	15[b]	13
Total FTE jobs created by sample traders (formulated and non-formulated)	749	509	1258
FTE jobs created for family labor	390	356	740
FTE jobs created for permanent labor	303	121	429
FTE jobs created for casual labor	56	32	88
FTE jobs created for ≤29 years (youth)	122	124	250
FTE jobs created for ≥30 years (non-youth)	627	385	1008

thirds of long term workers (65%) employed by retailers were < 29 years old, indicating some creation of youth employment.

Average daily wage rates earned by workers in feed supply businesses are comparable to the national average rate in Bangladesh (USD 2.14/day) (BBS, 2022). Casual workers hired by dealers earned significantly more ($p \leq 0.05$) (USD 2.47/day) than those hired by retailers (USD 1.91/day). This might reflect wages for unloading bags of feed being paid piece rate, with laborers working for dealers having opportunities to unload more bags per day. The average wage of USD 95/month paid to permanent workers did not differ significantly ($p \geq 0.05$) between dealers and retailers. However, the monthly wage rate was 51% higher than national minimum wage rate in Bangladesh (BBS, 2022). Feed retailing was significantly ($p \leq 0.05$) more labor intensive than feed dealing, with retailing generating demand for 15 labor days per ton of feed sold, while feed dealers required 9.2 labor days per ton of feed (Table 10).

Feed traders generated an estimated 43,937 full time equivalent (FTE) jobs in the seven districts surveyed (Table 11), which is equivalent to about 11% of the estimated total 401,820 FTEs generated by aquaculture farms in districts where the survey took place. Feed trading FTEs were distributed 59% to family labor, 34% to long term labor, and 7% to casual labor. Trade in formulated feed and non-formulated feed created a similar share of FTEs. Employment created by feed trading was performed almost exclusively by men (>99%), and predominantly by individuals over 29 years of age (75%).

Table 11
Total FTE jobs created by feed traders in southern Bangladesh.

Variables	Trader category		
	Dealer	Retailer	Overall
Total FTE jobs created	21,495	22,442	43,937
FTE jobs distribution by feed types			
Formulated feed	15,047	5386	22,847
Sinking formulated feed	6234	3501	8787
Floating formulated feed	8813	1885	14,060
Non-formulated feed	6449	17,056	21,090
FTE jobs distribution by labor types			
Family labor	11,194	15,708	25,856
Permanent labor	8687	5336	14,993
Casual labor	1615	1398	3088
FTE job distribution by gender			
Men	21,495	22,151	43,660
Women	0.0	292	277
FTE jobs distribution by labor age			
≤29 years (youth)	3493	5467	8720
≥ 30 years (non-youth)	18,002	16,975	35,217

3.5.2. *Impacts of COVID-19 on feed trading*

Like other aquaculture value chain segments in Bangladesh, feed trading businesses were negatively impacted by COVID-19 (Belton et al., 2021). Key informant interviews indicated that most traders stopped business operations entirely for 10–12 days due to COVID-19 containment measures. The great majority of traders (92%) reported selling less feed than usual, earning less income, experiencing difficulties purchasing feeds, and having fewer customers than usual (Fig. 4). The total volume of feed traded by businesses surveyed in 2020 was 23% lower than in 2019, implying that national fish production in Bangladesh was also likely considerably lower in 2020 than 2019. Our survey of aquaculture farms in the same seven districts also generated similar results, confirming that a large drop in production took place in 2020. Although reduction in Bangladesh's aquaculture production in 2020 was not reported by DOF (2022), other research on impacts of COVID-19 on aquaculture in Bangladesh also suggests strongly that production dropped sharply during the pandemic (Bashar et al., 2022; Belton et al., 2021; Hasan et al., 2021).

3.5.3. *Cost structure and profitability*

The mean annual gross margin was USD 4248, and the net margin (after deducting fixed costs) was USD 3882. These average profit margins are significantly higher than the average annual gross margin (USD 679) and net margin (USD 578) for aquaculture farmers in southern Bangladesh (farm survey results). Dealers earn significantly higher ($p \leq 0.05$) gross and net average incomes (USD 5799 and USD 5349) than retailers (USD 2302 and USD 2041) (Table 12). Transport (mainly 3PLS) accounted for the largest share of total costs for retailers (30%), while labor was the largest single cost for dealers (also 30%). This is likely because feed mills generally deliver feed to dealers without an explicit fee, whereas retailers usually collect feeds from suppliers at their own expense. Rental of shops/warehouses and interest on loans were the next largest costs, accounting for 14% and 13% of the total, respectively (Table 12).

The average margin earned on each feed transaction was 6.2% of the sales value for both dealers and retailers. These margins are modest, suggesting that the feed supply segment of the value chain is relatively competitive, and that the level of surplus extracted by feed traders from their transactions with farmers is not exploitative. These margins are in a similar range to those reported for aquaculture feed suppliers in Vietnam (4.1%) and Egypt (3–6%) (Hasan and Shipton, 2021; El-Sayed et al., 2015), but much lower than the levels reported for feed traders in Bangladesh (18–43%) by Sabur et al. (2010).

3.5.4. *Loss and waste*

No trader reported any waste or loss of feed occurring during the

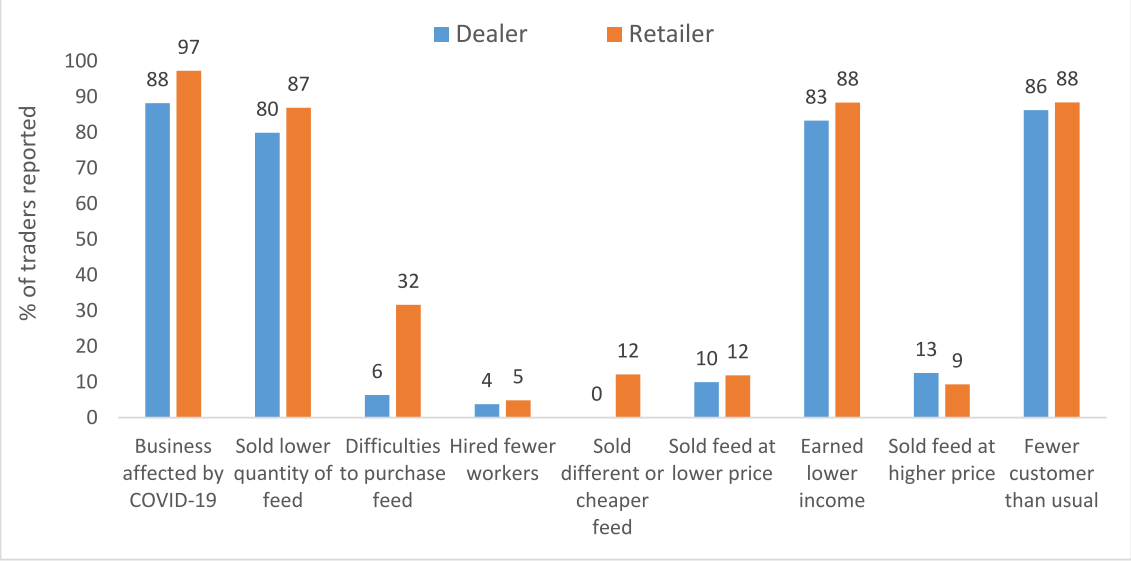

Fig. 4. Share of feed dealers and retailers facing COVID-19 related challenges in 2020.

Table 12
Annual costs and margins for feed trading operations.

Cost items	Trader category					
	Dealer		Retailer		Overall	
	Cost (USD/year)	% of cost	Cost (USD/year)	% of cost	Cost (USD/year)	% of cost
Variable cost (VC)						
Labor	1623	30	576	21	1159	27
Transport	1037	19	835	30	948	22
Shop/warehouse rental	778	14	393	14	607	14
Interest on loans	791	14	244	8.8	548	13
Entertainment	291	5.3	92	3.3	203	4.8
Vehicle maintenance	166	3.0	87	3.1	131	3.1
Communications	168	3.1	75	2.7	126	3.0
Packaging	61	1.1	151	5.4	101	2.4
Electricity and fuel	93	1.7	56	2.0	77	1.8
Sub-total	**5009**	**92**	**2509**	**91**	**3900**	**91**
Fixed cost (FC)						
Depreciation–shop/warehouse	227	4.2	133	4.8	185	4.3
Taxes and license fees	98	1.8	53	1.9	78	1.8
Depreciation – equipment	88	1.6	54	2.0	73	1.7
Depreciation – vehicle	37	0.7	21	0.8	30	0.7
Sub-total	**450**	**8**	**261**	**9**	**366**	**9**
Total cost (TC) = VC + FC	**5459**	**100**	**2770**	**100**	**4267**	**100**
Mean gross revenue (USD/year)	155,452		38,916		103,778	
Mean gross margin (USD/year)	5799		2302		4248	
Mean net margin (USD/year)	5349		2041		3882	
Profit margin (%)	6.0		6.5		6.2	

1 US Dollar = 84.75 Bangladeshi taka, April 2021.

most recently completed customer transaction. However, 5.9% of dealers and 4.4% of retailers reported that a small portion of feed was lost during transport from feed suppliers to traders' shops, equivalent to 0.7% and 2.8% of total volume of feed traded by each. These low numbers indicate that little feed is wasted upstream of the farm. To our knowledge this is the first published estimate of loss and waste in the feed trader segment of an aquaculture value chain.

3.6. Farmer's feed procurement and use

In this section we analyze feed procurement and use from our survey of farms located in the same upazilas as surveyed feed traders. Almost all farmers (95%) used some kind of supplementary feed in 2020 (Table 12) indicating that traditional extensive aquaculture has almost disappeared. Among farms using feed, 59% used both formulated and non-formulated feed, particularly in farms producing fish with prawn (PF; 71%) or fish only (FO, 56%). Farms producing shrimp, either in combination with prawn and fish (PSF; 50%) or with fish only (SF; 37%) were less likely to use both formulated and non-formulated feed. Accordingly, exclusive use of non-formulated feeds (i.e., more traditional semi-intensive farm management) was most common on farms producing shrimp (SF, 43%; PSF 41%) followed by FO (32%) and PF (18%) farms (Table 13). Exclusive use of formulated feeds remains rare (4% of farms), indicating that there is little highly intensive aquaculture in southern Bangladesh at present.

Comparing our figures on feed use in 2020 to figures reported by Hernandez et al. (2018), from a survey in 2013, the share of farms in Bangladesh using formulated feeds increased rapidly over this eight-year period, from 43% to 69%, while the share using non-formulated feeds increased from 56% to 92%. This result highlights an ongoing process of rapid intensification of fish production, under which many farmers have shifted from extensive to semi-intensive production while others have upgraded to more intensive production through increasing formulated feed use, but without abandoning cheaper unformulated feeds. Rising rates of feed use also reflect the shifting production system in the study zone from away from traditional shrimp-fish systems to include more prawn and diversified fish species that require formulated diets to attain optimal growth.

Formulated feed accounted for 37% of total feed use reported by farms, with floating feed accounting for almost one quarter of total feed use (22%); less than reported in the feed trader survey, which indicates that formulated feeds accounted for 52% of feed traded. This might be because farmers also source non-formulated feeds direct from businesses such a rice mills and village grocery stores that were not included in the dealer and retailer sample.

The average rate of feed use in 2020 was 3.25 t/ha (Table 13) an increase of 30–38% since 2013 (Jahan et al., 2015; Ali et al., 2016).

Table 13
Farmers' feed procurement and use practices.

Variables	Farmer category				
	FO	PF	SF	PSF	Overall
Feed use					
Any feed (%)	95	100	83	93	95
No feed (%)	5	0	11	7	5
Only formulated feed (%)	6	2	3	2	4
Only non-formulated feed (%)	32	18	43	41	33
Both formulated & non-formulated feed (%)	56	81	37	50	59
Total feed use (t/ha)	4.73	3.54	0.81	1.75	3.25
Formulated feed use (t/ha)	2.14	1.25	0.26	0.40	1.26
Non-formulated feed use (t/ha)	2.59	2.29	0.55	1.35	1.99
Formulated feed in total feed use (%)	52	33	31	26	37
Non-formulated feed in total feed (%)	48	67	69	74	63
Floating formulated feed in total feed (%)	32	12	9	9	22
Estimated feed use, all 7 districts (t)	391,722	293,171	67,081	144,929	896,903
Share of formulated feed purchased by type of supplier					
Feed mill (%)	1	0	0	1	1
Feed dealer (%)	67	40	29	47	54
Feed retailer (%)	32	60	71	51	45
Share of non-formulated feed purchased by type of supplier					
Feed mill (%)	2	2	0	4	2
Feed dealer (%)	16	33	1	34	28
Feed retailer (%)	77	63	99	56	65
Others (%)	6	2	0	6	5
Farmers getting feed as in-kind credit (%)	17	32	13	32	24
Farmers obligated to sell fish to in-kind credit provider (conditional) (%)	2.1	1.9	0	1.5	1.7
Feed deliveries made by vehicle type (%)					
Van	61	83	36	77	72
Bicycle	12	9	32	16	14
Autorickshaw	25	6	18	3	11
Motorcycle	1	1	14	3	2
Other	0	1	0	1	1
Deliveries made by own vehicle (%)	20	17	49	24	22
Deliveries made by rented vehicle (%)	80	83	51	76	78
Transport share in total cost of feed (%)	1.5	1.7	1.7	2.0	1.7

Source: Own farm survey.

There is a spectrum of intensification running from shrimp-dominated to fish-dominated production systems, with farms producing fish and freshwater prawn, with or without shrimp, occupying intermediate positions. Among the four categories of farm analyzed, those producing only fish (FO) had the highest rates of formulated and non-formulated feed use (2.14 and 2.59 t/ha, respectively) and those producing shrimp with fish (SF) the lowest (0.26 and 0.55 t/ha, respectively). This pattern is consistent other surveys of aquaculture in southwest Bangladesh (Jahan et al., 2015; Ali et al., 2018a).

The great majority of feeds used by surveyed farms (92% of total volume) were purchased. Farmers only produced 8% themselves, particularly rice bran and rice products. Most formulated feeds (54% of volume) were bought from feed dealers and the remainder were bought from feed retailers (45% of volume) and feed mills (1%). On the other hand, most non-formulated feeds (65% of volume) were bought from feed retailers, followed by dealers (28%), feed mills (2%), and others (5%). These results are in line with the feed trader surveys reported above.

One-quarter of farmers (24%) reported having received feed as in-kind credit from traders during the most recent production cycle, but only 1.7% of farmers who availed feed as in-kind credit reported being obligated to sell their produce to these traders, indicating that there is very little use of output-tied credit by feed suppliers. This is to be expected, given that very few feed suppliers (1.2%) also trade fish, so have no outlet for fish sales. Their primary objective is to realize profit by maximizing volumes of feed traded. Our key informant survey revealed that in some cases the price of feed purchased as in-kind credit was 1.5% higher than that of feed purchased immediately in cash but that, depending on the relationship between farmers and traders, interest was not always charged.

Farmers reported using feed from 35 companies, among which eight accounted for 74% of all feed used (Fig. 5). One company alone, Quality, accounts for 25% percent of the formulated aquafeed market in Bangladesh, indicative of a high degree of market concentration. Most feed companies (88%) are homegrown Bangladeshi companies, and remainder were foreign-owned (6%) or joint ventures (6%).

Farmers used a variety of vehicles to transport feed from traders to their homes or farms. Most feed deliveries (72%) were made by van, followed by bicycle (14%) and autorickshaw (11%). Farmers used rented vehicles for 78% of deliveries, again underlining the importance of 3PLS. The remainder of feed deliveries were made using farmers' own vehicles. Feed transportation costs from trader locations to farms accounted for just 1.7% of feed costs.

4. Conclusions

Feed underpins increases in the global supply of fish from aquaculture, contributing to farm intensification and corresponding increases in productivity (Naylor et al., 2021). Feed also accounts for by far the largest share of production costs in conventional pond-based tropical aquaculture systems. The structure, conduct, and performance of the feed supply segments of aquaculture value chains thus have important implications for aquaculture productivity and profitability. To date, only a handful of studies have touched on the characteristics of the feed retail segments of aquaculture value chains as part of larger studies (e.g., Hasan and Shipton, 2021; Joffre et al., 2021; Islam and Hasan, 2020; Macfadyen et al., 2012), or evaluated specific aspects of feed trader behavior such as credit provision (Islam et al., 2020) and transaction costs (Islam et al., 2022). The current study, based on a survey in 2021 of two types of feed suppliers - 'dealers' linked to feed companies and independent retailers - in the seven main aquaculture producing districts of southern Bangladesh, addressed this knowledge gap. The following results stand out:

First, we provide evidence on the role of feed trading business both emerging in response to demand from and inducing a process of ongoing intensification in aquaculture in Bangladesh, including in shrimp and fish farms widely considered to be emblematic of traditional extensive aquaculture. We find that 'pure' extensive farms using no feed have almost ceased to exist, and that demand for formulated and traditional non-formulated feeds is growing rapidly but with the former outpacing the latter, particularly for floating fish feeds, offering higher efficiency and growth, but at higher unit cost. Similar patterns of aquaculture intensification driven by formulated feed use are playing out across Asia, resulting land and freshwater sparing effects on-farm, but with potential to create greater tele-coupled environmental impacts elsewhere such as through demand for fishmeal or soy (c.f. Henriksson et al., 2018). The volume of traded feed almost doubled over the last 10 years and the growth of floating feed sales was faster than that of sinking feed and non-formulated feed.

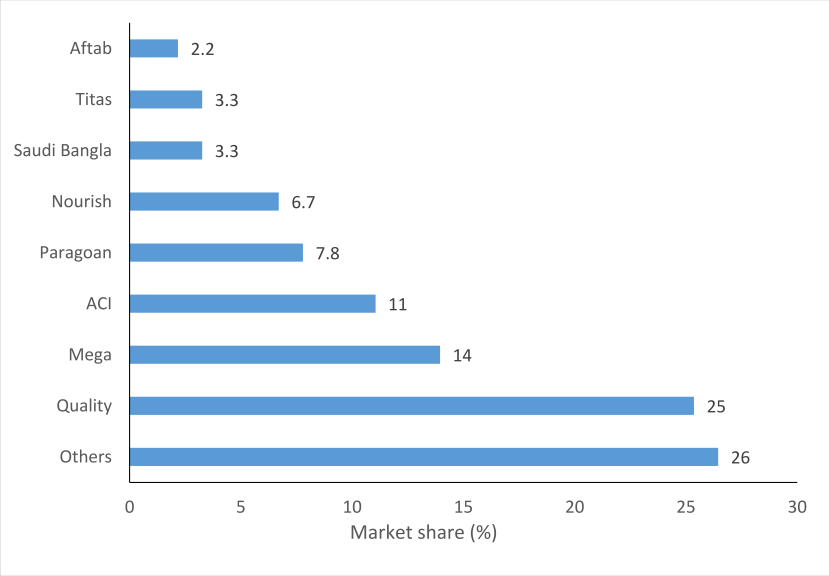

Fig. 5. Fish feed market share by brand (based on reported volumes of feed used by farmers).

Second, we find that the third-party logistics services (3PLS) firms were the primary form of transport used to distribute feed from suppliers to traders and traders to customers. This reliance on 3PLS indicates the significance of the role that these services play in feed trading and suggests that transport is an important but overlooked source of employment in the feed supply segment.

Third, we find that feed trading creates significant employment: approximately one FTE job in feed supply for every 10 FTEs on farm, for a total of 43,937 FTE jobs in surveyed districts of southern Bangladesh. However, this work is performed almost entirely by men, and with limited youth involvement, so is not particularly inclusive.

Fourth, we find that feed handling practices are efficient, with rapid stock turnover minimizing opportunities for spoilage, and minimal feed loss and waste between mill and farm. This finding runs contrary to the common image of feed supply chains performing poorly.

Finally, we find that feed trader profit margins are relatively modest at around 6%, without interlocking markets for feed and fish or feed and chemicals that could create opportunities of exploitative levels of surplus extraction by traders. In fact, traders appear to play an important role in reducing credit constraints by providing inputs as in-kind credit and accepting payments with a delay.

Collectively, these findings suggest that the feed supply segment of the aquaculture value chain in southern Bangladesh is dynamic, well-developed, and relatively competitive and efficient. This finding is contrary to the conventional wisdom, which often portrays the sector as inefficient and beset by problems.

Ethics statement

The research design was reviewed by Michigan State University Institutional Review Board (MSU Study ID: STUDY00003689). The study was determined to be exempt from IRB review on July 10, 2020.

CRediT authorship contribution statement

Hazrat Ali: Supervision, Conceptualization, Data curation, Formal analysis, Validation, Methodology, Writing – original draft. **Ben Belton:** Funding acquisition, Project administration, Conceptualization, Writing – review & editing. **Mohammad Mahfujul Haque:** Project administration, Supervision, Investigation, Writing – review & editing. **Khondker Murshed-e-Jahan:** Project administration, Supervision, Investigation, Writing – review & editing.

Declaration of Competing Interest

The authors have no competing interests to declare.

Data availability

Data will be made available on request.

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