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Published in:
Heliyon

Link to article, DOI:
10.1016/j.heliyon.2021.e08060

Publication date:
2021

Document Version
Publisher's PDF, also known as Version of record

Citation (APA):

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Prospects and challenges of yellow flesh pangasius in international markets: secondary and primary evidence from Bangladesh

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ARTICLE INFO

Keywords:
Pangasius
Yellow fillet
Water quality
Feed ingredients
White fillet
Export

ABSTRACT

The projected increase in aquaculture production by 2030 will mostly occur in countries of Asia and Africa, including Bangladesh. The pangasius (Pangasianodon hypophthalmus) produced in Bangladesh, the second-largest producer globally, is mainly consumed by low-income domestic consumers and is poorly demanded in international markets. One reason for this is the yellow flesh of fish; consumers generally in mainstream international markets prefer to fish with white flesh. Reviewing secondary evidence and analyzing primary data, this article assesses the underlying reasons for the discolored pangasius flesh in Bangladesh and synthesizes strategies for avoiding discoloration to induce exports. The findings indicate that farming practices with high stocking density, infrequent water exchange, high organic matter in pond water, and the growth of carotenoid-containing cyanobacteria contribute to the discoloration of pangasius flesh. Artificial and natural pigments in feed and poor post-harvest handling of fish are also contributing factors. Furthermore, a positive correlation between water exchange, price, and yield at the farm is found, which indicates that farm-gate price and yield per hectare can increase with more frequent water exchange. The findings of this study provide strong evidence that improved aquaculture practices can solve the problem of discolored pangasius flesh and establish an export-oriented pangasius industry in Bangladesh.

1. Introduction

The projected increase in aquaculture production by 2030 will occur mainly in countries of Africa and Asia, including Bangladesh (Kobayashi et al., 2015). The demand for cultured fish is increasing in many developed and developing countries because of rising income, urbanization, and decreasing supplies from captured fisheries (Kobayashi et al., 2015). To meet the increasing demand for fish, the world will depend mainly on aquaculture, especially from Asia. Vietnam, Bangladesh, India, and Indonesia are the major suppliers of aquaculture-based fish (more than 80%) and have great potential for further growth (Kobayashi et al., 2015).

However, there exist problems in achieving full market potential, both domestically and internationally, due to the poor quality of fish. For instance, the yellow flesh color of pangasius from Bangladesh makes it less preferred by customers both in the domestic and export markets. Solving the problems of fish quality may enhance export from Bangladesh and increase prices at the domestic market, which will safeguard the small-scale producers. The knowledge provided on the yellow color may also benefit aquaculture producers in other countries that face a similar problem.

Globally, Bangladesh ranked fifth in aquaculture production in 2018, having the second-highest growth rate of fish production in the world (FAO, 2020a). In Bangladesh aquaculture, pangasius (Pangasianodon hypophthalmus) is the dominant species, accounting for about 80% of the total production (FAO, 2020b). However, pangasius flesh is yellowish, which is not preferred by international buyers. To address this issue, this study aimed to assess the underlying reasons for discolored pangasius flesh in Bangladesh and to develop strategies for avoiding discoloration to enhance export potential.

Keywords: Pangasius, Yellow fillet, Water quality, Feed ingredients, White fillet, Export.
hypothesis) has become the most important pond-farmed species of fish, with its production contributing a total of 499,815 metric tons (MT) in 2017–2018 – an 18% share of total aquaculture production (DoF, 2018). This has made Bangladesh the second largest producer of pangasius in the world and, thus, the industry has the potential to become a vibrant sector of export earnings. Furthermore, the industry is a potential contributor to economic earnings in areas where development and poverty alleviation are important issues.

Currently, in Bangladesh, exports of pangasius are limited, and the fish is sold in the domestic market where it has become a cheap fish mainly eaten by lower-income consumers (Anwar, 2011). For many reasons, including pangasius’ contribution to the economy, global fish production, production practices, fish qualities, and accessibility to high-value local and international markets, Bangladesh could be the representative case for many countries in Asia and Africa where the sector is growing fast and shows potential for more growth.

Vietnam is the largest producer and exporter of pangasius with almost half of the total global production (1.4 million MT in 2019) (FAO, 2020b). Bangladesh, India, and Indonesia are the next three largest producers. Pangasius from Vietnam is exported widely to high-value markets because of its acceptability and affordability. Europe is the largest market for pangasius and could be a potential target for exports from Bangladesh (Belton et al., 2011). However, fillets produced in Bangladesh often have a yellow discoloration, which is commonly considered of lower quality and not preferred by European consumers (Belton et al., 2011; Little et al., 2012; Kulawik et al. 2015a, 2015b). Pangasius fillets from Vietnam are white and are in high demand to European consumers.

The European market for pangasius is closely integrated with markets for wild-caught whitefish such as cod, haddock, hake, and Alaska pollack (Brommann et al., 2016; Nielsen, 2005; Nielsen et al., 2009). Since the pangasius share of the European whitefish market is relatively small, even a substantial increase in pangasius exports will not induce a noticeable price reduction (Nielsen et al., 2016). Thong et al. (2017) confirm this result by estimating price flexibilities of the demand for pangasius in each continent, including Europe, as close to zero. Bangladesh could start exporting large quantities of pangasius without risking a reduction in prices; however, price fluctuations may come from other sources.

The structure of the international market reveals different habits. Vietnamese exports of pangasius fillets go to over 80 countries, including the United States. The export markets (including Europe and the United States) demand mainly frozen whitefillets without skin and bone (Guimaraes et al., 2016). The major export markets are for high-quality white pangasius fillets (Khiem et al., 2010) owing to a tradition of eating whitefish. Whitefish fillets such as cod and haddock that are slightly darkened or colored may receive lower market prices or be rejected (Vietnamese Association of Seafood Exporters and Processors, VASEP, 2019). Off-white pangasius fillets are sold at emerging markets such as Russia, while yellow fillets are sold domestically or regionally in Asia (Khoi et al., 2008). Therefore, other export options exist, even if it is not possible or considered too expensive for the Bangladesh pangasius industry to remove discoloration of pangasius fillets for markets in Europe or the United States. The color of a fillet is an important attribute for fish exporters, who want to present consumers with a product of standard appearance.

The large and growing pangasius industry in Bangladesh produces yellow-colored pangasius fillets, which are mostly consumed locally as a low-cost high-protein species. However, the same fish with white-colored fillets are in high demand from high-value domestic consumers and in global markets. While there are multiple reasons for the lack of pangasius exports to international markets, the color of the fillets is the critical one. The existing literature reveals that a white pangasius fillet is a sign of good farming practices. Good farming practices include low stocking density, frequent water exchange, using water with high oxygen content (Haque et al., 2016; Belton et al., 2011), and low levels of carotenoids in feed (Amaya and Nickell, 2015). Furthermore, low levels of chromophore cells (Qifuen et al., 2012) and good handling procedures, including draining the blood from the fillet to prolong its shelf life (Love, 2001), also contribute to a higher quality flesh in fish. Most of these practices can be adopted with the low level of investment and may even be a source of cost-cutting since good practices support dropping activities that do not add value at the farm level. This indicates that by solving the problem of the color of pangasius flesh, Bangladesh can improve its fisheries-based export earnings and even improve domestic demand by increasing the proportion of high-value domestic customers.

This paper, based on primary and secondary evidence, assesses the causes for the yellow discoloration of Bangladeshi pangasius fillets, identifies possible mitigation measures, and evaluates the economic viability of possible mitigation strategies. Its contribution to the literature is a synthesis of discoloration causes and solutions, taking economic viability, consumer color preferences, and market opportunities into account. The paper is organized as follows: section two provides the description of the materials and methods, section three presents and discusses the results, and the final section provides a conclusion to the study.

2. Materials and methods

This study was carried out as a literature review combined with an analysis of primary data gathered from a field survey in Bangladesh. Secondary information about the reasons for the yellow flesh of pangasius was collected from various sources including journal articles, reports, books, theses, and web materials. These evidence were supported by the information generated from the analysis of primary data surveyed from 645 pond aquaculture farmers, who mostly produce pangasius in Bangladesh. The interviews comprised questions related to water exchange, prices at the farm gate, and production volume. The survey questionnaire of pangasius farms from where water exchange and cost-related data were analysed for this study, is attached as supplementary material in Appendix-I. However, because most of the farmers interviewed were poorly educated and have little or no technical knowledge of fish farming, except a very few, they were unaware of the reasons for the discoloration of pangasius flesh. The farmers were interviewed face to face by trained enumerators with pre-validated interview questions. The questions proposed in each interview were verified in a focus group discussion with 20 pangasius farmers of at least five years’ experience and validated through a pilot survey with a different group of 20 farmers.

The farms in the study are located in the seven largest aquaculture producing districts (administrative areas) of Bangladesh, characterized by varying levels of access to open water, natural conditions and their economic backgrounds (Rahman et al., 2019). The selected districts cover 82% of total pangasius production in Bangladesh. The farmers were selected from the lists of farmers held by the local office of the Department of Fisheries.

The Spearman’s correlation coefficients, first between water exchange and price and then between water exchange and yield, were determined. Spearman’s correlation coefficient measured the correlation between an explanatory binary variable and an explained continuous variable (price and yield). The value of the binary variable, in this case, water exchange, was identified by dividing the farms into two groups: farms that regularly exchange water either by pump or by pipe (value = 1) and farms that do not do any water exchange (value = 0). If the value is positive, the price and yield increase with water exchange. The greater the value is, the greater the increase in price and yield with water exchange2. However,

\[ r_s = \frac{\sum (x - \bar{x})(y - \bar{y})}{\sqrt{\sum (x - \bar{x})^2 \sum (y - \bar{y})^2}} \]

where \( y \) is the price of pangasius, \( x \) represents the value 0 (water exchange not present) or 1 (water exchange present).
Spearman correlation parameters do not indicate if there is a statistically significant difference between the groups. Therefore, the Kruskal-Wallis test is additionally applied. The Kruskal-Wallis test is a non-parametric test comparing if the performance measured in terms of yield significantly differs between groups (water exchange and water non-exchange farms).

3. Results and discussion

The factors that cause discoloration of pangasius produced in Bangladesh are based on secondary evidence. The possible solutions to the discoloration issue described and discussed here are also based on secondary evidence. The results obtained by analyzing primary data to examine the economic feasibility of the most suitable solutions to discoloration are described and discussed in this section as well.

3.1. Why are pangasius fillets yellow?

3.1.1. Water quality and farming practices

The color of a fish’s fillet depends on the production and processing methods. Dissolved oxygen, stocking density, and water exchange practices in the culture system are also potential factors. For instance, pangasius fillet becomes darker color if pond water contains lower dissolve oxygen, water is exchanged infrequently, and if the stocking density is too high (SEAFISH, 2015) and Qiufen et al. (2012). Vietnamese pangasius farms are characterized by a average pond size of 3000m² with a depth of 4m, the stocking density of 14 fish/m³, and high yield (Lefevre et al., 2011). Ponds for pangasius in Vietnam typically contain 59.4% chlorophyceae, 17.4% bacillariophyceae, 12.2% euglenophyceae and 11.4% cyanophyceae with a low level of oxygen and a high level of ammonia (Da et al., 2016).

Although, the average pond size in Bangladesh is over 3000m², however, with a shallow depth of at least 1m pond, the lower stocking density of 4 fish/m³, higher levels of oxygen in the water, lower levels of ammonia, and lower yield (Ali et al., 2013). The lower stocking density in Bangladeshi ponds produces more oxygen and lowers ammonia than the ponds in Vietnam. Furthermore, the lower stocking density in shallow ponds may facilitate the growth and abundance of phytoplankton and different types of algae resulting off-flavor and discoloration of fish fillets (Ferdoushi and Haque, 2006). The dominating algae in Bangladeshi ponds is Chlorophyceae (47%) containing a higher levels of carotenoids (Mukherjee et al., 2013). The other algae Bangladeshi ponds are bacillariophyceae (23%), chlorophyceae (20%), and euglenophyceae (10%) (Ferdoushi and Haque, 2006).

Bangladeshi pangasius ponds are constructed on land with rice fields or on plain land where the source of water is rainfall and groundwater irrigation. Unlike the farmers in Vietnam, pangasius farmers in Bangladesh do not have sufficient access to clean river water (Ali et al., 2013; Haque et al., 2016). Poor water exchange in Bangladesh ponds (Table 3) is likely to increase the concentration of organic matter in the water, resulting in planktonic growth and the coloring of the flesh. For instance, the pangasius fillets produced in static ponds tend to be off-white in color, which renders it less saleable in the Western markets (Belton et al., 2011). It is because high-value international markets prefer pure white or pink fillets.

Vietnam is dominating Western markets being capable of supplying white or pink fillet because of its ponds location in close proximity of the Mekong Delta allowing more frequent water exchange. Frequent water exchange in ponds in Vietnam is likely to reduce the excessive growth of phytoplankton, which is responsible for the off-white color in pangasius meat. The key statistics of farms that exchange water and farms that do not exchange water are shown in Table 3. The price and yield of fish from farms that practiced water exchange was higher than farms that did not.

Table 1. Differences of ingredients used in pangasius feed in Vietnam and Bangladesh.

<table>
<thead>
<tr>
<th>Ingredients used in pangasius feed in Vietnam</th>
<th>Ingredients used in pangasius feed in Bangladesh</th>
</tr>
</thead>
<tbody>
<tr>
<td>Broken rice</td>
<td>Rice bran</td>
</tr>
<tr>
<td>Rice bran</td>
<td>Rice polish</td>
</tr>
<tr>
<td>Fish meal</td>
<td>Maize meal</td>
</tr>
<tr>
<td>Trash fish</td>
<td>Dry fish</td>
</tr>
<tr>
<td>Soybean cake</td>
<td>Fish meal</td>
</tr>
<tr>
<td>Soybean meal</td>
<td>Meat and bone meal</td>
</tr>
<tr>
<td>Others (egg, cassava, catfish extract oil, marine</td>
<td>Mustard oilcake</td>
</tr>
<tr>
<td>trash fish)</td>
<td></td>
</tr>
<tr>
<td>Methionine</td>
<td>Soybean meal</td>
</tr>
<tr>
<td>Mineral</td>
<td>Wheat flour</td>
</tr>
<tr>
<td>Premix</td>
<td>Salt</td>
</tr>
<tr>
<td>Pre-biotic (glucan)</td>
<td>Feed binder</td>
</tr>
<tr>
<td>Pre-biotic</td>
<td>Vitamin</td>
</tr>
<tr>
<td>Sorbitol</td>
<td>Growth promoter</td>
</tr>
<tr>
<td>Vitamin C</td>
<td>Calcium</td>
</tr>
<tr>
<td>Other additives</td>
<td></td>
</tr>
<tr>
<td>Lysine, Vitalex, Vemedin, Ţimbide, Pozyme, Pangarosol</td>
<td></td>
</tr>
</tbody>
</table>

and it acts as an antioxidant for fish. Carotenoids that have 7–15 conjugated double bonds appear yellow to red in color.

The catfish species channel catfish, pangasius, and African catfish are regarded as white-fillet fish where the limited carotenoids use are considered significantly (Amaya and Nickell, 2015). However, for some catfish (for example, yellow catfish and white spotted freshwater catfish), several commercial colorants are used to artificially improve its color and, as a result, cater to consumer demand and improve its economic value. For instance, Sodium bisulfite performed better than sodium bisulfate, ascorbic acid, butylated hydroxyanisole, citric acid, and sodium metabisulfite in reducing yellowness and increasing the brightness of channel catfish fillets after 12 days of storage. During storage, the total carotenoid content (lutein, zeaxanthin, and alloxanthin) of untreated fillets reduced significantly as compared to they were fresh. For fresh fillets (day 0), there was no significant difference between fillets treated with chemicals and untreated fillets (Li et al., 2013). Hu et al. (2015) found a linear correlation between the b* values (yellowness) and xanthophyll levels in catfish fillets where the xanthophyll level was calculated as the sum of lutein, zeaxanthin, and allo xanthin.

Protein quality, especially non-protein nitrogen (NPN) significantly contributes to fish flesh coloration. On the other hand, the quality and quantity of fat in feed regulates the pigment absorption, transportation, and deposition in the fish muscle (Qiufen et al., 2012). The deficiency of fat restricts the absorption of the color components including carotenoids in fish. However, fish is unable to synthesize carotenoids inside but can assimilate from feed ingredients. The extent of carotenoid deposition is directly associated with fat deposition levels in fish. The lower melanophores density in the skin and scales caused white or yellow fish fillets.

Furthermore, vitamins and minerals assist in retaining regular metabolism and metabolizing roles of chromatophore cells that affect the color of fish muscle by osmotic pressure (Qiufen et al., 2012). In the case of fish flesh coloration, vitamin-A and vitamin-E can contribute to increasing carotenoid absorption, and the other 13 types of vitamins accomplish the general biophysical activity and flesh color. Vitamin E or tocopherol is used as a vitamin and/or an antioxidant in fish feed or fishmeal so that the oil in it does not quickly become rancid. Consequently, the use of feed or fishmeal does not contribute to the discoloration of the fish body.

### 3.1.3 Physiology and genetics

Physiologically and genetically, fish contains two chromatophore cell bands combined mostly in the epidermis and dermis of the fish skin, which are transported by kinesin and cytoplasmic dynein and resulted cell bands combined mostly in the epidermis and dermis of the skin.

There is evidence that bruising can occur if a whole fish, soon after being harvested, is knocked against a hard surface. This bruising results in a patchy dark color in the fillet (Slack-Smith, 2001). This is caused by the rupture of fine blood vessels in the fillet and the blood not draining during gutting and icing. It was observed that when pangasius is harvested using a seine net, fishers throw them into hard silver pots or plastic drums which sometimes results in bruising. This is likely to cause a yellow color in the fillet after processing. Educating pangasius farmers and fishers about the consequences of this practice may help to improve the quality of pangasius fillets.

#### 3.1.5 Bruising

The link between the color of pangasius fillets and on-farm production practices suggests that improvements to production management could diminish the presence of yellow in the fillets. To control the yellow coloration of the fillet, monitor and control of the water quality parameters like transparency, salinity, dissolved oxygen, ammonia nitrogen, and blue-green algae are essential (Qiufen et al., 2012). Chinese consumers are more aware of fish flesh color and farmers should eradicate yellow in the fillets with improved cultivation techniques (Undercurrent, 2018).

Qiufen et al. (2012) suggested controlling oxidized lipid sources in fish to minimize yellow coloration of catfish, clarias leather, tilapia, and pangasius. Adding a certain amount of antioxidants to the ingredients of feed can prevent the carotenoid from oxidation with lipoygenase and prevent fat oxidation; subsequently, this can change the color of the fillet. Sørensen (2005) proposed controlling feed by regular monitoring for its composition and rancidity. Feed with low salt content and different premix formulation with vitamins and trace elements limit the color formation (Qiufen et al., 2012). From an industry perspective, although the alternative feed can result in a good production, it is only applicable for catfish that produce an acceptable white fillet.

However, current pangasius feeding and farming practices in Bangladesh fail to meet requirements for traceability and feed conversion efficiency demanded by various aquaculture certification schemes (Haque et al., 2021; Belton et al., 2011). As such, producers in Bangladesh should focus on improving pond management, feed nutrition, harvesting and transportation techniques, and careful monitoring of feed ingredients to achieve certification under the schemes of GlobalGAP, Best Aquaculture Practices (BAP) of Global Aquaculture Alliance (GAA), or Aquaculture Stewardship Council (ASC). In Vietnam, more than 70% of pangasius production meets ASC, BAP, GlobalGAP standards. The Bangladesh pangasius industry, to export pangasius, should meet international food standards, especially for the EU countries.

#### 3.1.4 Insufficient bleeding

Harvesting, slaughtering, and immediate post-harvest processing methods affect the color of fish fillets. Fillets could be white after processes such as gutting, bleeding, washing, and icing immediately after being caught. However, if the fish is filleted immediately after harvesting, the oozing blood gives the flesh a red color. The white fillets can then turn brown if fish is frozen and thawed immediately after harvesting (Love, 2001). It is because the blood has less chance to drain completely from a whole fish if fish are frozen soon after being gutted resulting in brown color flesh. Instead, if fish have been properly frozen and stored, the brown color of the fillets is not necessarily a sign of poor quality; rather, it is a reflection of the processing method (Love, 2001). However, in capture fisheries, when a fish is left whole for some hours in the holding ponds of a freezer trawler, its blood clots and does not drain when it is gutted. In these cases, the fillet, after freezing and thawing, can also acquire a brown color, which may be an indication of inferior quality. Residual blood in a fish fillet can result in a brown or darker color (Love, 2001). In Bangladesh, live pangasius is transported to processing facilities in plastic drums causing brown color fillets due to blood clotting during transportation. Therefore, the process of pangasius harvesting from the pond and means of transportation has implications for the fillet color.
3.3. Economic viability of increased water exchange

There are several solutions for the discoloration of fish flesh. Given that a causal relationship between the off-white coloration of pangasius fillets and the frequency of water exchange is not yet proven, exchanging pond water may be just one solution. Addressing the issue with more frequent water exchange may simultaneously address more factors behind discoloration, including the levels of dissolved oxygen in the water, the ammonia content, the quality of the water, and the capacity for higher stocking densities in the ponds.

Vietnamese pangasius farmers circumvent off-white coloration by practicing frequent water exchange (Belton et al., 2011, page 296). As a result, despite the high standing biomass of the fish stocked, the quality of the water can be maintained. In contrast, pangasius farmers in Bangladesh practice limited water exchange.

Increasing water exchange requires equipment such as pumps and pipes, which impose additional costs on farmers. For investment in more frequent water exchange to be worthwhile, the yield of pangasius per hectare or the price of pangasius must increase. Table 2 shows the Spearman's correlation coefficients for water exchange-price and water exchange-yield, together with data for price and yield. The sampled farms comprise 74% of medium and small (with a mean farming area of <2 ha) and 26% of large farms (with a mean farming area of >2 ha). All farms produce in earthen ponds (both homestead and commercial) following mostly extensive production systems.

There is a significant difference between the price of pangasius for farms with water exchange and without water exchange (Tables 2 and 3). Water exchange leads to better feeding and pond management practices through the removal of feed waste, resulting in improved water quality and fish. The mean difference of price is 43 Bangladeshi Taka (BDT), corresponding to a price premium of 45%. Furthermore, Spearman's correlation coefficient shows a positive relationship between the practice of water exchange and the price of fish. Hence, customers are willing to pay more when the fish is farmed in ponds with water exchange.

However, this finding indicates that all other factors that affect the price remain unchanged. One such factor is that farmers who practice water exchange may be more professional having higher skills and more bargaining power in setting the price of their fish. Nevertheless, Islam et al. (2020a) shows that even though pangasius and tilapia farmers in Bangladesh are in a dependency relationship with feed sellers for trade credits in purchasing feed, and the final market for pangasius and tilapia is competitive. This implies that the use of bargaining power is not possible.

The average yield (per hectare productivity) is 28.7 tons for farms that practiced water exchange water regularly and 27.8 tons for farms that did not. The coefficient confirms the positive correlation. The increased yield from regular water exchange might be because of the added feed elements (plankton) and the increased level of oxygen in the water. However, the difference in yield is small, which is due to the ability of pangasius to survive under the condition of low oxygen.

Mechanical recycling devices for exchanging water were not available at any of the farms in our survey. Farmers in Bangladesh usually exchange water in a natural way by connecting pipes to open water bodies or by using a water pump. Most farms located closed to open water sources use a plastic pipe to bring in and let out water, while farms located far from open water sources, especially on the periphery of urban areas, pump in underground water or take water in from nearby ponds. Thus, the cost of water exchange is low: 0.9% of the total costs.

To the extent that water exchange is the reason for the price premium, it is an important factor in a farm's profitability. Price premiums derived from water exchange far exceed the cost of implementing the practice, which suggests that earnings can be increased substantially by implementing water exchange practices on farms where it is currently not available.

Compared to Vietnam, the cost of water exchange is low in Bangladesh. This is because the technology used for the practice in Vietnam is more advanced than in Bangladesh. Of the total variable cost at medium and large-scale pangasius farms in Vietnam, the annual cost of sludge discharge and energy (electricity and fuel for water exchange and feed preparation) was US$ 2,300 and US$ 4,900 per hectare respectively (Ngoc, 2016). Vietnamese farmers invest a considerable amount of money in water exchange, pumping water mainly from nearby rivers to maintain a good quality of water (Nhut, 2016). Whether due to its role in whitening pangasius fillets or improving other aspects of farming, the use of water exchange seems to contribute to the significant price premium in Bangladesh. A non-parametric statistical analysis (Kruskal-Wallis test) has confirmed that the yield of farms exchanging water is significantly different from those farms not exchanging water.

Water exchange facilities can be improved if fish farmers have easier access to open sources of water bodies (rivers and canals) in most aquaculture production zones, which can be implanted easily since the country is criss-crossed by rivers and canals, and will benefit agriculture as well (Rahman et al., 2019). Rural electrification in Bangladesh has been expanded and improved tremendously and the government has

<table>
<thead>
<tr>
<th>Table 2. Spearman's correlation coefficient: water exchange and price, and water exchange and yield of 318 Tilapia and 327 pangasius farms.</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Average yield (tons/hectare)</strong></td>
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<tr>
<td><strong>Costs (as percentage of total costs)</strong></td>
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<tr>
<td><strong>Average price (BDT/kg)</strong></td>
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<td><strong>Spearman's correlation coefficient (ρ) water exchange with</strong></td>
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<tr>
<td><strong>Ann.: * significant at 5% and ** significant at 1%.”</strong></td>
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</tbody>
</table>

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<tr>
<th>Table 3. Key statistics of farms exchanging water and not exchanging water.</th>
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<tbody>
<tr>
<td><strong>Tilapia</strong></td>
</tr>
<tr>
<td><strong>Yes</strong></td>
</tr>
<tr>
<td><strong>Number of observation</strong></td>
</tr>
<tr>
<td><strong>Price (BDT)</strong></td>
</tr>
<tr>
<td><strong>Yield (kg)</strong></td>
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<tr>
<td><strong>Density</strong></td>
</tr>
<tr>
<td><strong>Traditional feed to total feed used (%)</strong></td>
</tr>
<tr>
<td><strong>FCR (kg)</strong></td>
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<tr>
<th><strong>Kruskal Wallis Test</strong></th>
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<tr>
<td><strong>Chi</strong></td>
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<td><strong>Df</strong></td>
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<td><strong>p-value</strong></td>
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</table>

Figures in parenthesis are standard deviation except in case of number of observations.

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3 While these average productivities in Bangladesh with and without water exchange are similar, they should be compared to the average productivity of pangasius farming in Vietnam: 206 tons per hectare in 2017 (Vietnamese Association of Seafood Exporters and Producers 2019). This is 7 times larger than in Bangladesh. The difference reflects the overarching nature of pangasius farming in Bangladesh. The difference may also be attributed to deeper ponds in Vietnam and, therefore, more cubic meters, better management skills in Vietnam, or possibly better product quality.
fixed the cost of electricity per unit for paddy cultivation much less than for fish farming. Aquaculture being a sub-sector of the agricultural sector in Bangladesh, fish farming has to pay double electricity bill per unit under commercial category than paddy farming as agricultural category (Rahman et al., 2017). Pangasius farmers will benefit if the cost of electricity is reduced like rice farming. Moreover, solar power-operated water pump is opening a new avenue reducing the cost of electricity in agricultural farming in Bangladesh sustainably which will contribute to controlling fish farming-led greenhouse emissions as well (Kim, 2018).

3.4. Market implications of yellow pangasius fillets

Pangasius competes with other whitefish species in the main European market, but the competing fish species differ from country to country. Pangasius exporters must be aware of the competing fish species in each market. In Germany and Poland, Alaska Pollock is the main competitor for pangasius, while in the UK consumers prefer Haddock and Cod. In countries of southern Europe, Hake and Alaska Pollock are the main competitors for pangasius. Global Cod landings showed an upward trend in 2008–2014, but have since declined slightly (FAO, 2019a). Moreover, Alaska Pollock is currently preferred over pangasius in some EU markets, for example, Germany and Poland, because of its stable catches, low prices, and better consumer perception (Bronmann et al., 2016). The taste of pangasius is weak (a flat taste) and does not have the same taste as other marine fish. Given this context, the color of the fillet is an important sensory quality for pangasius exports.

Khoi (2011) reported the major differences in pangasius export markets. In the current export market, the criteria applied to fish quality are color, size, disease, and antibiotic residues. Importing countries are also increasingly pressuring pangasius farmers to comply with different certification schemes, responsible aquaculture practices, and strong traceability systems. Of the attributes, color and size are important for the price of fish and its success in export markets. Consumers in the United States and the EU prefer white and pink fillets, for which they are willing to pay more. Yellow fillets are sold at lower prices (with lower quality) in Eastern European markets, such as Russia, and Ukraine, and Asian countries such as Singapore, and South Korea (VASEP, 2019). Prices in the United States, EU, Russia, and the Southeast Asian (ASEAN) markets are shown in Table 4. The price spread is related to the quality requirements or food safety standards imposed by the importing countries. However, there are significant differences in food standards applied in ASEAN countries, and the United States has stricter standards than those applied in Russia and ASEAN countries. For Bangladeshis pangasius farmers to enter the global market and demand higher prices, they must establish sustainable aquaculture certifications, which require improving legal frameworks and involving value-chain actors (Haque et al., 2021).

Vietnam reached US$ 2.3 billion in pangasius export revenue in 2019 (FAO, 2020b). Vietnamese pangasius is exported to over 80 countries worldwide (VASEP, 2019). The largest export market is the EU (44% of exports), followed by Russia (13%), ASEAN countries (9%), United States (5%), Australia (3%), and China and Hong Kong (5%). New markets in Ukraine, Egypt, and Mexico emerged in 2007 (Khoi, 2011). In recent years, China has continued to increase its share of the global pangasius market with strong consumer demand for pangasius and imports from Vietnam (FAO, 2020b). Chinese consumers prefer white fillets to pinkish or pink fillets, with pinkish or yellow fish fillets referred to negatively as ‘yellow meat’ (Undercurrent, 2018). EU importers recognized pangasius fillets as whitefish that costs about half as much as other quality white fish (VASEP, 2019). Sørensen (2005) focused on this area and, due to the lower market price, set the priority for reducing the number of yellow fillets. The study reported that yellow fillets can be sold in certain markets at a reduced price.

The main market for pangasius in the EU, taking 40% of products, mainly white fillets. Some pink fillets are sold to Germany at approximately US$ 2.8/kg. Yellow fillets are sold to Asia. White fillets fetch approximately US$ 3/kg, while yellow fillets receive approximately US$ 2/Kg (Sørensen, 2005). In EU markets, when compared with whitefish products from other countries, pangasius products are, on average, the cheapest. The Netherlands and the United States pay the highest average price per imported kilogram of pangasius, while Russia and Ukraine pay the lowest. Trifković (2014) stated that the emphasis on quality is important because farmers pay according to the quality grades set by processors. Pangasius products are marketed as high or low grade, with the higher quality products being light-colored trimmed fillets sold in Western markets. Pangasius products graded as lower quality are untrimmed with more intensive fillet color, and they are sold in markets with lower purchasing power. Figure 1 represents the visual differences in frozen pangasius fillets from Bangladesh (yellow fillet, image A) and Vietnam (white fillet, image B).

According to SEAFISH (2015) and CBI (2015), European consumers have a strong preference for white fillets and, sometimes light pink, although pink are not preferred. For most people living in developed countries, good nutrition is relatively assured. Consumers are, therefore, interested not only in their food’s nutritional value, they are also interested in the natural substances that improve the aesthetic (sensory) appeal of the food (for example, color and flavor) which may also have special effects on health. Appropriate color is an important sensory quality that clearly reflects the health and safety of the food and the organism from which it is derived. Exports of pangasius produced in Vietnam’s Mekong Delta region grow because of its flashy white fillets, firm texture, and neutral flavor. These characteristics have been widely accepted by consumers in the US, EU, and former Eastern Europe. Moreover, it has become a low-cost alternative to marine staples such as cod and haddock in Europe, and to the indigenous Channel Catfish (Ictalurus punctatus) in the US (Belton et al., 2011). In the EU, consumer demand and purchasing behavior for fisheries and aquaculture products have the greatest impact on purchasing decisions (58%), followed by cost (55%) and geographical origin (42%) (EUMOFA, 2017).

Whiteness in pangasius generally indicates the quality of the fish. In general, yellow pangasius fillets are often rejected by consumers (Amaya and Nickell, 2015). Pangasius has firm fillets and a mild flavor with slight shellfish overtones. The preferred form of pangasius is mostly natural skinless and boneless fillets, with the belly fat removed and the red meat cut off (SEAFISH, 2015). Islam et al. (2020b) found that the pangasius industry in Bangladesh can learn from the shrimp industry on the practical functioning of food safety regulations, even though the color of shrimp flesh is not an issue for exports in the way that it is for pangasius.

4. Conclusion

Bangladesh, the second-largest producer of pangasius globally, can be a leading importing country. However, relative to Vietnam, the world’s largest producer and exporter of pangasius, in Bangladesh production costs for feed remain high, water exchange facilities are limited, and consumer acceptability of Bangladeshi pangasius both in local and international markets is lower. The reason is that the pangasius produced in Bangladesh often has yellow fillets, compared to the white fillets from Vietnam, which have greater consumer acceptability and command a higher market price. It indicates that producers in Bangladesh and consumers worldwide may benefit if the quality of pangasius flesh from Bangladesh is improved.

<table>
<thead>
<tr>
<th>Market</th>
<th>Price (US$/kg)</th>
<th>Fillet color</th>
</tr>
</thead>
<tbody>
<tr>
<td>United States</td>
<td>3.17</td>
<td>White and pink</td>
</tr>
<tr>
<td>European Union</td>
<td>2.70</td>
<td>White</td>
</tr>
<tr>
<td>Russia</td>
<td>1.68</td>
<td>Light yellow</td>
</tr>
<tr>
<td>ASEAN</td>
<td>1.60</td>
<td>Yellow fillet</td>
</tr>
</tbody>
</table>

Source: VASEP (2019).
This study identified several possible reasons for the yellow in pangasius fillets in Bangladesh based on primary and secondary evidence. The evidence pointed to water quality and farming practices being important factors in the color of pangasius flesh. High stocking density leads to low levels of dissolved oxygen and high ammonia and no water exchange leads to poor water quality, which results in yellow pangasius fillets produced at farms in Bangladesh (Qiufen et al., 2012).

Moreover, evidence suggests that frequent water exchange leads to high levels of dissolved oxygen and low ammonia in the water (Hopkins et al., 1993), which tends to reduce the density of phytoplankton, ensures a comfortable environment for the pangasius and leads to white fillets. In addition, both artificial and natural color components (carotenoids and astaxanthin) and nutrient compositions (protein, oxidized fat, vitamin and mineral premixes) in fish feed are identified as highly influential for yellow fillets. Different chromophore cells, physiological characteristics of the fish (for example, size, age, sex, internal hormones, and enzymes) and post-harvest handling and processing may also affect the color of the fillets.

Export-oriented white pangasius fillets produced in Vietnam are exported to the EU, US, and 77 other countries worldwide (Thong et al., 2017). European consumers prefer pangasius fillets because of the high quality and white flesh, and as a low-cost alternative to cod and haddock, while American consumers consider it as an alternative to the indigenous Channel Catfish (Ictalurus punctatus). To access the international market with white pangasius fillets of international food standards, the Bangladeshi pangasius industry must implement new management practices, improve water quality, practice frequent water exchange and low-density stocking, and pursue environmental suitability through attaining sustainable aquaculture certification. In addition, training for pangasius producers, ideal farming demonstration, and expert-level knowledge sharing on reasons for pangasius flesh discoloration, and its remedial measures are important in this regard.

Economic gains can be achieved if facilities for more water supply are established. Although production costs would increase, it may be worthwhile, given that the price of pangasius increases with more frequent water exchange. If Bangladeshi pangasius farmers can produce white pangasius fillets, exporting to the EU and US may be possible since consumers in those markets prefer white and pink pangasius with white pangasius being exported to the EU, US, and 77 other countries worldwide (Thong et al., 2017).

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**Declarations**

**Author contribution statement**

Md. Sazedul Hoque: Conceived and designed the experiments; Performed the experiments; Analyzed and interpreted the data; Contributed reagents, materials, analysis tools or data; Wrote the paper.

Mohammad Mahfujul Haque: Conceived and designed the experiments; Performed the experiments; Analyzed and interpreted the data; Contributed reagents, materials, analysis tools or data; Wrote the paper.

Badiuzzaman: Conceived and designed the experiments; Analyzed and interpreted the data; Wrote the paper.

Md. Takibur Rahman: Performed the experiments; Analyzed and interpreted the data; Wrote the paper.

Md. Ismail Hossain: Performed the experiments; Contributed reagents, materials, analysis tools or data; Wrote the paper.

Sultan Mahmud: Conceived and designed the experiments; Contributed reagents, materials, analysis tools or data.

Anup Kumar Mandal: Performed the experiments; Analyzed and interpreted the data.

Marco Frederiksen; Erling P. Larsen: Contributed reagents, materials, analysis tools or data; Wrote the paper.

**Funding statement**

This work was supported by the Danish International Development Agency (DANIDA) of Denmark for the project “Upgrading pangasius and tilapia value chains in Bangladesh” (F387-A26778).

**Data availability statement**

Data included in article-supplementary material/referenced in article.

**Declaration of interests statement**

The authors declare no conflict of interest.

**Additional information**

Supplementary content related to this article has been published online at https://doi.org/10.1016/j.heliyon.2020.e03459.

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