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Research article

Quality evaluation of improved and traditionally dried Bombay duck (*Harpodon nehereus*) through biochemical, microbiological, and organoleptic analysis

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A R T I C L E I N F O

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A B S T R A C T

The study was conducted to compare the quality and shelf life of traditionally dried (collected from the local markets) Bombay duck (*Harpodon nehereus*) with improved dried products (produced using a newly developed fish dryer) to assess its suitability. The quality of these products was evaluated through organoleptic, water reconstitution, nutritional, chemical, and microbiological characteristics. The organoleptic quality of improved dried fish was excellent while those produced traditionally were with grayish and dark brown color, rancid odor, and soft and fragile texture with insect infestation. The water reconstitution properties of the improved dried sample were 75.71% and 89.39% at room temperature and 80 °C, respectively, which were comparatively higher than the traditional dried products. The protein, ash, and contents were significantly higher in improved dried fish products while the lipid and total volatile base nitrogen (TVB-N) content were much lower than those of market-dried samples. The total viable counts (TVC) of bacteria were significantly higher in the traditional products which indicated poor quality. To find out the best storage method, dried fish was kept at three different conditions: in the open air at room temperature, in a sealed pack at room temperature, and a sealed pack at refrigeration temperature (4 °C). The shelf life of the products in different storage conditions was evaluated by estimating their moisture, protein, lipid, ash, TVB-N, and TVC values. The products kept at 4 °C temperature was found almost unaltered in terms of their nutritional properties after 4-months storage period. Results indicated that the newly developed fish dryer produced high-quality dried fish products with longer shelf life can be expected if the dried fish is stored at 4 °C refrigeration temperature. Our findings will be a valuable tool for the fish processors to ease the fish drying process and its storage that will enable them to commercially supply good quality dried *Harpodon nehereus* in the market chain at a low-cost.

1. Introduction

Fish is an extremely perishable food and may spoil within 10–12 h depending on the species, methods of capture and storage [1,2]. There are several preservation techniques *viz.* freezing, drying, salting, smoking, and fermentation, that are practiced by the fish

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processors to keep the fish fresh and to increase its shelf life. The main aim of fish preservation is to reduce the rate of spoilage by reducing the water activity of the fish through these methods [3–5]. Fish processors in the remote areas of Bangladesh widely use different types of drying methods (including sun and wind drying) as it is a simple and inexpensive method of processing [6]. Drying inhibits the enzymatic degradation of bacteria thus, extending the shelf life of fish [7]. Dried fish is an important, popular, and frequently eaten type of foodstuff in many regions of Bangladesh. It contains a high amount of protein, vitamin A, and minerals (calcium, iron) and is also a good source of omega-3 fatty acids which are considered nutritious food for human consumption [8] Dried fish have good potential for both internal and international markets. Every year, Bangladesh earns a good amount of foreign currency by exporting dried fish. An estimated amount (about 20%) of the artisanal fish catch is sun-dried and consumed in the domestic market [9–11].

Although traditional sun drying is often considered a simple, and inexpensive technique; it has some limitations because it is exceedingly dependent on weather condition that is beyond the control of the fish processors. Along with sunlight, the other two important factors are relative humidity (RH) and wind flow directions, which are important factors that influence the efficiency of drying but are beyond the control of the fish processors while practicing in an open yard. During drying, another important problem is insect infestations by blowflies, house flies, and other insects/larvae that make the fish unacceptable for human consumption [12]. Under warm and humid conditions, sun-dried fish rapidly become infested by blowfly larvae. Also, during storage, dry fishes are attacked by several species of domestic beetle, viz., *Dermestes maculatus, D. frischii, D. ater* and mite, *Necrobia rufipes* [13] Due to poor sanitation and improper processing technique, the contamination and spoilage rate become excessive, and thus the use of insecticides to prevent insect infestation is a common practice [11]. Thus, low-quality dried fish is produced as a result of unhygienic handling, slow drying, adverse weather conditions, poor storage conditions, and possible degradation due to microbial and biochemical reactions [14]. Based on physical, chemical, and microbial quality the most available dried fish products in the market is not satisfactory for human consumption [14,15]. Considering the above drawbacks of traditional sun-drying techniques, it is necessary to develop an appropriate drying technique to produce safe and good quality dried fish products. Although several attempts were made, an appropriate drying technique is not yet established in Bangladesh. Therefore, in the present study, a low-cost fish dryer was developed in order to minimize the shortcomings of the traditional sun drying method. To determine the suitability of the newly designed fish dryer, a comparative study on the overall quality of dried *Harpodon nehereus* was carried out between the products collected from local fish markets produced by traditional sun drying techniques and improved dried products produced by the newly developed dryer. *Harpodon nehereus* is a very important fish in artisanal fishery because of its abundance and contains a high amount of moisture around 89% in its muscle, which considered the suitability of this as for drying [16]. It is considered a highly valued fish in dry conditions all over the region of Bangladesh especially, in Chattogram where dried fish are found in abundance [17]. We hypothesize that the quality of dried fish produced by our newly developed fish dryer will be superior to those produced by traditional sun drying techniques in terms of organoleptic characteristics, water reconstitution behavior, and nutritional, chemical, and microbial properties.

Questions have been raised about the safety and long-time consumption of these dried products after production because maximum dry fish are generally stored in dump warehouses. Freshly dried fish appearance an attractive cream color however during storage moisture retained from the environment turns to brownish yellow or brown color which indicates the spoilage of fish and is not satisfactory for the human diet [15,18]. Inappropriate storage like dry fish storage in an open place without packaging decreases the shelf life and quality. High-quality dry fish depend on the water content in the final product and storage at ambient temperature with proper packaging. Bangladesh is a tropical country, for this reason, dried fishes easily retain moisture from the environment and cause deterioration of nutritional and physical properties with the increasing storage period [19]. Most of the studies focused on the nutritional, chemical, and microbial assessment of different types of dried fish. However, far too little attention has been paid to the storage and packaging of dried fish.

This research attempts to determine the quality of dried *Harpodon nehereus* produced by the newly developed dryer and compare them with the market sample and also to find out the best storage condition and shelf-life aspects for dried *Harpodon nehereus*. For this purpose, we have assessed the shelf life of the improved dried products under three different storage conditions such as keeping the products (a) in the open air at atmospheric temperature, (b) in a sealed pack at atmospheric temperature, and (c) in a sealed pack at 4 °C temperature. Here, we also hypothesized that the shelf-life of dried products kept at 4 °C temperature after sealing will be more prolonged than other methods. So, the objective of this study is to justify the above hypothesis.

2. Materials and methods

2.1. Ethics statement

The study design and protocol were approved by the Director of Research and Extension, at Chattogram Veterinary and Animal Sciences University, Bangladesh. No special permission was required as the study did not involve any live animal and the study species (*Harpodon nehereus*) is not an endangered or protected species.

2.2. Location of the study

The study was performed in a newly developed fish dryer at the Faculty of Fisheries building, Chattogram Veterinary and Animal Sciences University, Chattogram, Bangladesh. The nutritional and microbiological assessment was conducted at the Nutritional and Processing Laboratory, Disease and Microbiology Laboratories of the Faculty of Fisheries, Chattogram Veterinary and Animal Sciences University.

2.3. Construction of improved fish dryer

A picture of the improved dryer is included in Fig. 1 (A). The improved fish dryer was constructed with a steel framework having a base of MS sheet. The framework was designed to have three chambers with a height of 5 feet, 4 feet wide, 9 feet long and 1.25 feet internal chamber height. The upper side of the dryer was covered by 12 mm transparent polythene sheet, whereas the sides were covered by a net of 3 mm mesh size to prevent the entrance of flies. A mobile heater, exhausted fan and industrial fan with a control panel were placed inside the dryer to regulate the drying temperature relative humidity (RH) and time of the fish. The capacity of the improved dryer is 120 kg for fish species.

2.4. Collection of samples

In this study, the Bombay duck (*Harpodon nehereus*) which is locally known as Loittya was used for drying as it is a lean fish and is used extensively in drying. The raw fish with 18–22 cm fork length size and 14–16 pieces/kg wet weight were collected from Firingi Bazar, and Karnaphuli fish market, Chattogram. The traditionally dried fish was collected from Chaktai bazar, a well-known wholesale dry fish market in the Chattogram area. Dried fish samples were placed tightly in polyethylene bags, transported to the laboratory, and kept chilled during the study. These samples are further termed "Market-dried" samples.

2.5. Fish drying performed in the improved dryer

A picture depicting the Bombay duck drying in the improved dryer is included in Fig. 1 (B). Properly dressed and washed fish was soaked in the 5% salt solution for 2 min to reduce water activity and initial microbial growth during drying as it is reported that low salt percentage of 5% in dry salting yields low microbial count in dried fish, compared to the common use of 30% salt [20]. After that fish

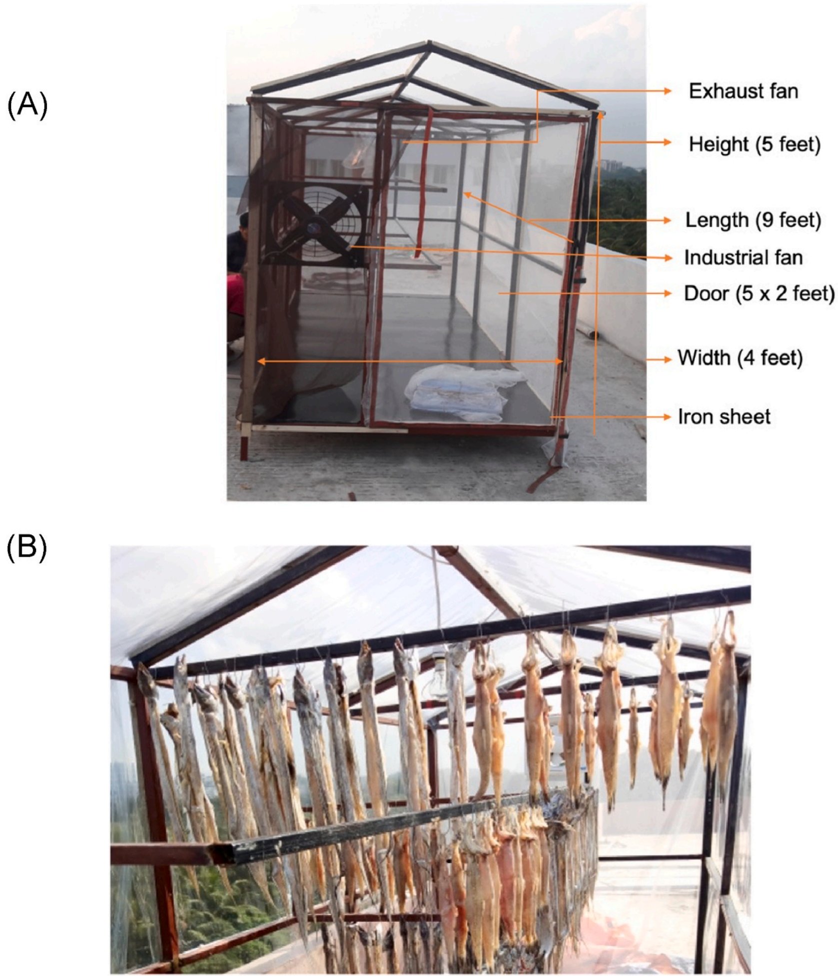

Fig. 1. Pictures depicting the labeled structure of the improved fish dryer (A) and drying of Bombay duck (B) in the present study.

were hung up on strings and placed in the improved dryer, these samples are further termed "improved-dried" samples. In the dryer, a thermometer and hygrometer were used to measure the temperature and relative humidity, respectively. All equipment was connected and regulated by a control panel, where every parameter was continuously displayed on its screen. To maintain a constant temperature, the heater produces heat at night when sunlight is absent, while the industrial fan produces a significant amount of air during the day. The exhaust fan works to remove humid air and allows fresh air to enter, thus maintaining the required humidity level inside the dryer. A previous report proposed the optimization of fish drying time and moisture content by drying at a high temperature initially; and then lowering it to prevent spoilage in a convective fish dryer [21]. Drying was carried out under a controlled temperature with a range of relative humidity as provided in (Table 1).

2.6. Organoleptic quality assessment of dried fish

A sensory assessment based on color, flavor, texture, insect infestation, presence of broken pieces, and overall acceptance of dried fish from two sources was performed by a trained panel of expert members using a 9-point hedonic scale (9 = extremely like, 1 = extremely dislike) [22].

2.7. Storage of dried fish

The dried fish produced from the improved fish dryer was stored under three different conditions, such as in open air at room temperature (25–28 °C), in a sealed pack at room temperature, and in a sealed pack at refrigeration temperature (4 °C).

2.8. Nutritional quality assessment

The nutritional quality (moisture, protein, lipid, and ash) of samples were analyzed according to the AOAC method [23] with certain modifications. Moisture content was determined using a hot air oven (BINDER-ED115, Germany) at 105 °C for 12 h, ash content of samples was determined by a muffle furnace (Nabertherm-L9/13, Germany) at 550 °C for 6 h. A Soxhlet apparatus (FOOD ALYTRD40, Germany) was used to determine the lipid content and the crude protein of samples was estimated by the micro-Kjeldahl apparatus (DK 20/26, Italy) and distillation unit (UDK129, Italy).

2.9. Chemical quality assessment

The total volatile-base nitrogen (TVB-N) was analyzed to observe the chemical quality of dried fish. TVB-N was determined according to the European steam-distillation method [24]. Briefly, 100 g homogenized dried fish sample was mixed with 200 ml of 7.5% trichloroacetic acid and blended for 2 min and filtered. Then 25 ml of these extracts were taken for distillation following the protocol and titrated against 0.025 N H_2SO_4 to the endpoint change to pink color.

2.10. Microbiological quality assessment

Microbiological analysis was also conducted according to AOAC [23] and FDA BAM method [25]. The consecutive decimal dilution (10^{-1}, 10^{-2}, 10^{-3}, 10^{-4}, and 10^{-5}) method was used to determine the TVC of bacteria and the presence of any harmful bacteria like *E. coli,* and *Salmonella* was determined using the selective Mac-Conkey agar, Xylose-lysine-deoxycholate (XLD) and TSI agar.

2.11. Statistical analysis

The obtained data were analyzed by Microsoft Excel 2020 package and the significant differences were examined through one-way analysis of variance (ANOVA) and Duncan's multiple range tests using SPSS software (IBM SPSS Statistics 23). The significance level was set at the level of $p < 0.05$.

Table 1
Drying parameters conditions in the improved fish dryer to produce better quality dried fish. A series of temperatures and relative humidity inside the dryer were maintained mechanically and periodic checking was in place to monitor any deviation from the desired conditions.

Duration		Temperature (°C)	Relative humidity (%)
Day-1		45	35–45
Day-2	12 h	40	35–45
	12 h	35	55–60
Day-3		25–30	55–60

3. Results

3.1. Organoleptic quality assessment

The organoleptic characteristics of dried Bombay duck from improved and market samples are presented in Table 2. The quality of the dried fish samples was assessed based on color, odor, texture, insect infestation, and the presence of broken pieces. The improved dried Bombay duck had whitish color with a firm and elastic texture whereas, market-dried fish contained grayish to brown discoloration with a soft texture and somehow strong-fishy odor. There was no insect infestation and broken pieces found in improved dried fish, but some insect infestation and broken pieces were exhibited in the market sample. In the hedonic test, the overall acceptance of the improved dried fish sample was 8.24 which was higher than the market-dried sample (5.45).

3.2. Water reconstitution analysis of dried fish

The results of the water reconstitution behavior of dried fish are shown in Fig. 2 and it showed that the rehydration ability of samples is directly related to soaking duration and temperature. Water reconstitution of the dried samples was assessed at both room temperatures (for 60, 100, and 150 min) and at 80 °C (for 20, 40, and 60 min). After 60 min the water reconstitution rate of the improved dried and Market dried samples was 52.86 ± 1.11%, 42.36 ± 1.65% respectively; which increased up to 75.71 ± 1.95%, and 63.84 ± 1.35% after 150 min. At 80 °C, for both samples the rate was 54.43 ± 0.96%, and 40.72 ± 0.58% respectively, after 20 min; which finally reached the highest level (89.39 ± 0.79% and 62.39 ± 0.61% respectively) after 60 min. In all cases, the water reconstitution was significantly higher for improved dried samples than the market-dried samples (ANOVA, $p < 0.05$).

3.3. Proximate composition analysis

The proximate composition, especially the moisture and protein content in the final product plays a significant role in determining the nutritional status of dried fish. Results of the proximate composition of different samples of dried Bombay duck have been shown in Fig. 3. The moisture content of the improved, market-dried sample was 18.10 ± 0.79% and 26.53 ± 1.45%. The improved dried fish contained 62.60 ± 1.25% protein, 5.83 ± 0.73% lipid, and 12.70 ± 0.81% ash; whereas in the market dried sample, it was 45.41 ± 2.39% protein, 3.95 ± 0.66% lipid, and 6.67 ± 0.89% ash. Statistical analysis by ANOVA showed that there is a significant difference ($p < 0.05$) among the proximate compositions of different dried fish.

3.4. Chemical assessment of total volatile base nitrogen (TVB-N)

The value of TVB-N observed in improved, and market-sample dried Bombay duck were 20.8 ± 0.77 mg/100 g and 86.73 ± 0.72 mg/100 g. The higher TVB-N value was observed in the market-dried Bombay duck sample.

3.5. Microbial assessment of total viable count (TVC)

In the present study, a lower microbial load was recorded in improved dried Bombay duck fish than in market-dried fish. The lowest microbial load (1.69×10^5 cfu/g) was found in the improved dried sample where the pathogenic bacteria *E. coli* and *Salmonella* were absent. On the other hand, the microbial load of the market dried sample was 3.02×10^5 cfu/g which was significantly ($p < 0.05$) higher than the improved dried sample. The pathogenic bacteria *E. coli* and *Salmonella* both were present in the market sample.

4. Shelf-life attributes of the improved dried products

4.1. Changes in organoleptic quality during storage

Further assessment was conducted to evaluate the quality changes of dried fish products up to 4 months of storage in three different conditions. Here, only an improved-dried sample was considered because the exact date of market-dried fish production was unknown. The three storage conditions are in the open air at room temperature, in a sealed pack at room temperature, and in a sealed pack at 4 °C temperature. The evaluation was done based on color, odor, texture, insect infestation, presence of broken pieces, and overall quality.

Table 2
Organoleptic characteristics of dried Bombay duck. This study was conducted based on five characteristics (color, odor, texture, insect infestation and broken pieces) using a hedonic scale method. Dried fish from an improved dryer possess excellent quality than dried fish collected from the market.

Sample types	Color	Odor	Texture	Insect infestation	Broken pieces	Overall acceptance
Improved dried fish	Whitish and cream	Characteristics odor	Firm and elastic	No infestation	No broken pieces	8.24
Market dried fish	Grayish to dark brown	Rancid	Soft and fully loss of elasticity	Some infestation	Some broken pieces	5.45

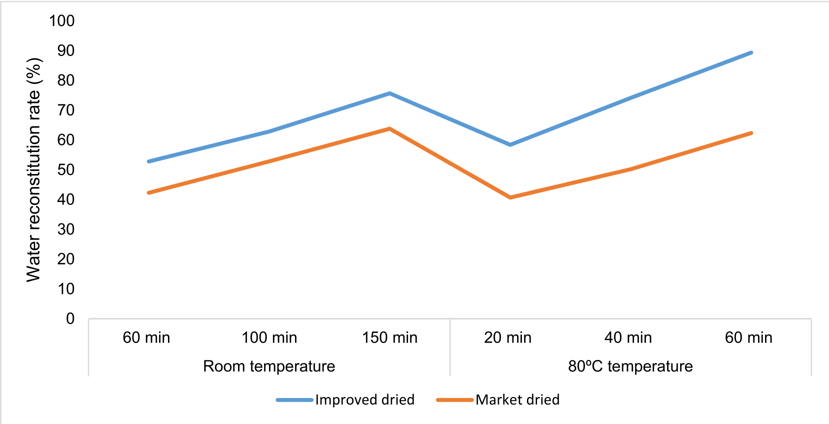

Fig. 2. Water reconstitution rate of improved and market-dried samples at different temperatures. The rehydration rate was analyzed at room temperature (28 °C) and 80 °C temperature. After a soaking duration (150 and 60 min) at both conditions, the rehydration rate was high in improved dry fish indicated in a blue-colored line graph. (For interpretation of the references to color in this figure legend, the reader is referred to the Web version of this article.)

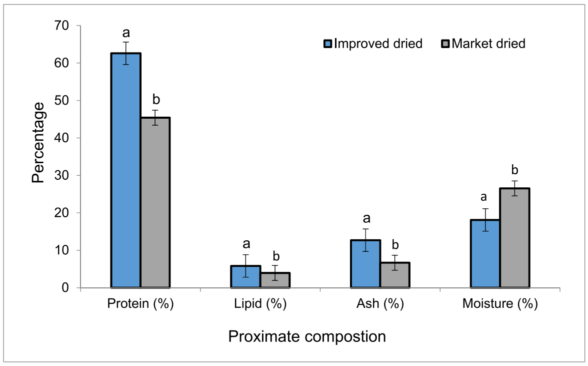

Fig. 3. Comparison of nutritional quality of improved and market-dried Bombay duck. Different superscripts (a, b) represent significant differences ($P < 0.05$) between means and the bar diagram is represented as vertical bar ± standard deviation. The crucial findings of the analysis were that improved dried fish contain a high amount of protein and lipid than dried fish from the market.

The overall quality of dried Bombay duck was excellent in sealed pack and refrigeration temperature and no infestation and broken pieces were found during the 4-month storage period (Table 3). In a sealed pack, only color changes occur at the 4th-month storage duration other qualities remained excellent. Dried fish stored in open air showed dark brown and greenish color; soft and total loss of elasticity in texture and no broken pieces were found during the storage period.

4.2. Changes in proximate composition during storage

Changes in the proximate composition of improved dried Bombay duck during storage were determined at three storage conditions such as in open air at atmospheric temperature, in a sealed pack at atmospheric temperature, and in the refrigerator, at 4 °C are presented in Table 4. The proximate composition (moisture, protein, lipid, and ash) of dried fish storage in the open air varied from 18.15 to 21.69%, 62.83–58.97%, 5.82–4.94%, and 12.22–10.99% respectively; in case of the sealed pack was varied from 18.15 to 19.05%, 62.83–61.23%, 5.82–5.12% and 12.22–11.29% respectively; in case of storage at 4 °C temperature was varied from 18.15 to 18.93%, 62.83–62.07%, 5.82–5.60% and 12.22–12.10% respectively.

4.3. Changes in chemical quality during storage

During 4 months of storage, the changes in TVB-N values (Fig. 4) were observed in small amounts in the first 2 months and then in the last 2 months. In the open air at room temperature, the TVB-N value was raised from 20.80 mg/100 g to27.05 mg/100 g; in the sealed pack at room temperature, it was25.35 mg/100 g, and at 4 °C temperature in the sealed pack it was found lowest 23.00 mg/100 g.

Table 3
Changes in organoleptic quality of improved dried Bombay duck at different storage conditions for 4 months duration. The key findings of this assessment were that dried fish stored in the open air at room temperature showed drastic changes in physical characteristics during storage than the other two conditions.

Storage duration	Ambient temperature (Open air)			Ambient temperature (Sealed pack)			4 °C temperature		
	Characteristics (color, odor, texture, presence of broken pieces)	Infestation	Overall quality	Characteristics (color, odor, texture, presence of broken pieces)	Infestation	Overall quality	Characteristics (color, odor, texture, presence of broken pieces)	Infestation	Overall quality
Freshly dried fish	Whitish, cream color; natural fishy odor; firm and elastic; no broken pieces	No infestation	Excellent	Whitish, cream color; natural fishy odor; firm and elastic; no broken pieces	No infestation	Excellent	Whitish, cream color; natural fishy odor; firm and elastic; no broken pieces	No infestation	Excellent
1 month	Light whitish to light browning; natural fishy odor; firm and some loss of elasticity; no broken pieces	No infestation	Excellent	Whitish, cream color; natural fishy odor; firm and elastic; no broken pieces	No infestation	Excellent	Whitish, cream color; natural fishy odor; firm and elastic; no broken pieces	No infestation	Excellent
2 months	Light browning; slight fishy odor; slight soft and loss of elasticity; no broken pieces	No infestation	Good	Whitish, cream color; natural fishy odor; firm and elastic; no broken pieces	No infestation	Excellent	Whitish, cream color; natural fishy odor; firm and elastic; no broken pieces	No infestation	Excellent
3 months	Browning; slight rancid odor; soft and loss of elasticity; no broken pieces	Some infestation	Good	Slight whitish, cream color; sight fishy odor; firm and elastic; no broken pieces	No infestation	Excellent	Whitish, cream color; natural fishy odor; firm and elastic; no broken pieces	No infestation	Excellent
4 months	Dark brown, greenish; rancid; soft, total loss of elasticity; no broken pieces	Presence of fungus	Poor	Light brown color; slight rancid; slight soft and elastic; no broken pieces	No infestation	Good	Whitish, cream color; natural fishy odor; firm and elastic; no broken pieces	No infestation	Excellent

Table 4
Changes in proximate composition of improved dried Bombay duck in three storage conditions at different storage times. The analysis was carried out according to dry matter basis. In open-air condition, moisture content was drastically changed which initiated changes in other components like protein and lipid. There were no noticeable changes that took place in dried fish stored at 4 °C temperature. The values in the table are presented as mean ± standard deviation.

Storage period	Ambient temperature (Sealed pack)				Ambient temperature (Open air)				4 °C temperature			
	Moisture (%)	Protein (%)	Lipid (%)	Ash (%)	Moisture (%)	Protein (%)	Lipid (%)	Ash (%)	Moisture (%)	Protein (%)	Lipid (%)	Ash (%)
Freshly dried fish	18.15 ± 0.41	62.83 ± 0.09	5.82 ± 0.32	12.22 ± 0.28	18.15 ± 0.41	62.83 ± 0.09	5.82 ± 0.31	12.22 ± 0.28	18.15 ± 0.41	62.83 ± 0.09	5.82 ± 0.32	12.22 ± 0.28
1 month	18.31 ± 0.16	62.49 ± 0.22	5.60 ± 0.16	12.04 ± 0.13	18.96 ± 0.20	61.04 ± 0.15	5.53 ± 0.18	12.02 ± 0.20	18.17 ± 0.22	62.50 ± 0.21	5.79 ± 0.20	12.20 ± 0.45
2 months	18.54 ± 0.19	62.12 ± 0.17	5.48 ± 0.12	11.89 ± 0.20	19.80 ± 0.19	60.53 ± 0.25	5.21 ± 0.28	11.80 ± 0.20	18.27 ± 0.14	62.27 ± 0.10	5.71 ± 0.11	12.18 ± 0.36
3 months	18.83 ± 0.31	61.86 ± 0.28	5.32 ± 0.19	11.65 ± 0.22	20.17 ± 0.24	59.83 ± 0.32	5.03 ± 0.23	11.31 ± 0.13	18.68 ± 0.14	62.19 ± 0.19	5.63 ± 0.09	12.15 ± 0.20
4 months	19.05 ± 0.13	61.23 ± 0.24	5.12 ± 0.19	11.29 ± 0.13	21.69 ± 0.31	58.97 ± 0.16	4.94 ± 0.22	10.99 ± 0.16	18.93 ± 0.12	62.07 ± 0.14	5.60 ± 0.13	12.10 ± 0.16

4.4. Changes in microbial quality during storage

The total viable count (TVC) changes of dried fish throughout the storage duration are presented in Table 5. Storage in the sealed pack at room temperature varied from 1.73 to 2.36 × 10^5 cfu/g, in the open air at room temperature was 1.73–2.92 × 10^5 cfu/g and at 4 °C temperature in a sealed pack was 1.73–1.92 × 10^5 cfu/g. Only *E. coli* was present in the dried sample stored in the open air at room temperature and *E. coli* and *Salmonella* both were absent at the rest of the two storage conditions.

4.5. Cost-benefit analysis

One of the major criteria of a new technology is its economic feasibility. Table 6 summarizes the cost-benefit analysis conducted on drying Bombay duck using an improved dryer. The analysis included both quantitative and qualitative factors to determine the economic feasibility of producing dried Bombay duck in the dryer under study. In this study, drying fish in the dryer showed a positive net present value of 1.3471 which depicted 34.71% of benefits.

5. Discussion

Dried *Harpodon nehereus* is known as a culinary delight among the coastal communities in Bangladesh while this type of processed food is very popular in the south-east Asian countries. The present study was conducted to determine the quality of improved dry against the market sample, and changes in quality and shelf-life aspects of dried *Harpodon nehereus* during storage. The similarities and dissimilarities in results between this study and previous studies conducted by other authors are also included in this section along with possible explanations of the results.

The organoleptic quality was determined based on color, odor, texture, insect infestation, and the presence and number of broken pieces in the final dried fish. The improved dried sample exhibited creamy and whitish color, characteristic odor, and firm and elastic texture with no evidence of insect infestation and broken pieces. On the other hand, dried fish collected from the local market exhibited grayish to brown discoloration with a soft texture and some insect infestation with many broken pieces. This is due to poor hygiene and inappropriate drying techniques and storage measures that make the market samples unacceptable for human consumption. It is

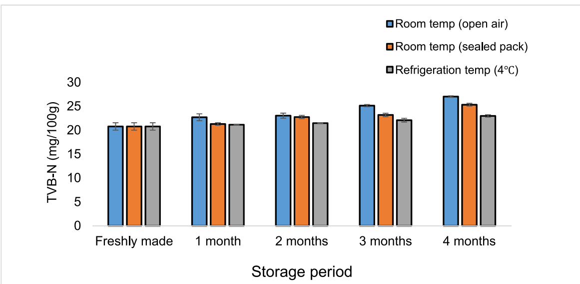

Fig. 4. Changing pattern of TVB-N content of dried Bombay duck at different storage conditions. In the bar diagram, the blue color bar indicates the changes in TVB-N content at room temperature in open-air conditions and it shows more rapid changes than the other two conditions. (For interpretation of the references to color in this figure legend, the reader is referred to the Web version of this article.)

Table 5
Changes in the microbial content of dried fish at different storage times and conditions. The values of TVC are presented as means ± standard deviation. Values in the same row followed by different letters (a, b and c) indicate a significant difference ($p < 0.05$).

Storage period	Ambient temperature (sealed pack)	Ambient temperature (open air)	4 °C temperature
	TVC (cfu/g)	TVC (cfu/g)	TVC (cfu/g)
Freshly dried	$(1.73 \pm 0.14 \times 10^5)^c$	$(1.73 \pm 0.14 \times 10^5)^c$	$(1.73 \pm 0.14 \times 10^5)^a$
1 month	$(1.82 \pm 0.11 \times 10^5)^c$	$(1.92 \pm 0.2 \times 10^5)^{bc}$	$(1.8 \pm 0.24 \times 10^5)^a$
2 months	$(1.97 \pm 0.09 \times 10^5)^{bc}$	$(2.16 \pm 0.19 \times 0^5)^b$	$(1.77 \pm 0.18 \times 10^5)^a$
3 months	$(2.17 \pm 0.09 \times 10^5)^{ab}$	$(2.79 \pm 0.16 \times 10^5)^a$	$(1.87 \pm 0.26 \times 10^5)^a$
4 months	$(2.36 \pm 0.25 \times 10^5)^a$	$(2.92 \pm 0.03 \times 10^5)^a$	$(1.92 \pm 0.06 \times 10^5)^a$

Table 6
Cost-benefit analysis of dried Bombay duck production in the improved dryer. All costs incurred to dry 50 kg of raw fish during the study is shown here. The values shown here are in the Bangladesh currency (Taka, BDT).

Sample	Parameters	Values
Dried Bombay duck	**Particulars**	**Cost in Bangladesh currency (BDT)**
	Electricity (fan, light)	300.00
	Raw fish (50 kg)	6200.00
	Labor	250.00
	Packaging	100.00
	Marketing	100.00
	Other miscellaneous	155.00
	Total cost	7105.00
	Total production	11.25 kg
	Per kg production cost	631.00
	Benefits	
	Selling price (per kg dried fish)	850.00
	Net benefits (NB/kg)	219.00
	Cost-Benefit Ratio = Benefits/Total costs)	850/631 = 1.3471 (34.71% profit)

reported that hardness and brittleness increase with decreasing excessive moisture content during drying, leading to making the textural attributes of dried products unacceptable for human consumption [26]. The brittleness of the market samples is due to over-drying as it is reported that excessive drying leads to the brittleness of the product making them less palatable [27]. Since the dried samples produced in the newly developed fish dryer exhibited excellent quality in the hedonic test, it indicates the importance of proper drying with optimum conditions and duration with appropriate hygiene and storage measures.

The water reconstitution rate for improved dried fish was found higher at 80 °C temperature after 60 min and at room temperature after 120 min which was significantly ($p < 0.05$) higher than the market sample. This indicates that the increase in time and temperature increases water reconstitution capacity through opening the capillary structure of dried fish muscle [28]. A previous report suggested that fish dried in a solar-LPG hybrid dryer exhibited a significant increase in rehydration ratio within the first hour of soaking in water [29], which is similar to the findings of the present study. Therefore, a close relationship was observed between the rehydration ability and physical changes with drying methods. Inappropriate drying with excessive temperature and relative humidity is associated with poor rehydration ability [14]. Therefore, the poor rehydration ability of the market-dried sample was due to irreversible changes in protein structure as well as severe damage to cellular surface structure.

The moisture content of the improved dried sample was found lower than the market-dried sample. Numerous studies suggested that if the moisture content in the dried fish remains less than 20%, it helps to extend the shelf life by inhibiting the growth of most microorganisms [13,30]. The protein, lipid and minerals contents were found significantly ($p < 0.05$) higher in improved dried samples indicating their higher nutritional value and palatability. Previous reports suggested that optimum drying conditions and shorter drying times increase fish protein content [31]. The high protein content in the dried fish produced by the improved drying method therefore helps to prevent the destruction of nutritional properties during drying.

Total volatile base nitrogen (TVB-N) is considered an important criterion in the freshness test of fish and fishery products. A higher TVB-N value indicates a poor-quality product which unfit for human consumption. This test combinedly measures the trimethylamine, dimethylamine, ammonia, and other volatile bases nitrogenous compounds. According to the European Union directive on fish hygiene, if there is any doubt about the freshness of fish, TVB-N must be used as a chemical analysis by the inspector [32]. Another study reported that the TVB-N value for dried fish is 35–40 mg/100 g considered an upper acceptable limit, and if the value exceeds this limit the dried fish are unfit for human consumption [33]. The value of TVB-N of the market-dried Bombay duck (86.73 mg/100 g) exceeds the highest acceptable limit might be due to a variety of chemical reactions and breakdown of protein during the drying process and remaining in the market for a long time. On the other hand, the TVB-N values were under the control limit in the improved dried fish which was significantly different from the market-dried products ($p < 0.05$). This highlights the efficiency of the newly developed dryer and the quality of the dried fish produced by it.

The acceptable limit recommended for TVC of processed and dried fish is no more than 10^6 cfu/g, as well as not containing any pathogenic bacteria hazardous to human health [34]. The total viable count (TVC) of the improved dried and the market dried sample was not significantly different ($p > 0.05$) and was found within the acceptable limit. It is plausible that drying reduced the microbial load in Bombay duck where the raw sample had 3.6 × 106 CFU/g TVC, which was reduced to 2 × 104 CFU/g in the dried fish which is consistent with the previous report where a similar phenomenon occurred during drying [35]. Among the pathogenic bacteria, *Salmonella* sp. is only detected in market-dried samples, which indicates poor hygiene status or cross-contamination during processing or distribution to the market. Since there was no *Salmonella* detected in the improved dried fish, it indicates that the dried fish produced in the improved dryer was of superior quality and indicates the efficiency of the newly developed fish dryer.

Storage of dried fish is an important aspect since the produced dried fish may soon lose its original quality due to lack of proper storage conditions, shelf life of the improved dried products was evaluated at three different storage conditions and the results revealed that the overall quality of dried Bombay duck was excellent in the sealed pack at refrigeration temperature and there was no evidence of insect infestation and broken pieces during the 4-month storage period. It indicated that using lower temperatures with moisture and oxygen-free packs during storage can preserve the physical quality of dried fish for an extended period. In sealed packs at an atmospheric temperature, only slight color changes occurred at the 4th-month storage duration whereas other qualities remain excellent. In sealed pack condition color change may be happened due to lipid oxidation in the presence of oxygen inside the package. Dried fish stored in open air showed comparatively good quality up to 1 month of storage period. But after 1 month, the color, texture, odor and other quality parameters like protein, lipid, and moisture degraded significantly ($p < 0.05$) which made it unacceptable for human consumption due to environmental influences. Moreover, insect infestation was also found at the 4th-month storage condition as it was easily prone to insect infestation. In open air, dried fish easily retained moisture from the environment and the presence of oxygen caused oxidation during storage which accelerated protein and lipid content degradation. The breakdown of lipids results in the production of high number of poly-unsaturated fatty acids *viz.* peroxides, aldehydes, ketones, and free fatty acids that can develop an off-smell in the finished product [36]. Besides this, the higher TVB-N values indicated the chemical breakdown of nutrients [37]. From these three storage conditions, the higher microbial content was exhibited in open air at room temperature. It is presumed that dried fish stored with low moisture content stored without protection under high humidity can be the vehicle for most of the types of bacteria responsible for food spoilage [27]. The significant increase in moisture conditions, microbial propagation, oxidation of lipids and insect infestation finally made the products unacceptable for consumption [38]. Considering these findings, the present study thus reveals that storage at refrigeration temperature in sealed packs is the best suitable method for the dried fish.

A major criterion of a new technology is its economic feasibility so that it can be affordable for everyone. The cost-benefit analysis from the present study indicates that this improved fish dryer is cost-effective, and bulk drying can be performed with a satisfactory margin of profit. The improved dryer could overcome the drawbacks of insect infestation, inconsistent temperature, excessive drying and brittleness of dried fish at a low-cost and therefore, could be affordable by small-scale as well as large-scale fish processors, which indicates the suitability of this dryer in the fish drying community.

6. Conclusions

Overall, our study depicted that dried fish from the developed fish dryer was superior to traditionally dried market samples in terms of organoleptic quality, nutritional values, insect infestation, presence of pathogenic microbes, and hazardous chemicals which highlights the suitability of the newly developed fish dryer. Since the quality control of the finished product is an integral part of the distribution and marketing channel, we determined that storage at refrigeration temperature in the sealed pack is the best suitable method to enhance the shelf life for a long time. Our findings will be a valuable tool for the fish processors to ease the fish drying process and storage that will enable them to commercially supply good quality dried *Harpodon nehereus* in the market chain.

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Data availability statement

All data associated with the study has been included in the supplementary file of this manuscript and can also be obtained from the corresponding author upon reasonable request.

CRediT authorship contribution statement

Nafisa Nawar Tamzi: Writing – original draft, Visualization, Methodology, Investigation, Formal analysis, Data curation. **Farjana Ferdous Rozee:** Methodology, Data curation. **Tahsin Sultana:** Methodology, Data curation. **Md Faisal:** Writing – review & editing, Formal analysis. **Mohammed Nurul Absar Khan:** Writing – review & editing, Investigation. **Subrata Kumar Ghosh:** Writing – review & editing, Visualization, Supervision, Software, Project administration, Methodology, Investigation, Funding acquisition, Formal analysis, Conceptualization.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supplementary data

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