



Evaluation of Different Drying Methods on Shelf-life Quality of Mrigal *Cirrhinus mrigala* (Hamilton, 1822)

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Abstract

Smoking and sun-drying are the standard methods practised for fish drying in Nepal. Solar and hybrid-solar drying methods were evaluated along with the smoking and sun-drying methods for shelf-life quality of dried mrigal *Cirrhinus mrigala* (Hamilton, 1822). The moisture content of fish increased significantly ($P < 0.05$) from 0 to 30 days of storage in all the drying methods. There was no significant decrease ($P > 0.05$) in the crude protein content of dried fish in all the drying methods during 30 days of storage except in hybrid-solar dried fish. The crude fat content decreased significantly ($P < 0.05$) in all the drying methods from 0 to 30 days of storage except in smoke-dried fish. The pH value, free fatty acid (per cent oleic acid) and total plate count (cfu.g⁻¹) were within the permissible range in all the drying methods. The increment of peroxide value in smoking and hybrid-solar dried samples was within the permissible range, and those of sun and solar dried samples were above the range. Based on the results of short drying hour and permissible peroxide value, smoking and hybrid-solar drying methods were selected for experiment to verify the quality of the dried fish stored for 90 days in two mountain districts (Rasuwa and Jumla). The results of 90 days storage experiment were similar to the previous results of smoking and hybrid-solar dried fish for 30 days storage. The present study suggests that mrigal fish dried by smoking and hybrid-solar drying methods are safe to consume for 90 days.

Keywords: dried-fish, smoking, hybrid-solar, nutrient quality, storage time

Introduction

Dried fish are traditional products commonly available in Nepal. It is used as a substitute when fresh fish is not readily available (Bille and Shemkai, 2006; Oyero et al., 2007; Chukwu and Shaba, 2009; Oduor-Odote et al., 2010). Dried fish is used for human food, religious and festivals item, aquaculture and poultry feed, instant noodle ingredient, and flower nurseries fertiliser. The hygienically processed dried fish retains its nutritional quality better when compared to fresh fish (Faruque et al., 2012). It is believed that dried walking catfish *Clarias batrachus* (Linnaeus, 1758) can cure disease like rickets in human (Pradhan et al., 2017). Small-sized fish species such as rosy barb *Puntius conchonius* (Hamilton, 1822), large razorbelly minnow *Oxygaster bacaila* (Hamilton, 1822), climbing perch *Anabas testudineus* (Bloch, 1792), mud

perch *Nandus nandus* (Hamilton, 1822) and Assamese snakehead *Channa stewartii* (Playfair, 1867) are dried in the sun more prominently in Terai region of Nepal (Shrestha, 1999). Fish drying by smoking is a standard traditional activity widely used in different parts of the country. Over the last few years, commercially smoked mrigal *Cirrhinus mrigala* (Hamilton, 1822) is available in the markets, which has a high consumer demand in different parts of Nepal. The traditional methods commonly used for preserving fish are salting/brining, sun-drying and smoking. Enhanced shelf-life and lightness of the dried fish makes it easy to transport to distant markets where fresh fish are scarcely available (Oduor-Odote et al., 2010; Darvishi et al., 2013). Fish is rarely eaten raw and usually cooked in different ways before consumption. Cooking (boiling, baking, roasting, frying and grilling) and preservation (freezing, sun-drying, solar drying

and smoking) techniques can alter the proximate composition and nutritional quality of fish (Castrillon et al., 1997). It is not easy to provide the increasing quantities of food required for the growing world population and produce quality food products for a healthy life. Dried fish products have reduced oil and moisture content and more protein content on weight basis (FAO, 1989). Improper preservation techniques may cause significant loss in dried fish quantity and protein quality (Wilman et al., 1998). Improperly or inadequately dried fish could reabsorb moisture and develop favourable condition for bacterial and mold growth. Nutritional and hygienic quality of dried mrigal available at different market outlets and processing sites of Nepal were found to be less hygienic (Pradhan et al., 2018). The quality of dried fish is always ignored during different stages of processing, storage and marketing (Gupta and Samuel, 1985). There is a lack of information on nutrient quality, cause and level of deterioration of dried fish available in Nepal.

Smoking is one of the oldest and simplest methods of fish preservation as it does not require any expensive equipment and well-trained manpower (Olayemi et al., 2011). The process of smoking is not affected by the climatic condition as well as the smoked fish has a distinctive taste and aroma. Sun-drying is a traditional practice of fish preservation which is practised in many south and south-east Asian countries. In the Terai region of Nepal, fish are sun-dried by spreading on the mat during September and October. Rosy barb *P. conchonius* comprises 75 %, and the remaining 25 % are the sun-dried Assamese snakehead *C. stewartii* and Asian needlefish *Xenentodon cancila* (Hamilton, 1822). Open-air sun-drying is a common practice in many developing countries. However, there are many problems such as space availability, labour-intensive, contamination with dust and sand, insect infestation, and eaten by birds, animals and rodents. Hence, solar dryer machine is the alternative for open-air sun drying.

Use of solar radiation and energy on fish drying has become more than necessary in the present context as fish smoking demands a huge quantity of fuel-wood, causing pressure on the forest resources. Solar drying is an improved method of sun-drying which consists of closed-system minimising some of the limitations of open sun-drying. Solar drying works only in daylight period and to overcome this discrepancy hybrid-solar dryer has been developed. The hybrid-solar dryer operates with solar energy and biomass energy (Saravanan et al., 2014; Dhanushkodi et al., 2015). The solar dryer and hybrid-solar dryer were considered for this study after taking into consideration the need to improve fish processing and preservation. Hence, this study aims to evaluate different drying methods on shelf-life quality of dried-fish stored at room temperature in mountain regions of the country.

Materials and Methods

Two experiments were conducted for shelf-life quality evaluation of dried-fish. Experiment 1: Drying fish using different methods was conducted at the Fisheries Research Division, Godawari from November 2016 to December 2016. Experiment 2: Shelf-life quality validation of dried fish using two best drying methods obtained from experiment 1, were conducted from August 2017 to November 2017 at two mountain districts of Nepal.

Experiment 1

Sample collection and cleaning

Fresh 50–60 g of *C. mrigala* were bought from the Lagankhel market of Lalitpur district. The fish were kept in ice and transported to Fisheries Research Division (FRD), Godawari, Nepal. On arrival at the laboratory, damaged fish were discarded, and the remaining fish were gutted, beheaded, gills removed, split opened vertically, and washed properly with tap water.

Drying of processed samples

The cleaned fish were dried using one of the four drying methods: 1) sun-drying (SUD) (Fig. 1), 2) solar drying (SOD) (Fig. 2), 3) smoke drying (SMD) (Fig. 3), and 4) hybrid-solar drying (HSD) (Fig. 4). There were four replicates for each drying method. A total of 76 fish (average body weight of 55 g) were used in each replicate. Bodyweight (g) of fish was recorded every day in each treatment. Temperature (°C) of drying fish was recorded by keeping a thermometer in the drying racks. After completion of drying, the fish was left to cool and subsequently packed in plastic bags and stored at room temperature for further analysis.

Proximate, chemical and microbial analysis

The samples were subjected to proximate, chemical and microbial analysis at the Public Laboratory, Lalitpur. The proximate composition of the samples was determined following standard AOAC methods (AOAC, 2005). Moisture was determined by drying at 105 °C to a constant weight. Nitrogen was estimated by the Kjeldahl method (2200 Kjeltex, Foss Tecator, Sweden) and crude protein was estimated by multiplying the per cent nitrogen by 6.25. The ether extract was measured by the solvent extraction method (1045 Soxtec, Tecator, Sweden) using diethyl ether (boiling point 40–60 °C) as a solvent. A digital pH meter was used to measure pH. Peroxide value (mEq O₂.kg⁻¹ of fat) was determined using the method as described in AOAC (2005). Total plate count (cfu.g⁻¹) was determined by the most probable number (MPN) technique and pour plate method for enumeration of mold following APHA (1992).



Fig. 1. Sun-drying of *Cirrhinus mrigala*.



Fig. 2. Smoking of *Cirrhinus mrigala*.



Fig. 3. Solar drying of *Cirrhinus mrigala*.



Fig. 4. Hybrid-solar drying of *Cirrhinus mrigala*.

Statistical analysis

All the data were presented as mean \pm standard error (SE). The differences between the means of moisture content, crude protein content, crude fat content, peroxide value (PV), total plate count (TPC), were tested by one way analysis of variance (ANOVA). Duncan's multiple range test (DMRT) was applied to determine the significance of differences between the means. All statistical tests were performed using the statistical package SPSS (Version 20.0). Comparisons were made at 5 % probability.

Experiment 2

Based on the results of experiment 1, the best two drying methods, i.e., smoking and hybrid-solar drying, were selected for shelf-life storage quality verification over a 90 days period in the mountainous regions of the country. Samples were subjected to smoke-drying and hybrid-solar drying. There were four replicates in each drying method. Bodyweight (g) of fish was recorded every day in each treatment. Temperature ($^{\circ}\text{C}$) of drying fish was recorded by keeping a thermometer in drying racks and drying tray. After completion of drying, the fish were left to cool. The cooled, dried fish samples were packed in

plastic bags and sent to two sites in Dhunche of Rasuwa, and Ghuthi Chour of Jumla which are potential markets in the mountain region of Nepal for dried-fish where fresh fish are rarely available. The verification trial was carried out for 90 days whereby the samples were analysed at a monthly interval for proximate, microbial and chemical analysis.

Results

Experiment 1

Drying methods and moisture removal

The drying temperature, drying period and the initial and final moisture (%) of mrigal processed by different drying methods are presented in Table 1. The time required to dry the fish by sun-drying, smoking, solar drying and hybrid-solar drying was 60.0 ± 4.1 h, 12.8 ± 1.1 h, 74.3 ± 6.1 h, and 49.3 ± 0.7 h, respectively. The minimum time (12.8 ± 1.1 h) required to dry the fish was by smoking and the maximum time (74.3 ± 6.1 h) was by solar drying. The moisture removal of fish by sun-drying, smoking, solar drying and hybrid-solar drying was 73.7 ± 0.8 %, 77.0 ± 1.0 %, 73.8 ± 0.6 % and 72.8 ± 0.4 %, respectively. Higher moisture removal

(77.0 ± 1.0 %) was by smoke drying and the least (72.8 ± 0.4 %) by hybrid-solar drying.

The effect of all the drying methods on fish biomass is presented in Figures 5, 6, 7 and 8. In sun-drying, the biomass of fish declined rapidly in the first 25 h of

drying (Fig. 5). From 25 to 38 h the biomass of fish declined slowly, again and after 38 h it decreased sharply to 47 h. After 47 h the decline in biomass of fish slowed down and drying was completed in 60 h.

Table 1. Results on the drying temperature, drying period, initial and final moisture of mrigal *Cirrhinus mrigala* exposed to different drying methods (mean ± SE)(n = 4).

Drying method	Drying temperature (°C)	Drying period (h)	Initial moisture (%) of fish	Final moisture (%) of fish	Moisture removal (%) from fish
Sun-drying	17-32	60.0 ± 4.1	74.0 ± 0.0	26.3 ± 0.2	73.7 ± 0.8
Smoking	26-90	12.8 ± 1.1	74.0 ± 0.4	23.0 ± 0.1	77.0 ± 1.0
Solar drying	26-64	74.3 ± 6.1	74.0 ± 0.2	26.2 ± 0.0	73.8 ± 0.6
Hybrid-solar drying	22-80	49.3 ± 0.7	74.0 ± 0.1	27.2 ± 0.4	72.8 ± 0.4

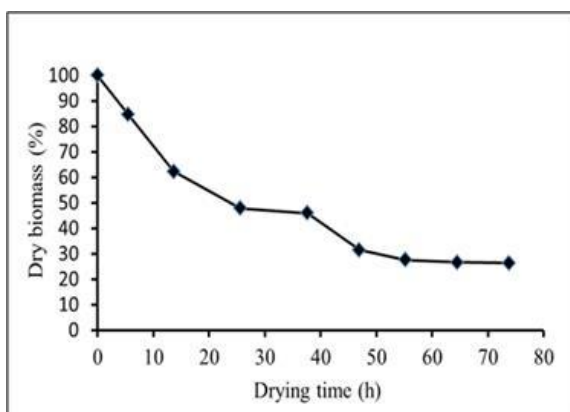


Fig. 5. Decrease in dry biomass (%) of mrigal *Cirrhinus mrigala* during sun-drying.

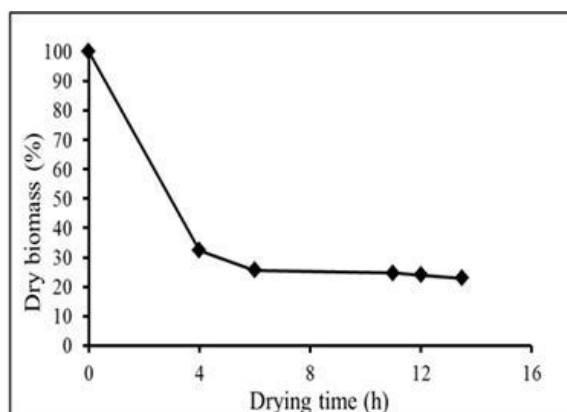


Fig. 6. Decrease in dry biomass (%) of mrigal *Cirrhinus mrigala* during smoking.

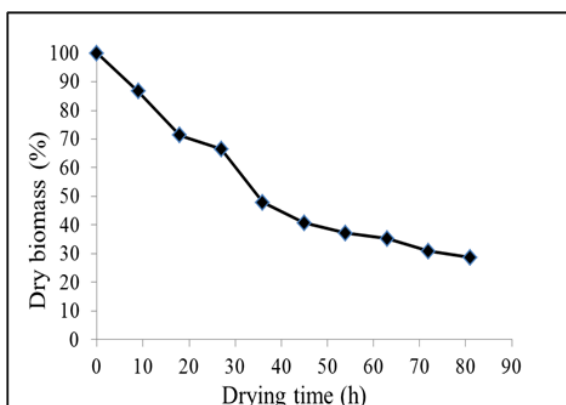


Fig. 7. Decrease in dry biomass (%) of mrigal *Cirrhinus mrigala* during solar-drying.

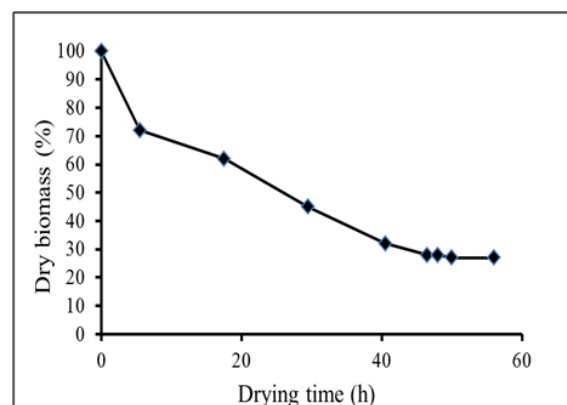


Fig. 8. Decrease in dry biomass (%) of mrigal *Cirrhinus mrigala* during hybrid-solar drying.

In smoking, the biomass of fish declined sharply in the first 4 h of drying (Fig. 6), and the drying was completed in 13 h. In solar drying, the biomass of fish declined rapidly in the first 18 h of drying (Fig. 7). From 18 to 27 h the biomass of fish declined slowly, and after 27 h it declined sharply up to 36 h. After 36 h the decline in biomass of fish slowed down and the drying was completed in 74 h. In hybrid-solar drying, the biomass of fish declined rapidly up to 40 h of drying (Fig. 8). After 40 h the decline in biomass of fish slowed down in all treatment and drying was completed in 49 h.

Nutrient quality and microbial load

The moisture content of dried fish processed in all the drying methods increased from 0 to 15 days and 15 to 30 days, but the increment was non-significant ($P > 0.05$) (Fig. 9). However, the increase was significant ($P < 0.05$) between 0 to 30 days of storage.

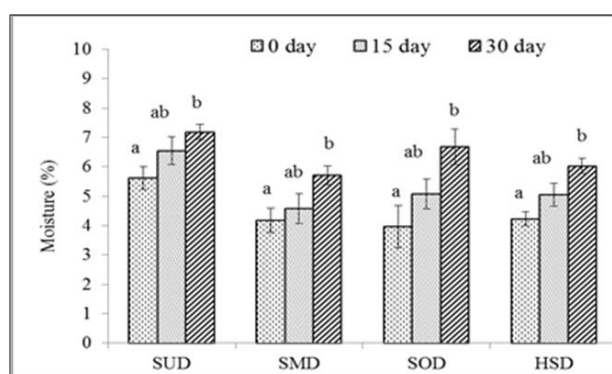


Fig. 9. Moisture content of sun-dried (SUD), smoked-dried (SMD), solar-dried (SOD) and hybrid-solar dried (HSD) mrigal *Cirrhinus mrigala* at 0, 15 and 30 days of storage.

There was no significant ($P > 0.05$) difference in decrease in the crude protein content of dried-fish processed in all the drying methods during 30 days of storage except in hybrid solar-dried fish (Table 2).

A reduction in crude fat content during 30 days of the storage period in fish processed by different drying methods is shown in Table 3. There was no significant ($P > 0.05$) decrease of crude fat content in sun-dried and smoke-dried fish from 0 to 15 days, but a significant decrease was ($P < 0.05$) from 0 to 30 days of storage except in smoke-dried fish. The decrease

of the crude fat content from 15 to 30 days of storage period was not significant ($P > 0.05$) in all the drying methods.

The peroxide value (PV) of sun-dried and solar-dried fish increased from 39.5 ± 1.7 to 80.3 ± 6.2 , and 35.7 ± 2.1 to 61.3 ± 21.2 mEq $O_2.kg^{-1}$ of fat respectively and those values were above the permissible range (Table 4). The increase of PV in smoke-dried (2.5 ± 0.1 to 2.8 ± 0.2 mEq $O_2.kg^{-1}$) and hybrid-solar dried (3.5 ± 1.4 to 8.3 ± 6.6 mEq $O_2.kg^{-1}$) fish were within the permissible range ($10 - 20$ mEq $O_2.kg^{-1}$ of fat) during 30 days of storage.

The free fatty acid (FFA) (% oleic acid) content of dried fish samples at 30 days of storage is presented in Table 5. The FFA of sun-dried, smoke-dried, solar-dried and hybrid-solar dried fish increased from 1.03 ± 0.26 to 1.43 ± 0.11 , 0.35 ± 0.02 to 0.42 ± 0.04 , 0.59 ± 0.03 to 0.82 ± 0.03 , and 0.31 ± 0.00 to 0.44 ± 0.05 , respectively. The increase was significant ($P < 0.05$) in solar -dried and hybrid-solar dried fish from 0 to 30 days of storage. The FFA content of sun-dried fish was significantly higher ($P < 0.05$) than the fish dried by the other three methods. The FFA of solar-dried fish was significantly ($P < 0.05$) lower than sun-dried and higher than smoked and hybrid-solar dried fish. But the FFA values of dried fish by all four methods were within the permissible range (0.5–1.5 % oleic acid).

The pH of dried fish processed by all four methods is presented in Table 6. The pH of dried fish increased from 5.5 to 5.7, 5.6 to 5.8, 5.3 to 5.5 and 5.5 to 5.8 in sun-dried, smoke-dried, solar-dried and hybrid-solar dried fish, respectively. The dried fish products from all drying methods were within the acceptable range of below pH 6.8.

The TPC (cfu.g⁻¹) of fish processed by different drying methods are presented in Table 7. All TPC values increased with storage time but were within the permissible level of below 1×10^5 cfu.g⁻¹.

Mold was found only on the 30th day in sun-dried ($5.0 \times 10^1 \pm 8.7 \times 10^1$ cfu.g⁻¹), smoke-dried ($5.0 \times 10 \pm 1.0 \times 10^1$ cfu.g⁻¹) and solar-dried fish ($2.5 \times 10^1 \pm 5.0 \times 10^0$ cfu.g⁻¹) and no mold was seen during the whole storage period in hybrid-solar dried fish.

Table 2. Percentage of crude protein in dried mrigal *Cirrhinus mrigala* at 0, 15 and 30 days of storage after undergoing different drying methods (mean \pm SE)(n = 4).

Day	Sun-dried fish	Smoke-dried fish	Solar-dried fish	Hybrid-solar dried fish
0	60.3 \pm 0.6 ^a	63.3 \pm 0.5 ^a	60.9 \pm 0.7 ^a	60.5 \pm 0.3 ^b
15	59.9 \pm 0.4 ^a	62.9 \pm 0.3 ^a	59.1 \pm 0.9 ^a	59.1 \pm 0.7 ^{ab}
30	58.9 \pm 0.7 ^a	62.2 \pm 0.5 ^a	58.6 \pm 0.6 ^a	58.5 \pm 0.7 ^a

Different superscript letters within the same column are significantly different at $P < 0.05$.

Table 3. Percentage of crude fat content of dried mrigal *Cirrhinus mrigala* at 0, 15 and 30 days of storage after undergoing different drying methods (mean \pm SE)(n = 4).

Day	Sun-dried fish	Smoke-dried fish	Solar-dried fish	Hybrid-solar dried fish
0	2.8 \pm 0.20 ^b	2.5 \pm 0.13 ^a	3.6 \pm 0.27 ^b	4.4 \pm 0.42 ^b
15	2.5 \pm 0.04 ^{ab}	2.4 \pm 0.14 ^a	2.7 \pm 0.13 ^a	2.5 \pm 0.14 ^a
30	2.2 \pm 0.10 ^a	2.3 \pm 0.16 ^a	2.3 \pm 0.10 ^a	2.3 \pm 0.13 ^a

Different superscript letters within the same column are significantly different at $P < 0.05$.

Table 4. Peroxide value (PV)(mEq O₂.kg⁻¹ of fat) of dried mrigal *Cirrhinus mrigala* at 0, 15 and 30 days of storage after undergoing different drying methods (mean \pm SE)(n = 4).

Day	Sun-dried fish	Smoke-dried fish	Solar-dried fish	Hybrid-solar dried fish
0	39.5 \pm 1.7 ^a	2.5 \pm 0.1 ^a	35.7 \pm 2.1 ^a	3.5 \pm 1.4 ^a
15	42.3 \pm 2.8 ^a	2.6 \pm 0.0 ^a	40.6 \pm 23.5 ^a	4.3 \pm 1.4 ^a
30	80.3 \pm 6.2 ^b	2.8 \pm 0.2 ^a	61.3 \pm 21.2 ^b	8.3 \pm 6.6 ^b

Different superscript letters within the same column are significantly different at $P < 0.05$.

Table 5. Free fatty acid (FFA)(per cent oleic acid) of dried *Cirrhinus mrigala* at 0, 15 and 30 days of storage after undergoing different drying methods (mean \pm SE)(n = 4).

Day	Sun-dried fish	Smoke-dried fish	Solar-dried fish	Hybrid-solar dried fish
0	1.03 \pm 0.26 ^a	0.35 \pm 0.02 ^a	0.59 \pm 0.03 ^a	0.31 \pm 0.00 ^a
15	1.28 \pm 0.11 ^a	0.38 \pm 0.03 ^a	0.61 \pm 0.03 ^a	0.32 \pm 0.01 ^a
30	1.43 \pm 0.11 ^a	0.42 \pm 0.04 ^a	0.82 \pm 0.03 ^b	0.44 \pm 0.05 ^b

Different superscript letters within the same column are significantly different at $P < 0.05$.

Table 6. pH of dried *Cirrhinus mrigala* processed at 0, 15 and 30 days of storage after undergoing different drying methods (mean and range)(n = 4).

Day	Sun-dried fish	Smoke-dried fish	Solar-dried fish	Hybrid-solar dried fish
0	5.5(5.2-5.7)	5.6(5.6-5.7)	5.3(5.2-5.5)	5.5(5.4-5.7)
15	5.6(5.3-5.8)	5.8(5.7-6.2)	5.4(5.2-5.5)	5.7(5.4-6.1)
30	5.7(5.4-6.2)	5.8(5.7-5.9)	5.5(5.4-5.8)	5.8(5.7-6.0)

Table 7. TPC(cfu.g⁻¹) content of dried *Cirrhinus mrigala* at 0, 15 and 30 days of storage after undergoing different drying methods. (mean \pm SE)(n = 4).

Day	Sun-dried fish	Smoke-dried fish	Solar-dried fish	Hybrid-solar dried fish
0	2.3 \times 10 ² \pm 1.3 \times 10 ² ^a	2.3 \times 10 ² \pm 5.3 \times 10 ¹ ^a	2.2 \times 10 ² \pm 1.4 \times 10 ^{2a}	1.2 \times 10 ² \pm 1.6 \times 10 ^{2a}
15	3.6 \times 10 ² \pm 1.3 \times 10 ² ^a	2.8 \times 10 ² \pm 7.8 \times 10 ¹ ^a	3.0 \times 10 ² \pm 1.1 \times 10 ^{2ab}	3.1 \times 10 ² \pm 1.2 \times 10 ^{2ab}
30	4.4 \times 10 ² \pm 1.9 \times 10 ² ^a	3.0 \times 10 ² \pm 8.2 \times 10 ¹ ^a	5.0 \times 10 ² \pm 7.5 \times 10 ^{1b}	3.4 \times 10 ² \pm 9.9 \times 10 ^{1b}

Different superscript letters within the same column are significantly different at $P < 0.05$.

Experiment 2

Results showed a trend of increasing moisture content with storage period in both smoke-dried and hybrid-solar dried samples. Smoke-dried fish samples showed relatively higher moisture increasing trend compared to hybrid-solar dried samples (Fig. 10).

The trend of crude protein content decreased with storage period in both smoke-dried and hybrid-solar dried fish. Smoke-dried fish samples showed a significant difference in crude protein decreasing trend compared to hybrid-solar dried samples (Fig. 11).

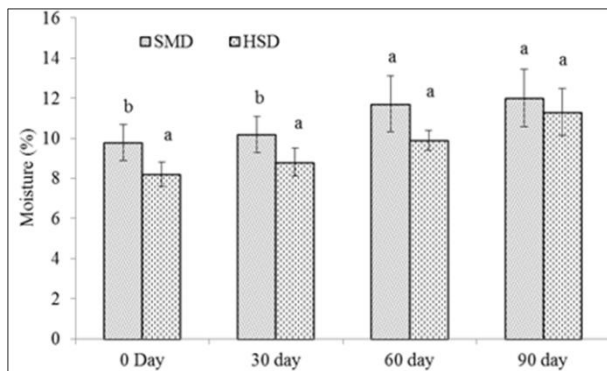


Fig. 10. Moisture (%) of smoke-dried (SMD) and hybrid-solar dried (HSD) *Cirrhinus mrigala* at 0, 30, 60 and 90 days of the storage period.

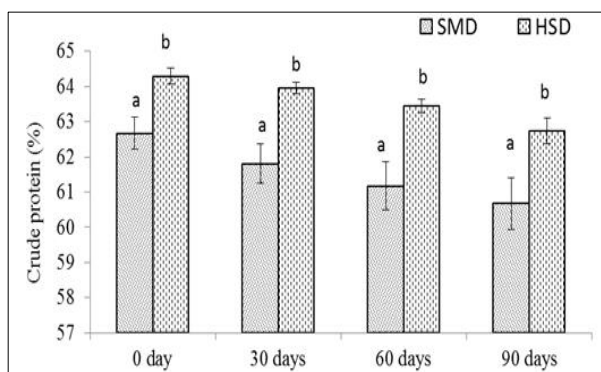


Fig. 11. Crude protein (%) of smoke-dried (SMD) and hybrid-solar dried (HSD) *Cirrhinus mrigala* at 0, 30, 60 and 90 days of the storage period.

The trend of crude fat content decreased with storage period in both smoke-dried and hybrid-solar dried fish. Smoke-dried fish samples showed relatively higher fat decreasing trend compared to hybrid-solar dried samples (Fig. 12).

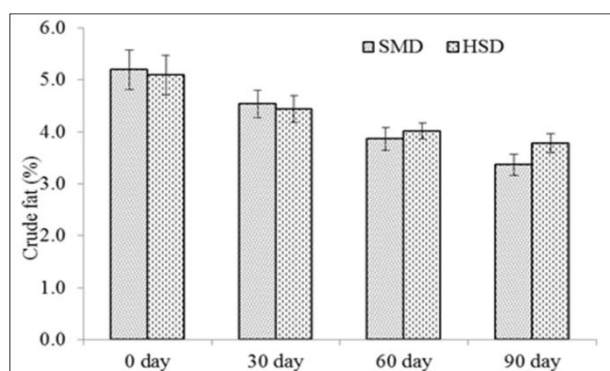


Fig. 12. Crude fat (%) of smoke-dried (SMD) and hybrid-solar dried (HSD) *Cirrhinus mrigala* at 0, 30, 60 and 90 days of the storage period.

The trend of peroxide value (PV) increased with storage days in both smoked-dried and hybrid-solar dried fish. However, the increase in PV of samples

was not significant in smoke-dried fish (Fig. 13). But the hybrid-solar dried samples showed significantly higher PV with duration of storage.

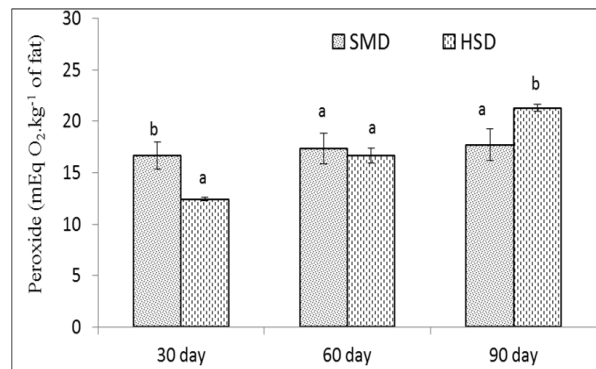


Fig. 13. Peroxide value (PV) (mEq O₂.kg⁻¹ of fat) of smoke-dried (SMD) and hybrid-solar dried (HSD) *Cirrhinus mrigala* at 30, 60 and 90 days of the storage period.

The FFA (per cent oleic acid) values showed a significant increase ($P < 0.05$) in both smoked samples and hybrid-solar dried samples with each storage days (Fig. 14).

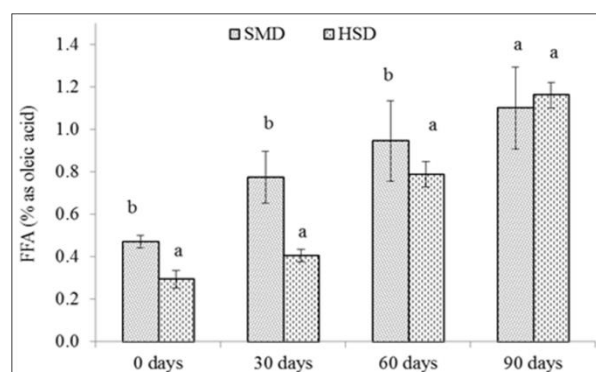


Fig. 14. Free fatty acid (per cent oleic acid) of smoke-dried (SMD) and hybrid-solar dried (HSD) *Cirrhinus mrigala* at 0, 30, 60 and 90 days of the storage period.

The values of pH of dried fish processed by both smoking and hybrid-solar drying methods were within the acceptable range of below pH 6.8 (Table 8).

Table 8. pH of dried *Cirrhinus mrigala* processed by smoking and hybrid-solar drying during 90 days of storage (mean and range)(n = 4).

Day	Smoked-dried fish	Hybrid-solar dried fish
0	6.2 (6.2-6.3)	6.2 (6.2-6.4)
30	6.4 (6.3-6.6)	6.5 (6.3-6.7)
60	6.6 (6.4-6.9)	6.7 (6.5-6.9)
90	6.7 (6.4 - 7.1)	6.8 (6.6 - 7.0)

The increment in TPC content of fish dried by hybrid-solar dryer was significantly higher ($P < 0.05$) than smoke-dried samples at all storage days (Fig. 15).

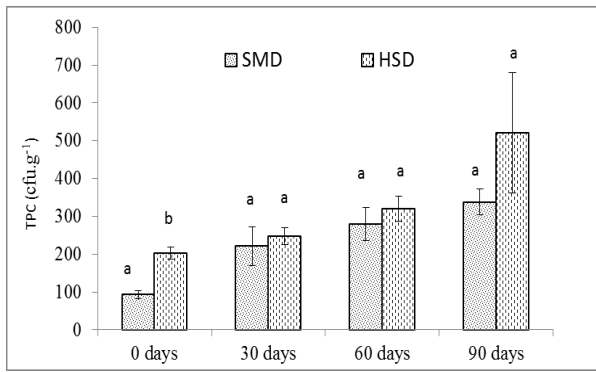


Fig. 15. Total plate count (TPC)(cfu.g⁻¹) of smoke-dried (SMD) and hybrid-solar dried (HSD) *Cirrhinus mrigala* at 0, 30 60 and 90 days of the storage period.

Discussion

Sun-drying and smoking are the commonly practised methods of drying fish in Nepal. The present study was conducted to investigate the quality of the fish subjected to solar drying and hybrid-solar drying methods along with the common drying methods in Nepal. Fish samples subjected to all four drying methods showed an initial high loss of biomass that declined considerably as the drying process continued. Heat intensity and water movement control the drying rate (Yusheng and Poulsen, 1988) and the initial moisture content of the samples also affects the drying rate. Heat intensity is directly related to drying hour. Smoke drying showed significantly minimum drying time compared to all other three drying methods. Similarly, the hybrid-solar drying method showed significantly less time than the solar-drying and sun-drying methods. The drying rate of fish samples decreases with the increase in drying time (Sankat and Mujaffar, 2006; Kilic and Tiwari, 2009). The decrease in dry biomass of fish was used to calculate the per cent removal of moisture with drying time. Drying evaporates water from the fish, thus reducing the biomass (Eyo, 2001). Fish biomass decreased with increasing drying time in all the drying methods, and the decrease was highest during the initial stage of drying when the moisture content was higher which agrees with Sankat and Mujaffar (2006). In the first 2 h of drying, the surface moisture of fish is removed, and the reduction rate depended on the surrounding environment like relative humidity and temperature. Moisture loss trend gradually slowed down from 3 to 10 h. In this phase, moisture from the deeper portion of the muscle is evaporated. Drying rate becomes slower as the rate of movement of moisture from deeper part to surface slows down. Later on, the percentage moisture removal of dried fish was affected by drying

methods. Smoking was effective in removing significant moisture in a short period which could be the result of direct heat that was used to dry the fish. Similarly, the hybrid-solar dryer also resulted in direct heat intensity compared to the solar dryer and sun-drying. Sun-drying and solar drying both depend on sun heat and intensity which varied with the time of the day, and there is no heat at night.

Moisture content increased with the duration of storage in all four drying methods with a similar pattern at 0 to 15 days and 15 and 30 days. Similar results were seen during the second experiment conducted with smoking and hybrid-solar drying methods with dried fish stored for 90 days in mountain region markets of Nepal. The moisture content of fish dried by all four methods was lower than the moisture content (15.3 %) of smoked Nile tilapia *Oreochromis niloticus* (Linnaeus, 1758) reported by Idah and Nwankwo (2013). Higher moisture content in sun-dried fish (53.2 ± 0.2 %) than solar-dried fish was reported in commerson's anchovy *Stolephorus commersonnii* Lacepède, 1803 by Patterson et al. (2018); 36.1 to 52.0 % in dried ribbon fish *Lepturacanthus savala* (Cuvier, 1829) by Basu et al. (1989) and 14.1 % in Bombay-duck *Harpadon nehereus* (Hamilton, 1822) to 19.7 % in silver jaw *Notropis buccatus* (Cope, 1865) by Sultana et al., (2008). Similar to the results of this study, moisture content was found to increase weekly in bony tongue *Heterotis niloticus* (Cuvier, 1829), African carp *Labeo coubie* Rüppell, 1832, African obscure snakehead *Parachanna obscura* (Günther, 1861), Nile tilapia *O. niloticus* (Linnaeus, 1758) and African sharp-tooth catfish *Clarias gariepinus* (Burchell, 1822), from the initial average of 10.41 ± 0.02 % to 10.62 ± 0.05 % within 8 weeks of storage (Daramola et al., 2007).

In the current study, the crude protein content was 63 % in smoke-dried fish compared to 60 % in other dried fish and decreased to 62 and 58 %, respectively in smoked-dried and other drying methods during 30 days of storage. During the 30 days of storage, the crude protein contents of dried fish dried by all four methods were lower than reported by Sultana et al., (2008) in silver jaw *N. buccatus* (71.9 %) and Bombay-duck *H. nehereus* (80.5 %). The similar decreasing trend of protein content was found with the duration of storage in both smoked-dried fish and hybrid-solar dried fish during 90 days of storage during the second experiment. Smoke-dried fish samples showed relatively higher protein decreasing trend compared to hybrid-solar dried samples which might be due to higher moisture increasing trend in smoked-dried fish than in hybrid solar-dried fish. As protein decomposes with increasing storage time (Ghezala, 1994), the crude protein levels declined in the present study, which was also observed by Abolagba and Melle (2008). The crude protein was found to vary from 45.25 % (0 day) to 44.81 % (4 months) and 74.85 % (0 day) to 74.12 % (4 months) for smoke-dried Indian River shad *Gudusia chapra* (Hamilton, 1822) and Asian

needlefish *X. cancila*, respectively, during storage at room temperature (Nahid et al., 2016). Degradation of protein molecules into volatile compounds and the leaching out of soluble protein molecules decreases the protein content during storage (Goulas and Kontominas, 2005; Daramola et al., 2007). Similar drop in crude protein concentration has been reported for vundu *Heterobranchus longifilis* Valenciennes, 1840 by Abolagba and Osifo (2008).

The crude fat content of sun-dried fish was lower ($2.2 \pm 0.1\%$) and highest in hybrid-solar dried fish ($4.4 \pm 0.8\%$) but decreased to 2.2 - 2.3 % after 30 days with all drying methods. A similar decreasing trend was found until 90 days of storage during the second experiment though the decreasing trend was slow with the increased storage time. Sultana et al. (2008) reported higher value (8.1 %) in sun-dried Bombay-duck *H. nehereus* and 19.2 % in silver jaw (*N. buccatus*). Dried fish exposed to sunlight for a longer period of time oxidizes the lipids and reduces the nutritional quality of fish (Morales et al., 2015). The decrease of fat levels during storage could be due to oxidation of poly-unsaturated fatty acids of fish tissue like peroxides, aldehydes, ketones and the free fatty acids (Horner, 1997). The decrease in crude fat content from 5.3 to 4.3 % and 10.8 to 7.7 % respectively, for smoked-dried, Asian needlefish *X. cancila* (Hamilton, 1822) and striped spiny eel *Mastacembelus pancalus* Hamilton, 1822, respectively, have been reported during storage at room temperature (Nahid et al., 2016).

The PV is used as a primary indicator of rancidity due to fat oxidation increased during the storage period in dried fish dried by all methods. Fat oxidation is affected by the stage of the raw fish as well as oxidation of fats during processing and storage. Fish develop rancid taste and smell when peroxide value is above 10-20 mEq of O_2 . kg^{-1} of fat (Connell, 1980). In the present study, the PV values of sun-dried fish were above the acceptable limit (10-20 mEq of O_2 . kg^{-1} of fat) (Connell, 1980). Whereas the PV values of smoke-dried and hybrid-solar dried fish stored for 30 days were within the acceptable limit. Similar results of the PV values of smoke-dried and hybrid-solar dried fish were found until 90 days of storage during the second experiment, and the values were also within the acceptable limit. The results of increased PV in dried fish has been reported by Gupta and Basu (1985), Chattopadhyay et al. (1986), Shiriskar et al. (2010a), Shiriskar et al. (2010b). The peroxide values reported for several species ranged from 3.2 to 24.5 mEq of O_2 . kg^{-1} of fat of anchovy *Stolephorus indicus* (van Hasselt, 1823) (Shiriskar et al., 2013), 0.8 to 1.2 mEq of O_2 . kg^{-1} of fat for herring *Clupea harengus* Linnaeus, 1758 (Smith et al., 1980), 5.60 mEq of O_2 . kg^{-1} of fat for wild turbot *Scophthalmus maximus* (Linnaeus, 1758) (Ozogul et al., 2005) and 27.6 mEq of O_2 . kg^{-1} of fat for fresh European pilchard *Sardina pilchardus* (Walbaum, 1792) (Cho et al., 1989). The PV value observed in both smoke-dried and hybrid-solar dried fish were above than reported by Smith et al.

(1980) and Ozogul et al. (2005) but lower than reported by Cho et al. (1989). Fish develop rancid taste and smell when peroxide value is above 10-20 mEq of O_2 . kg^{-1} of fat (Connell, 1980).

Free fatty acid (FFA) is a tertiary product of rancidity, and it increases with the storage period. The FFA is a measure of hydrolytic rancidity and is acceptable between 0.5-1.5 % FFA as oleic acid (Eyo, 1993). The FFA (as % oleic acid) in fish subjected to all the different drying methods during 30 days of storage and all the values were within the permissible range (Eyo, 1993). The significant increasing trend of FFA was found in smoke-dried and hybrid-solar dried fish until 90 days of storage during the second experiment, but the values were within the permissible range.

In general, pH of fresh-water fish flesh is almost neutral (Vitra, 2009) and pH increases with the decomposition of nitrogenous compounds in fish flesh during the post-mortem period (Shenderyuk and Bykowski, 1989). The favourable range of pH for most of the microorganisms to grow is between 6.6 and 7.5. Kolodziejska et al. (2002) reported the pH change from 6.1 to 6.2 during 21 days of storage at 2 °C in hot smoked mackerel. However, pH value increased significantly at the 60 days storage in sun-dried and smoked Burjor's brilliance *Laubuka dadiburjori* Menon, 1952 (Al-Reza et al., 2015). In the present study, the increase of pH in fish dried by four methods was within the acceptable level of below pH 6.8 (Huss, 1988) within 30 days of storage. Similar results were observed during the second experiment conducted with smoking and hybrid-solar drying methods stored for 90 days at mountain region markets of Nepal.

The acceptable limit of TPC in fresh fish is considered to be 5×10^5 (cfu.g⁻¹) at 37 °C, but the permissible limit for cooked or dried fish, is 1×10^5 (cfu.g⁻¹) at 37 °C (Surendran et al., 2006). In the present study TPC content of dried fish increased with duration of storage in all the methods of drying. Similar increase in TPC content of smoke-dried fish samples of Indian river shad *G. chapra*, Asian needlefish *X. cancila* and striped spiny eel *M. pancalus*, was reported from 3.3×10^4 (0 day) to 4.2×10^6 cfu.g⁻¹ (4 months), 3.6×10^4 (0 day) to 4.0×10^6 cfu.g⁻¹ (4 months) and 3.7×10^3 (0 day) to 3.3×10^6 cfu.g⁻¹ (6 months) respectively (Nahid et al., 2016). Increase in TPC content in dried fish samples with the duration of storage is due to the growth and multiplication of the microbes (Bilgin et al., 2008). Moisture absorption in dried fish increases with the increase in storage time and provides the environment for microbial growth. The TPC (cfu.g⁻¹) of fish in all the different drying methods were below the unsafe level of above 1.0×10^5 cfu.g⁻¹ (Surendran et al., 2006) during 30 and 90 days of the storage and were in the safe range.

Conclusion

Smoking and solar drying are the common methods practised for fish drying in Nepal and many south and south-east Asian countries. Results of the study showed that smoking and hybrid-solar drying performed better than sun-drying and solar drying in terms of time required to remove moisture, maintain nutrient quality and microbial loads. A verification experiment was conducted to check the shelf-life quality of fish dried by smoking and hybrid-solar drying. Both methods of drying gave similar results with the exception that smoked-drying takes a shorter time. However, the study recommends that hybrid-solar drying would be a better option since it does not require fuelwood. The findings from this study suggest that smoke-dried and hybrid-solar dried fish are safe for human consumption up to 90 days when stored at ambient temperature in the hilly market region of Nepal.

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