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Research Article

Quality Improvement of Dried Anchovies at Three Solar Drying Methods

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Fish drying is one of the traditional methods where the fishermen land their catch on the beaches for drying traditionally under sun for several days. Dried fish provides valuable and economical sources of animal protein. The quality of dried fish is significantly influenced by the presence of microorganisms. Therefore, this study aims to determine the physical quality changes in anchovy under three different solar drying methods which are open sun drying (OSD), solar greenhouse tunnel dryer (GTD), and forced convective solar dryer (FCD) and to verify the chemical and microbial contamination in solar-dried anchovy. About (20 kg) of fresh anchovy were taken for experiments. Quality analyses were conducted in the samples before, during, and after drying. The parameters analyzed included three main analyses which are physical, chemical, and microbial analyses. The drying rate was higher in GTD compared to the two other methods. Moisture content, drying rate, and moisture ratio were significantly affected by drying methods. GTD required less time (6 hr) to dry anchovies compared to other drying methods (9 hr time). The highest reduction in lightness is in GTD dried anchovies followed by FCD and OSD. The drying methods and drying time statistically affect the lightness (L) of dried anchovies ($p \leq 0.05$). The water activity of solar-dried anchovies was 0.3. Experimentally dried anchovies were found to have lower microbial count compared to the dried fish quality standards. The total viable count (TVC) in fresh anchovy was 6.44 log CFU/g compared to the greenhouse tunnel dryer 2.90 log CFU/g, open sun dryer 4.16 log CFU/g, and forced convective dryer 4.19 log CFU/g anchovies. Water activity and moisture content did not affect total viable count (TVC) significantly, but it affects total fungal count (TFC) ($p \leq 0.05$). There was a significant difference on Krusal Wallis between the samples of three methods of drying and a fresh one on the water activity, ash content, and fat content ($p \leq 0.05$).

1. Introduction

The high protein and nutritious content of fish makes it the staple diet in many countries around the world. The coastline of Oman is very long comparing to other Gulf countries, and therefore, fishing is the most economic activity for many people in the coastal area. Oman is the biggest fish producer in the Gulf region [1]. Fish production in Oman is estimated at about 840,000 tons, with a total value of RO 364 million in 2020 [2].

Anchovy is a small coastal fish that can be found in many different environments in most seasons. It also used to produce different traditional products like dried, marinated, salted, smoked, and pickled anchovies. The anchovies are usually caught using a trawling net in the Arabian Gulf regions and that carried out in conditions with low hygienic, where it is dried traditionally in the open sun drying for three to five days, and then it is stored in conditions with ambient temperature [3]. Also, anchovies are considered as traditional products in Oman and other countries. Anchovies are a very healthy food

that are especially useful for supplying high-quality protein that is superior to that found in meat and eggs [4]. However, in areas with hot climates, fish perishes quickly and for that reason people normally try to extend their shelf life by employing various methods like smoking, salting, and drying [5]. Sun drying is a traditional method of preserving fish that is used all around the world [6]. Drying fish especially anchovies creates income for local communities in many countries. The process of drying fish is a physical process as the fish is exposed to hot air and the moisture evaporates from the surface area to the air. This process can extend the shelf life of the products and produce the desired texture and flavors and these practices are done in many communities and societies [7]. Anchovy fish contains high moisture content, which leads to faster deterioration. Moisture content is a key factor affecting the quality of anchovy fish during storage and handling [8].

The process of drying is not only used to increase the shelf life of any fresh product but also to reduce the weight, volume, package, storage, and cost of transportation and to increase the productivity of marine and agriculture [9]. Traditional fish drying methods have the drawback of losing 30–40% of the dried fish's quantity to dogs, birds, cats, and rodents [10]. In fact, this component lowers the earnings from dried fish. In addition, sun-dried fish could develop health risks and unhygienic when insects and larva attack the dried fish. Microorganisms have an impact on dried fish's quality. Nowadays, health concerns of consumers make the determination of microbiological quality and safety of dried fish very important. The quality of products is also considered to be the main influential parameter in the open solar drying technique as it was affected by unexpected rain and foreign bodies left by the animals and birds. As fish products are very perishable, because of their important microbial load, satisfactory solar drying may preserve their physicochemical quality which allows their storage over an extended period. No specific study was conducted to assess the impact of drying methods on microflora and fatty acids content of anchovies in the Oman seas. Therefore, the objective of this study is to improve the quality of locally produced dried fish using solar driers. It determines the physical quality changes in anchovy under solar drying methods. This study also verifies the chemical and microbial contamination in solar-dried anchovy.

2. Materials and Methods

About 20 kg of fresh anchovies were purchased from Oman local market and stored in a cool box with ice to being transported from a Barka's beach, Oman to be finally shifted to the Laboratory in College of Agricultural and Marine Sciences. Before drying, there were three different analyses carried out which are physical, chemical, and microbial analyses, and each analysis has different tests as shown in Figure 1. During drying, there were three different methods of drying which are open sun drying (OSD), greenhouse tunnel drier (GTD), and forced convective solar drier (FCD). Water activity, color, and weight were measured each hour during drying. Weather data like temperature, relative humidity, and solar radiation were recorded each hour during July 2021 from 7 AM to 4 PM at SQU Experimental Station. Physical, microbial, and chemical analysis were conducted before and after drying experiment.

2.1. Fish Drying Experiments

2.1.1. Open Sun Drying (OSD) Method. A quantity of fresh anchovy was purchased from the local market and placed on perforated trays. The anchovy samples were placed at a 1-meter height from ground to obtain an appropriate amount of solar radiation.

2.1.2. Forced Convective Solar Dryer (FCD). A preliminary model design of a forced convective solar dryer was installed at Sultan Qaboos University Experimental Station, Muscat, as shown in Figure 2. It consisted of two main parts: (1) upper inclined solar collector and (2) lower flat drying chamber. The solar collector is composed of a single glass cover tilted by an angle of 23.6° to the south and black granite was used on the bottom to absorb the highest amount of solar radiation [11]. The surrounding air was drawn through the forced convective solar dryer by centrifugal fans with an air velocity of 0.36 m/s that were placed in the lower chamber. The fish samples, placed inside the drying chamber, are dried by the conventional hot air flush that is coming from the main solar collector.

2.1.3. Greenhouse Tunnel Dryer (GTD). Greenhouse tunnel dryers consist of two parts which are a solar heat collection section and a drying chamber and it is 15 m length with 2 m width as shown in Figure 3. The structure of GTD was covered by a polyethylene sheet and the air inlet (1.8×0.2 m) was protected by a fine nylon mesh to prevent the intrusion of small particles such as dust and insects. Two fans were fixed opposite to the air inlet side to withdraw the heated drying air through the cavity of the GTD, and they were operated at an air velocity of constant flow at 0.36 m/s [11].

2.2. Physical Quality Analysis

2.2.1. Moisture Content. In order to calculate the moisture content of fresh fish, whole sample of anchovy was weighed before and after oven drying at 105°C for 24 hours with five replicates. The percentage of moisture content in wet-basis (X_m, %) was calculated as follows:

$$\text{moisture content \%} = \frac{\text{fish samples wet weight (g)} - \text{fish samples dr ied weight (g)}}{\text{fish samples wet weight (g)}} \times 100. \quad (1)$$

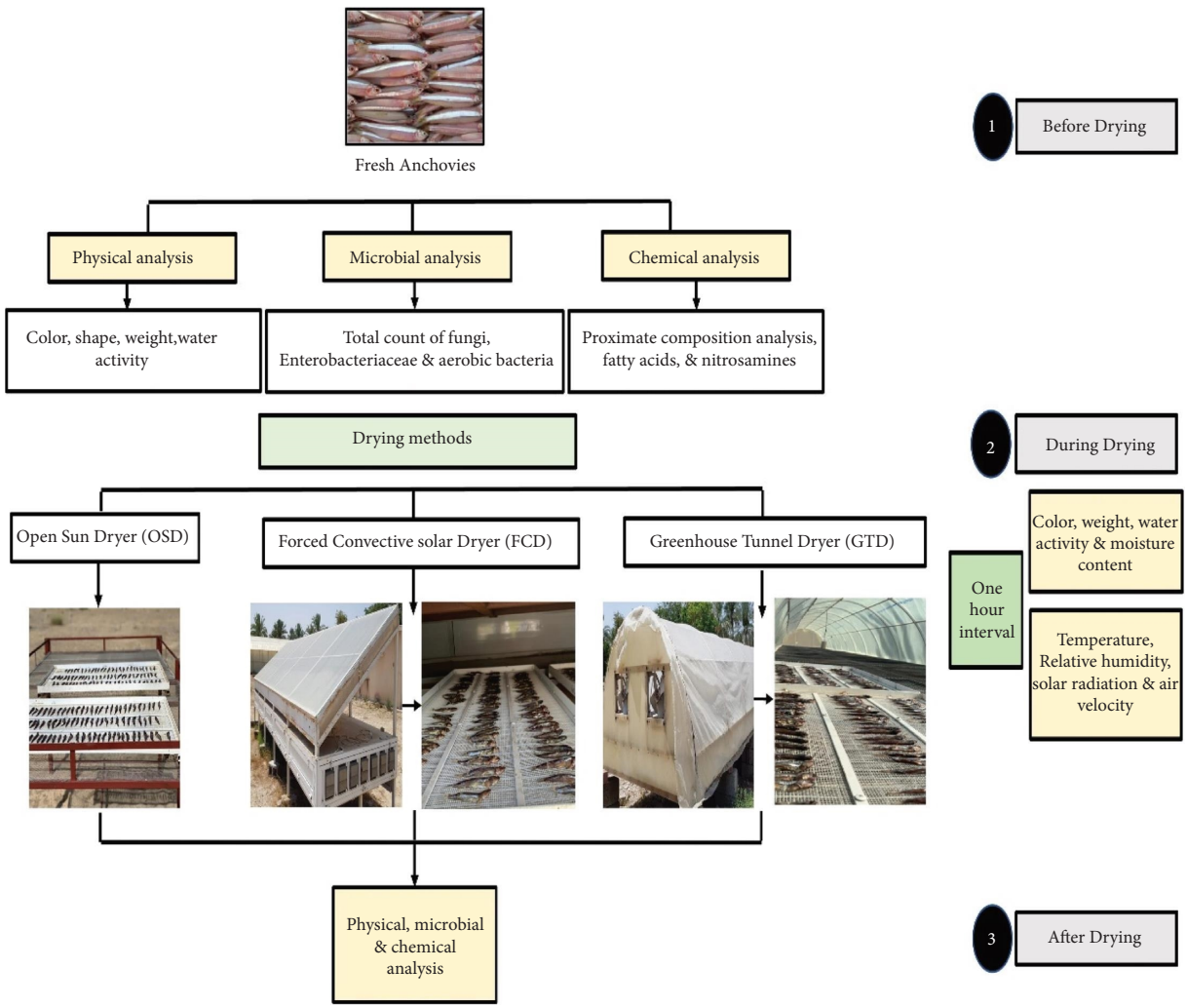

Figure 1: Overall experimental design.

Figure 2: Installed forced convective solar dryer (FCD) at agricultural experimental station, SQU.

Figure 3: Greenhouse tunnel dryers (GTDs), agricultural experimental station, SQU.

2.2.2. Color Measurements. In the color measurement of the study, the values of color for fresh samples and dried treated anchovies were taken using a colorimeter (NR110, Shenzhen ThreeNH Tech, China). For each method of drying, three samples were taken and five replicated were taken for each measurement (N). The color was measured in the central part of anchovy body. The color coordinates of L^*, a^*, and b^* were taken by the colorimeter device. Furthermore, the Chroma for the color intensity and hue for the color purity angle were detected in the study [12].

2.2.3. Water Activity Measurement (a_w). Water activity measurement (a_w) for the anchovy's samples were determined using a lab-based water activity meter (M.10′972, HygroLab C1, Rotronic, USA). For each method of drying, whole sample was taken and three samples were measured, and the measurements of each sample were recorded in every hour of drying starting from the start of the fish drying process.

2.3. Chemical Quality Analysis

2.3.1. Fatty Acids. The fish sample (0.2 grams) was weighted in a 10.0 ml Sovirell pyrex tube and then grounded to small pieces. Then, a 4.0 ml of chloroform : methanol mixture of 2 : 1 (v/v) was mixed in the tube. 1.0 ml of the internal standard was then added and clearly mixed for around 30 seconds using a lab vortex mixer. The mixture was left in a freezer at −20°C for overnight. Next, the frozen sample was clearly filtered and then dried using a rotary evaporator. The remained residue was dissolved in a 6.0 ml of diethyl ether. Then, it was easily transferred to a test tube and let dried in a stream of treated nitrogen. Next, a 1.0 ml portion of Caustic Soda (NaOH) was added to a 0.5 M methanol. The sample was then mixed using a lab vortex mixer. It was heated for around 15 minutes at a boiling temperature of 100°C. Next, the mixture was cooled in liquid water for rapid heat loss. Nearly 2.0 ml of BX_3/CH_3OH (X F or Cl) mix was then added and mixed using a vortex mixer [13]. The mixture was heated for nearly 5 min at a boiling temperature of 100°C. The mixture was then cooled. A subsequent portion of 1.0 ml of hexane and 2.0 ml of water (H_2O) were added to the mix. It was mixed for nearly 15 seconds using a lab vortex mixer. The mixture was placed in a lab centrifuge at 3000 rpm. Nearly 1.0 ml of hexane was added to the available mixture using a lab vortex mix. The sample was centrifuged for the collection of the hexane phase of 1.0 ml. The total 2.0 ml hexane phase was collected. The collection was concentrated or diluted based on the final fat content. Finally, a gas chromatographic analysis was conducted using a GC (M. GC-2010 Plus, brand Shimadzu, United States) for the fatty acid analysis.

2.3.2. Ash. The weight of porcelain crucible was recorded. 2.0 grams sample was placed on the crucible. The weight (g) of the crucible with the sample was taken. The crucibles were placed in muffle furnace (Model: RWF 12/5, CARBOLITE) and heated at 600°C ± 2°C for 5 hours. Then, the crucibles were allowed to cool into a lab desiccator. Finally, the weight of the crucibles (g) after ashing was recorded. Three replicates were taken for each ashing method. The ash content (%) is calculated as follows:

$$\text{ash \%} = \frac{\text{crucible weight after ashing} - \text{crucible and sample weight before ashing}}{\text{weight of sample}} \times 100. \quad (2)$$

2.3.3. Fats. A number of flasks were oven dried, cooled, and weight recorded prior to soxhlet extraction. 1–5 g of fish samples were placed into numbered extraction thimbles. 100 ml of petroleum spirit was added into the soxhlet distillation flask. The extractor was fixed to each of the individual flask and placed on the heater part. The extraction solvent was then heated at 50°C. The extraction was performed for 8 hours. Thimbles were removed from the Soxhlet apparatus. The distilled solvent was collected and stored in a separate bottle. The collected fat was removed in the flask. Then, it was dried in a conventional air-drying oven at 80°C for 1 hour to remove remained solvent in the flask. Weight of the flasks (g) in replicates (N) including the collected fat was taken. The percentage of fat (%) is calculated by using the following equation:

$$\text{fat \%} = \frac{\text{removed flask with fat weight (g)} - \text{empty flask weight (g)}}{\text{sample}^{'}\text{s weight (g)}} \times 100. \quad (3)$$

2.4. Microbial Assessment

2.4.1. Preparation of Media. Several selective and nonselective media were prepared according to Al Bulushi [14] as in Table.1. 19.5 g of Sigma powder of Potato Dextrose Agar (PDA) was mixed with a 500 ml of distilled water.

11.75 g of Sigma powder of standard plate count (SPC) was mixed with a 500 ml of distilled water in a media bottle. 9.5 grams of the Sigma powder of maximum recovery diluent (MRD) was mixed with 1000 ml of distilled water. Following the same sterilization process, 225 ml of the diluent was placed for each experiment. 9.0 ml test tubes were used for each diluent. 18.3 g of Sigma powder of tryptone bile X-glucuronide agar (TBXA) was mixed with 500 ml of the distilled water. 15.0 ml of the agar media was poured in Petri dishes and cooled at room temperature °C. 33.16 g of Sigma powder of baird parker agar (BPA) was thoroughly mixed with 500 ml of distilled water on a boiling plate using a lab vortex mixer. 25 ml of concentrated egg yolk emulsion was then added to the agar. 15 ml of the agar was poured on a petri dish plate for the *S. aureus* microbial count. Violet-red bile agar was used for the enumeration of coliforms species and *Enterobacteriacea* count. 20.76 g of Sigma-powder of violet-red bile agar (VRBA) was mixed with 500 ml of distilled water on a boiling plate using a vortex mixer. All prepared medium were then sterilized at 121°C for 2.5 hours in an autoclave (Tomy SX-500 Lab Autoclave, TOMY, USA). 15.0 ml of individual agar media was placed and cooled to room temperature in a separate Petri dish.

2.4.2. Total Fungal Count (TFC). The total fungal count was conducted for the fish sample. 25.0 g of the fish sample was placed into a sterile stomacher bag (Seward, UK). Nearly, 225 ml of the maximum recovery diluent was added to the collected mass in the stomacher bag to achieve the initial 10^{-1} dilution. The mixture was then homogenized using a lab-based stomacher (Seward, UK) for 1 minute. Solutions were serially up to 10^{-3} dilutions.

0.1 ml or 100 μl from each test tube of the three dilutions of 10^{-1}, 10^{-2}, and 10^{-3} dilution was aseptically transferred into duplicate plates of the Potato Dextrose Agar (PDA) plate. The mixture was then spread on a flame starting from the highest dilution of 10^{-3} to the lowest dilution 10^{-1}. All the petri dish plates were incubated aerobically at an ambient temperature of nearly 25°C for 3–5 days in a lab incubator. The colony forming units counts were counted using a colony counter equation:

$$\text{cfu} = \sum_{n=1} \text{number of colonies on the plate} \times \frac{1}{\text{di lution factor X volume taken}}. \quad (4)$$

2.4.3. Total Aerobic Bacterial Count (TABC). 25.0 grams of the fish sample was placed into a sterile stomacher bag. Nearly 225 ml of the maximum recovery diluent was added making a 10^{-1} dilution. This mixture was homogenized in a stomacher bag for 1 minute. Dilutions of 10^{-2} and 10^{-3} were prepared using 1.0 ml into 9.0 dilutions.

0.1 ml or 100 μl from the three dilutions were transferred aseptically in duplicate plates of Standard Plate Count Agar (SPCA) plate. The mixture was then spread on the petri dishes on alcohol flamed spreading from the highest dilution of 10^{-3} to the lowest dilution of 10^{-1}. All petri dish plates were incubated aerobically at 35°C for 48 hours. Colony counts were taken after the 48 hours using the colony counters. Equation (4) was used to calculate the colony forming units per gram of the fish sample.

2.4.4. Enterobacteriaceae Count. For *Enterobacteriaceae* count, 12.0 ml of molten VRB Agar at 44–47°C was added using a pouring plate technique. All petri dish plates were incubated for 24 hours at 35°C in a lab microbial incubator. Colony counters were used to count the pink colonies on the plates. Colony forming units per gram of the fish sample was calculated using equation (4).

Table 1: Types of media used in the microbial assessment.

Tests	Media	Manufacturer
Total fungal count (TFC)	Potato dextrose agar (PDA)	Sigma-Aldrich
Total viable count (TVC)	Standard plate count agar (SPCA)	Sigma-Aldrich
The diluent	Maximum recovery diluent	Sigma-Aldrich
Escherichia coli counts c.f.u/g	Tryptone bile X-glucuronide agar (TBXA)	Sigma-Aldrich
Staphylococcus aureus counts c.f.u/g	Baird–Parker media agar (simply BPA)	Sigma-Aldrich
Coliforms total counts and *Enterobacteriacea* count c.f.u/g	Violet-red bile agar (simply VRBA)	Sigma-Aldrich

2.4.5. Bacterial Test

(1) Enumeration of E. coli in Dried Fish. 50 grams of fish sample was placed in a beaker and mixed well. 25 grams of the mix was taken to the stomacher bag of 225 ml of diluent to make a 10^{-1} dilution. 10^{-2} and 10^{-3} dilutions were made using a vortex mixer of mixing 1.0 ml into 9 ml of dilutions. 0.1 ml from each test tube of 10^{-1}, 10^{-2}, and 10^{-3} dilution was aseptically transferred in duplicate of Tryptone Bile X-Glucuronide Agar (TBXA) plate. Next, spreading of 0.1 ml from the dilution using alcohol flamed spreading was conducted starting from the highest dilution of 10^{-3} to the lowest dilution of 10^{-1}. Colony counters were used to count the blue or green colonies on the plates. Colony forming units per gram of the fish sample was calculated using equation (4).

(2) Enumeration of Staphylococcus aureus. The dilution mixes of 10^{-1}, 10^{-2}, and 10^{-3} were prepared using the same tools and techniques explained in the previous sections. Molten Baird–Parker Agar was used in the agar medium for the incubation of *S. aureus*. All petri dish plates were incubated for 24 hours at 35°C in a lab microbial incubator. Colony counters were used to count the black colonies on the plates. Colony forming units per gram of the fish sample was calculated using equation (4).

(3) Enumeration of Coliforms. The dilution mixes of 10^{-1}, 10^{-2}, and 10^{-3} were prepared using the same tools and techniques explained in the previous sections. 1.0 ml from each dilution in duplicate was aseptically transferred to sterile petri dishes. Around 12 ml of molten VRB Agar at 47°C was prepared on microbial petri dishes. All petri dish plates were incubated for 24 hours at 35°C in a lab microbial incubator. Colony counters were used to count the pink colonies on the plates. Colony forming units per gram of the fish sample was calculated using equation (4).

2.5. Data Analysis.

Three tests of repeated drying were conducted throughout the experiment. All data were tabulated in an excel sheet for data analysis. Summary statistics was carried out for the study analysis. Mean and standard deviation were reported. Analysis of Variance ANOVA with a $p \leq 0.05$ was considered for the significance difference analysis. Chi-square analysis along with Pearson's correlation methods was conducted. $p \leq 0.05$ was considered for significance level.

3. Results and Discussion

3.1. Solar Data.

The maximum temperature was 49.35°C and that was around 12 PM. The average temperature was around 43.99 ± 3.34°C and the minimum temperature was 39.04°C (Figure 4). Maximum relative humidity was 28.76% at around 8 AM and the average was around 19.17 ± 5.07%, and the minimum RH was11.99%. Average solar radiation was 565.50 ± 0.18 W/m^2.

3.2. Effect of Drying Methods on Physical Quality Characteristics of Anchovy

3.2.1. Moisture Content, Drying Rate, and Moisture Ratio.

Moisture content was significantly affected by drying time ($p = 0.04345$) and drying methods ($p \leq 0.00001$) (Figure 5(a)). The percentage of moisture content reduction for OSD was about 78.90% after 9 hours drying, for FCD was about 79.08% after 9 hours drying and for GTD was 80.27% after 6 hours of drying, and it is the highest reduction comparing to the other methods. The results showed that the GTD sample has the lowest moisture content compared to FCD and OSD and that could be related to high temperature inside the greenhouse tunnel dryer [11]. Similarly, the drying rate was highly influenced by drying methods ($P \leq 0.00001$) and the time of drying ($p = 0.03874$) (Figure 5(b)). The study confirmed that the drying rate was higher in GTD compared to the two other methods. Similar trend was observed in the moisture ratio of dried anchovy in all three methods, where drying time (($P \leq 0.00001$)) and drying methods ($p = 0.03511$) significantly influenced the moisture ratio of dried anchovy. This might be related to the lowest average RH and highest average temperature during daytime in GTD and for that the evaporation process of the drying air would be increased [11].

3.2.2. Color Change.

Color is a key factor in drying technique selection and optimization, as well as market value. The results showed that the lightness of anchovy was highly affected by drying methods ($P \leq 0.01$) and drying time ($P \leq 0.01$) (Figure 6). The L^* value of anchovies was changed during the drying process in all drying methods. The lightness was high in the fresh sample and decreased significantly at the end of drying. During drying, anchovies dried in GTD showed the highest decrease on L^* value from 51.19 ± 1.19 to 9.95 ± 0.82 from hour 0 to hour 6, respectively. This was followed by anchovies dried in FCD

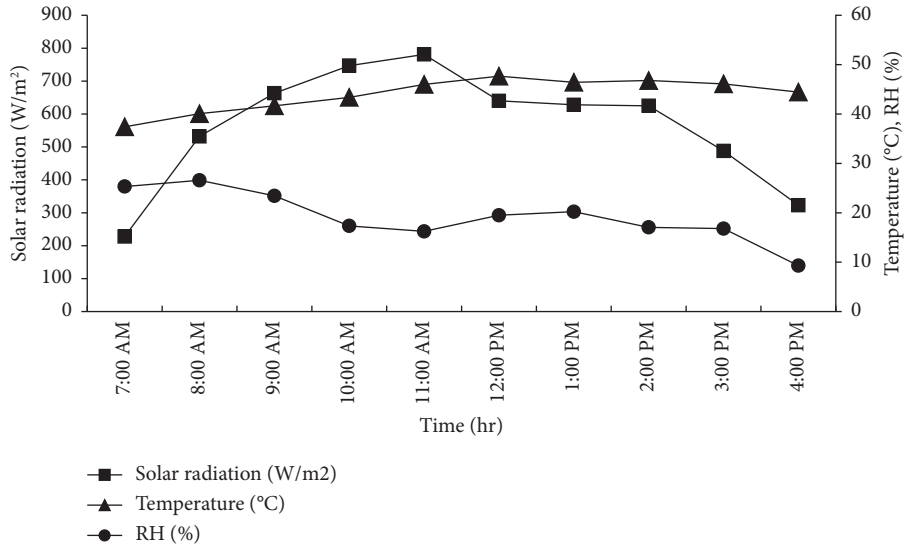

Figure 4: A typical day weather data during the experimental period.

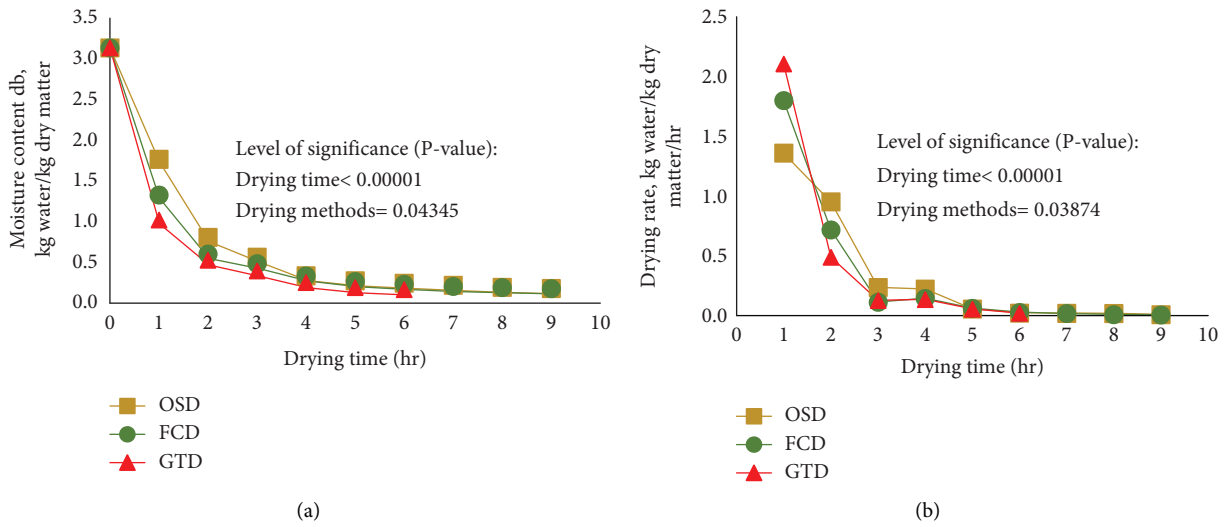

Figure 5: Changes in moisture content (a) and drying rate (b) of anchovy using GTD, OSD, and FCD.

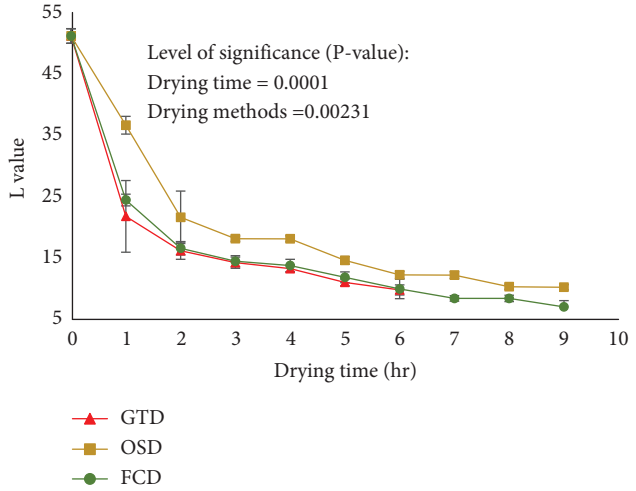

Figure 6: Lightness value of anchovy dried using GTD, OSD, and FCD.

lightness was decreased from 51.19 ± 1.19 to 7.20 ± 1.02 from hour 0 to hour 9, respectively (Figure 6). Same scenario was observed on anchovies dried in OSD, where the L^* value reported was decreased from 51.19 ± 1.19 to 10.39 ± 0.42 from hour 0 to hour 9, respectively. This could be due to the reaction of nonenzymatic and decomposition of pigments of color which produce darkness [11]. Nadia et al. [15] reported similar results for air dried sardine (*Sardina pilchardus*) muscles. With drying time, the color attribute of L^* is showed a decrease trend for all drying methods. The anchovy L^* values decreased due to the binding of the unsaturated fatty acids with oxygen, thereby accelerating anchovy oxidation and affecting the Maillard reaction [16]. In addition, the highest reduction in lightness is in GTD dried anchovies followed by FCD and OSD and this might be related to high temperature in GTD. It has been reported in different researches that the decrease in L^* value increases the darkness of some food materials and destruction of the pigments [11, 17].

3.2.3. Water Activity. The water activity is a very reliable indicator for food preservation and of microorganism growth and spoilage of dry fish products. Each type of food has exhibited a water activity limit below which microbial growth stops. Almost all bacteria grow at about $a_w = 0.85$, while fungi at $a_w < 0.7$ and mould and yeast at about $a_w = 0.61$ [18]. Figure 7 shows the water activity value of dried anchovy using GTD, OSD, and FCD. The water activity was statistically influenced by drying method ($p < 0.01$) and drying time ($p < 0.01$). The GTD showed the highest reduction in water activity during drying time. During drying process, the water activity of anchovies dried in GTD was decreased from 0.92 ± 0.02 to 0.30 ± 0.04, water activity of FCD anchovies was decreased from 0.92 ± 0.02 to 0.30 ± 0.01, and the water activity of anchovies dried in OSD was decreased from 0.92 ± 0.02 to 0.35 ± 0.04. After the drying process, it was found that the percentage of water activity reduction in GTD was 67.95% after 6 hours drying. However, it was 49.23% and 43.33% for FCD and OSD after 9 hours drying, respectively. In addition, the water activity level in GTD was decreased rapidly compared to other methods and that showing the anchovy fish are sufficiently dried and are able to prevent the growth of hazardous microorganisms. The reduction in the water activity prevents oxidation and enzymatic reaction [19]. Oparaku et al. [20] found that moulds keep their growth at water activity not less than 0.7, while bacteria likes to grow at water activity of 0.9 [21]. Therefore, keeping water activity at a level of about $a_w = 0.6$ ensures the absence of microbial growth of most microorganisms. The storage stability of the product is also affected by a_w, as dried products have a longer shelf life than moist products. Controlling water activity can help to prevent fish spoilage. For every microorganism, there are minimal, optimum, and maximum levels of water activity for growth. Reducing water activity (a_w) can thus decrease putrefaction and improve fish preservation [22].

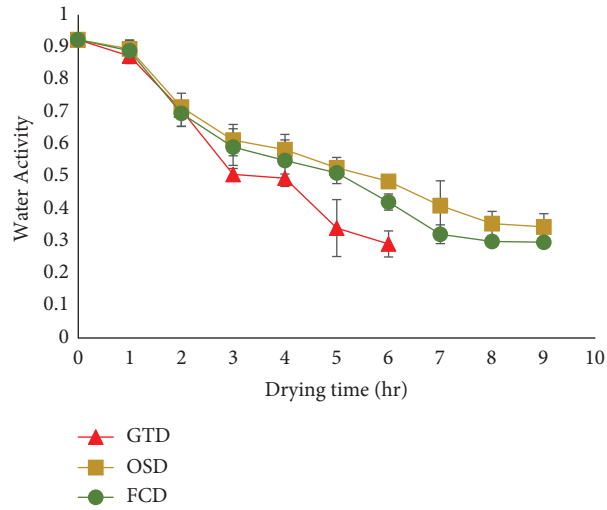

Figure 7: Water activity values of anchovy dried using GTD, OSD, and FCD.

3.3. Effect of Drying on Chemical Quality Characteristics of Anchovy

3.3.1. Fatty Acids. The study revealed a significant difference in fatty acids compositions among the three different drying methods as well as fresh samples with ($p \leq 0.05$). There is also a significant correlation between polyunsaturated fatty acids contents in mg/g and the amount of Omega-3 fatty acids compositions mg/g with ($p \leq 0.05$). As polyunsaturated fatty acids increase the Omega-3, fatty acids increase. This explains the presence of 5,8,11,14,17-Eicosapentaenoic acid, methyl ester, (all-Z)- and 4,7,10,13,16,19-Docosahexaenoic acid, methyl ester in the anchovies fish sample. Results showed a significance difference of fatty acid composition for tunnel dried sample (p value = 0.039), forced convective drying (p value = 0.0282), and open sun-dried sample (p value = 0.0300) from that of the fresh sample prior to drying. Table 2 shows fatty acids in fresh, GTD, OSD, and FCD anchovy's samples for the four main types of fatty acids which are Omega-3, saturated, mono-unsaturated, and poly-unsaturated. In the fresh sample, Omega-3 fatty acids were the highest (9.32 ± 0.22), followed by saturated fatty acids (4.81 ± 1.37), polyunsaturated fatty acids (2.95 ± 0.92), and monounsaturated fatty acids (1.68 ± 0.23). The omega-3 fatty acids are the highest in all different samples compared to the other fatty acids. For the comparison between samples of anchovies before and after drying, the results of this study show sample after drying has a high amount of fatty acids in all dried samples compared to fresh sample.

3.3.2. Fat Contents in Wet-Basis of Samples. Figure 8 shows the percentage of fat content in anchovy's samples before and after drying. Fat content was increased in dried samples after the drying process compared to fresh samples. It was highly increased in FCD anchovy samples followed by GTD and OSD and this due to the reduction that happens of moisture content after the drying process. This finding of an

Table 2: Fatty acids in fresh, GTD, OSD, and FCD anchovies samples.

	Fresh	OSD	FCD	GTD
Omega-3	9.32 ± 0.22	40.05 ± 6.47	42.44 ± 4.94	50.99 ± 4.69
Saturated	4.81 ± 1.37	22 ± 6.13	23.49 ± 6.54	21.80 ± 6.06
Monounsaturated	1.68 ± 0.23	7.47 ± 1.43	8.78 ± 1.19	7.31 ± 1.30
Polyunsaturated	2.95 ± 0.92	14.35 ± 4.97	15.41 ± 4.65	21.35 ± 7.82

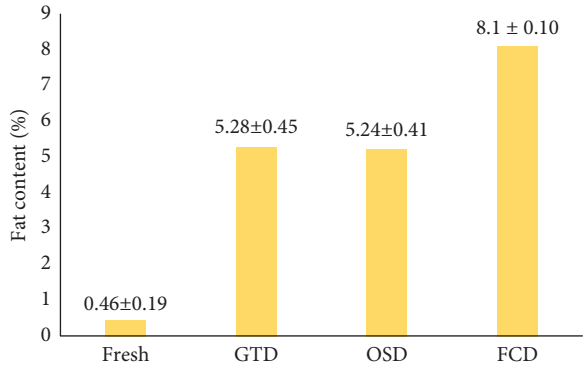

Figure 8: Fat content (%) value of anchovy before and after drying using GTD, OSD, and FCD.

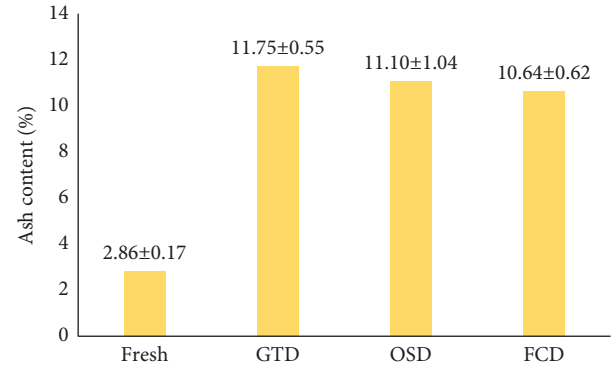

Figure 9: Ash content (%) value of anchovy before and after drying using GTD, OSD, and FCD.

increase in fat content after drying is similar to the study of Abraha et al. [23] who have carried out a comparative study on the quality of dried anchovy (*Stelophorus heterolobus*) using open sun rack and solar tent drying methods. The increase of fat content could be related to dehydration that was caused by increasing the temperature during drying process [24].

3.3.3. Total Ash Contents of Sample. Figure 9 shows the percentage of ash content in anchovy's samples before and after drying. Ash content was increased in samples after drying process. Increasing of ash content in anchovies after drying can be related to decreasing of moisture content in anchovies. This result is similar with those Tenyang et al. [24] who reported that the ash content of fish is increasing during drying process. Besides, there was a significant effect of water activity (a_w) and moisture content (MC) on ash content. As well, increasing ash content can be related to increasing the dry matter content per unit of weight for sample after dehydration [25].

3.4. Effect of Drying on Microbial Quality Characteristics of Anchovy

3.4.1. Total Fungal Count (TFC), Total Aerobic Bacterial Count (TABC), and Enterobacteriaceae Count. Table 3 shows the results of different microbial counts in Fresh, GTD, OSD, and FCD, and it is clear that the microbes were decreased in the samples after the drying process. Using statistical analysis found that water activity and moisture content do not affect TVC significantly with ($p = 0.072$, $p = 0.081$), respectively. However, they significantly affect TFC with $p \leq 0.05$. Experimentally dried anchovies found lower microbial content values compared to the dried fish

Table 3: Different microbial analysis tests in fresh, GTD, OSD, and FCD of anchovies samples.

Tests	Type of sample			
	Fresh	OSD	FCD	GTD
TVC (log CFU/g)	6.44	4.16	4.19	2.90
TFC (log CFU/g)	n.d	0.60	0.60	0.78
Enterobacteriaceae count (log CFU/g)	2.45	n.d	n.d	n.d
a_w	0.92	0.35	0.30	0.29
MC wb (%)	75.82	16.44	15.86	14.96

quality standards that reported by the studies of [26, 27]. Similarly, various research studies reported that the allowable level of TVC has to be less than 10^5 log cfu/g, TFC has to be less than 10^3 log CFU/g, and *Enterobacteriacea* has to be less than 10^2 log CFU/g [26, 27]. Microorganism growth is accelerated by long periods of open sun drying in high humidity environments [10]. Bacterial activity stops when the moisture content of the fish falls below 25%, while fungal activity stops when the moisture level falls below 15% [28]. The stability of microbiological growth in dried fish is determined by the amount of moisture present during the processing and storage period [29].

4. Conclusions

Anchovies are among the highest quantity fish in Oman. It has a lot of socioeconomic dimension to food and feed security in the country. The most common problem that influenced the safety and quality of dried anchovies is contamination caused by fungi and bacteria. The present study used three types of drying methods (open sun dryer, greenhouse tunnel dryer, and forced convective dryer) to

determine each drying method characteristics and to determine the physical, chemical, and microbial quality changes in anchovy under solar drying methods. Generally, temperature plays a vital role in the process of drying as it lay to increase the drying rate and leads to reduce the drying time. GTD required less time (6 hr) to dry anchovies compared to other drying methods (9 hr). The independence variable (drying methods and drying time) showed a significant effect ($p \leq 0.05$) on anchovy's lightness values. There was a significant difference between the fresh and dried samples on the water activity, ash content, and fat content ($p \leq 0.05$). Experimentally dried anchovies found lower microbial content values compared to the dried fish quality standards. Water activity does not affect TVC significantly, but it significantly affects TFC with $p \leq 0.05$. Solar dryers protect the dried fish from atmospheric and insect contaminations as well as microbial contaminations as they dry fish in a significantly shorter time and shelter the dried fish from rain, dust, insects, rodents, animals, and humid environments.

Data Availability

The data used to support the study are available upon request.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

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