Original Article

Western Indian Ocean
JOURNAL OF
Marine Science

Suitability of a superheated steam dryer for drying sardines

Prissillah Antelm[1,2], Leonard M.P. Rweyemamu[1], Lillian D. Kaale[1]*

[1] University of Dar es Salaam, Department of Food Science and Technology, PO Box 35134 Dar es Salaam, Tanzania

[2] Ministry of Livestock and Fisheries, PO Box 2847, Dodoma, Tanzania

Open access

Citation:
Antelm P, Rweyemamu L.M.P., Kaale L.D. (2023) Suitability of a superheated steam dryer for drying sardines. Western Indian Ocean Journal of Marine Science 22(2): 13-23 [doi: 10.4314/wiojms.v22i2.2]

Received:
August 27, 2022

Accepted:
July 12, 2023

Published:
October 19, 2023

*** Corresponding author:**
elykaale@gmail.com

Abstract

The suitability of a superheated steam dryer for drying sardines was investigated. Proximate composition (moisture, crude protein, crude fat, ash, and crude fibre; minerals-calcium, zinc, iron) for fresh, oven dried (OD) at 100 °C, oven dried (OD) at 120 °C and superheated steam dried (SSD) sardines at 120 °C was evaluated and the results reported on a dry matter basis. There were significant differences ($p<0.05$) in moisture, crude fat, and ash content among fresh and dried samples, but not for crude protein or crude fibre. The crude protein % content of fresh, OD at 100 °C, OD at 120 °C, and SSD, was 78.17, 78.40, 75.77, and 76.05 and crude fibre % was 0.59, 0.12, 0.02, and 0.13, respectively. The SSD sardines had the highest fat content (11.8 %) and the fresh sardines had the lowest (8.1 %). There was a significant difference in calcium content ($p<0.05$) but not for zinc and iron content. Overall, SSD retained the nutrients of sardines well.

Keywords: superheated steam dryer, sardine, proximate composition, micronutrients, oven drying

Introduction

Sardines are among a group of small pelagic fish namely including Herrings, Anchovies, and Sardines (HAS) (Kripa *et al.*, 2019). In Tanzania sardines are harvested from marine waters of the Indian Ocean in the five regions of Tanga, Pwani, Dar es Salaam, Lindi, and Mtwara. However, Zanzibar, Pemba, and Mafia Island are the major producing areas (Sekadende *et al.*, 2020). Marine sardines make up about 1/3 million tons of the annual catch, according to the official statistics (SWIOFP, 2012). Small pelagic fish, particularly sardines, contain a significant amount of polyunsaturated fatty acids (PUFAs) of the omega-3 series in the form of docosahexaenoic acid (DHA) and eicosapentaenoic acid (EPA) responsible for the development and functioning of the brain and retina (Njinkoue *et al.*, 2016). These PUFAs play a crucial role in the prevention of atherosclerosis, heart attack, depression, stroke, diabetes, obesity, premature aging, hypertension, and cancer in humans and improve visual power and memory (Stephen *et al.*, 2010). In addition, PUFAs are essential for normal growth, development, and reproduction in all vertebrates, including fish and humans, and must be supplied through diet. Small pelagic fish contain all the elements of a healthy and nutritionally optimal food source for humans and are an important contributor to the food and nutritional security of many poor, low-income households in developing countries (Isaacs, 2016). Moreover, fish protein is of high biological value due to the presence of essential amino acids in the right proportions (Hoffman and Falvo, 2004). Lysine, methionine, and cysteine are important essential amino acids that can significantly raise the value of cereal-based diets, which are poor in these essential amino acids (Kasozi *et al.*, 2014).

Fish is a highly demanded and nutritious food product as detailed in the previous section, yet perishability remains the biggest challenge for its preservation (Tavares *et al.*, 2021). Since fish are not normally eaten raw, processing and preservation measures are employed in preparing them for consumption (Okpanachi *et al.*, 2018). Sun drying, salting, and boiling followed by sun drying, smoking, and chilling are

methods used by processors to extend the shelf life of fish and fishery products. These traditional preservation techniques have some drawbacks like exposing the product to rain, foreign matter like dust, microorganisms like bacteria and fungi, birds, and rodents. In addition, existing conventional hot air drying is an energy-intensive technique that consumes around 15–25 % of national industrial energy in most developing countries; Tanzania being an example (Sehrawat *et al.*, 2016). Using air as a drying medium leads to oxidation and combustion reactions which pollute the environment by releasing undesirable components, and its operation needs continuous improvements to reduce energy consumption and preserve quality (Sehrawat *et al*., 2016). It also often results in loss of nutrients, colour degradation and non-uniform product quality (Sehrawat and Nema, 2018). Recent studies have also shown that traditional processing methods can cause a loss of nutrient availability in processed fish (Ayinsa and Maalekuu, 2013; Sehrawat *et al.*, 2016).

In Tanzania, particularly at Mafia Island, small pelagic fish processing is carried out by boiling in sea water mixed with salt using firewood as a source of energy before sun drying on racks or the ground (Fig. 1). This technology is not ideal because it has the potential to significantly lower the quality of the final product (dust, sand, flies). Additionally, the majority of small pelagic fish that are boiled fragment in the process of boiling. They also lose the silvery colour and once dried they are very difficult to chew due to shrinkage as a result of salting. During the rainy season, the process ceases as there is no alternative drying method, especially at Mafia Island.

Fortunately, there are some solutions available. Technologies such as heat pump drying, and superheated steam drying (SSD) have been proven to reduce nutrient loss and extend the shelf life of dried products. SSD is an affordable way of drying foods/fish using steam to dry the foods/fish. The benefits of SSD in food drying include minimizing energy consumption (Alfy *et al.*, 2016), reducing lipid oxidation, and preserving food nutrient substances, colour, and texture (Idrus and Yang, 2012).

The present study aimed to investigate the suitability of the application of a superheated steam dryer for drying sardines through the determination of proximate composition (moisture, protein, fat, ash, and crude fibre) and mineral content (calcium, iron, and zinc).

Materials and methods

Study location

This study was carried out on Mafia Island (Fig. 2) at Kilindoni Village (landing site). The Island is one of the six districts of the Pwani region with a coverage area of 972 km^2 of which 407 km^2 is dry land while 565 km^2 is covered by water (Kweka, 2017).

Collection of raw material

Fresh sardines for this study were bought from the local fishermen in Mafia Island and hygienically

Figure 1. Traditional small pelagic processing technique practiced by indigenous people on Mafia Island. From left to right: boiling process; boiled sardines ready for drying; fresh sardines under shade.

packed in a cool box containing flaked ice and then transported to the Department of Food Science and Technology Laboratory, College of Agriculture and Food Technology, University of Dar es Salaam for analysis. On arrival at the laboratory, the sardines were divided into two portions with the first portion subjected to proximate analysis before drying.

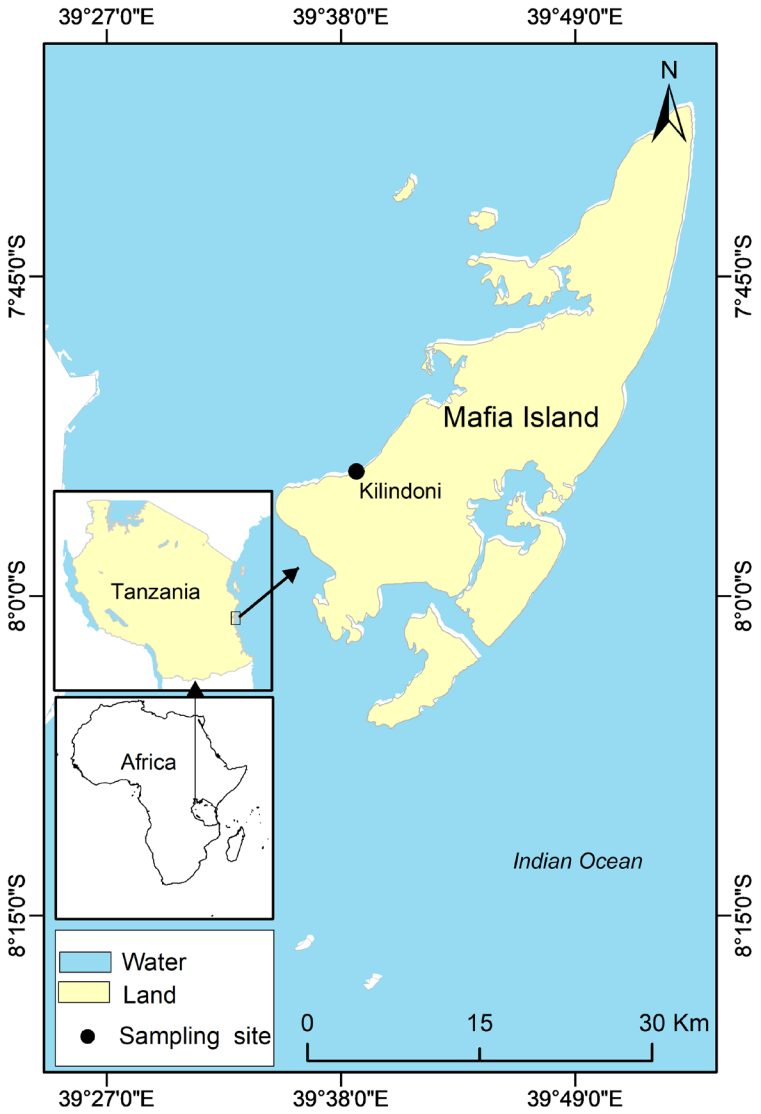

Figure 2. Map of Tanzania showing the location of the sampling site on Mafia Island (Shape file source: National Bureau of Statistics –Tanzania).

The remaining portion was divided into three for Oven Drying at 100 °C, Oven Drying at 120 °C, and SSD at 120 °C.

Superheated steam drying

Figure 3 represents a schematic diagramme of the superheated steam dryer and associated units. The dryer consists of a boiler, an air exchange pipe, and a drying chamber. The drying chamber is a stainless steel vessel with two partitions equipped with perforated stainless steel trays for holding food products during drying. It is 1.5 m × 1.5 m with the capacity of holding 24 trays of 60 × 30 cm. After preparing the dryer for operation, the boiler is started by heating the air exchange pipes and at the same time generating steam. The fresh sardines are spread on trays in the air chamber for drainage purposes for 30 min at 50 °C air temperature and a flow rate of 4 l/min. The drained sardines are shifted to the steam chamber only once the boiler pressure is about 7 bars. Water is boiled under atmospheric pressure conditions to a temperature of 100 °C, using liquefied petroleum gas as a source of energy. The generated steam is then further

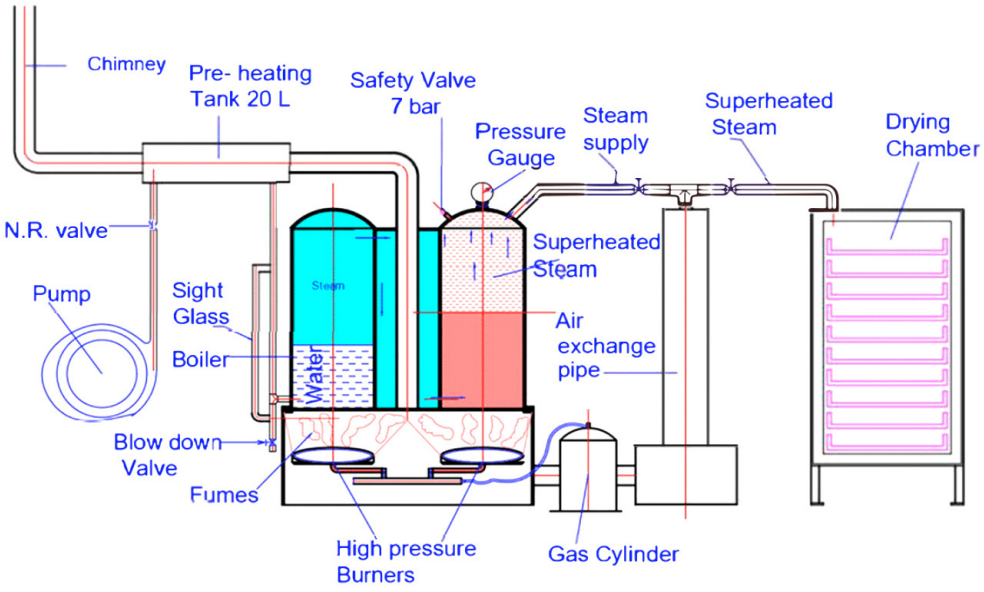

Figure 3. A schematic diagramme of a superheated steam dryer and associated units.

heated at a pressure of 7 bars in the drying chamber. The sardines are first moistened by steam exposure owing to condensation, but when the temperature rises to 120 °C, the water in the sardines is evaporated. The water condenses on the drying chamber walls and is collected at the steam trap as condensate. The sardines are dried for one hour in the drying chamber before being shifted to the hot air chamber for surface water removal. In the chamber, the sardines are exposed to heated air for an hour. Sardines are then moved to a conditioning room where they are kept for four hours before packaging for further analysis.

Oven drying

Sardine samples were dried in an oven at two different temperatures and times (100 °C for 90 min and 120 °C for 60 min). Once the sardines were dried, the packaging procedures were followed (Fig. 4a and b) and stored in the refrigerator at 4 °C for further analysis.

Proximate composition analysis

Proximate composition (moisture, protein, fat, ash, and crude fibre) was carried out on the samples of fresh, oven dried (OD) at 100 °C for 90 min, OD at 120 °C for 60 min, and SSD at 120 °C for 60 min.

Determination of moisture content

Approximately 2 g of each sample was weighed in preconditioned Petri plates that were pre-heated in an oven set at 105 °C for 2 h and cooled in a desiccator for 2 h. The samples were dried in a hot air oven (Model Memmert 854) at 105 °C overnight until constant weight was attained. The moisture content was calculated as a percentage loss in weight using Eq. (1).

$$\textit{Moisture content}\ (\%) = \frac{W_2 - W_3}{W_2 - W_1} \text{ x } 100 \qquad (1)$$

Where W_1 = weight of the weighing dish (g),
W_2 = weight of the moist dish and sample before drying (g), and
W_3 = weight of the dish and sample after drying (g).

Determination of protein content

An aliquot of 2 g of each sample was placed into a labeled Kjeldahl tube followed by adding Kjeltec catalyst [3 selenium oxide (2 g) tablets] and 20 ml of concentrated sulfuric acid (98 %). The tubes and the contents were inserted in the digestion unit (Foss Tecator™ Digester) and digested completely (until white fumes and blackish mass were absent) for 2 h at 400 °C. The digests were cooled to 29 ± 2 °C and then distilled for 5 min using an auto-distillation unit (Foss Kjeltec™ 8200) that had been rinsed and calibrated using the following setup: 80 ml of dilution volume (deionized water); 90 ml of sodium hydroxide (alkali solution 40%); and 3 ml of mixed indicator (70 ml of 0.1 g methyl red and 100 ml of 0.1 g bromocresol green dissolved in 100 ml methanol). The distillate was collected in the flasks. In addition, it was titrated with 0.104 M hydrochloric acid solution. The protein

content in the sample was calculated and expressed on a dry basis, according to Eq. (2).

$$\textit{Crude protein}\ (\%) = \frac{\left((T-B)\text{x}\,\text{M}\,\text{x}\,14.007\,\text{x}\,6.25\,\text{x}\,\text{MCF}\right)}{W}\ \text{x}\ 100 \quad (2)$$

Where T = volume of the standard hydrochloric acid used in sample titrations (mL),
B = volume of the standard hydrochloric acid used in blank titrations (ml),
M = molarity of the acid used in the titrations (mol/L),
W = mass of the sample used in grams (g),
MCF = the moisture correction factor [100/ (100 – % moisture content)],
6.25 = factor used to convert percent N to percent crude protein, and
14.007 = molecular weight for N (g/mol).

Determination of crude fat

The fat content of samples was determined using the Soxhlet system (Foss Soxtec™ 2043, Hilleroed, Denmark). Aluminum cups were pre-heated in an oven set at 105 ± 2 °C for 2 h, and thereafter cooled in a desiccator for 30 min. Each aluminum cup was filled with 30 ml of petroleum ether and placed under an adapter holding thimble loaded with 2 g of the sample. Each thimble was submerged in boiled petroleum ether for 20 min to extract fat. Fat remaining in the samples was rinsed out by reflux using boiling petroleum ether for 45 min. Excess petroleum ether was recovered by evaporation from each cup into the condenser unit of the Soxhlet system for 10 min. The fat extract was dried in a hot air oven set at 105 °C for 30 min. The fat content was expressed on a dry matter basis, as shown in Eq. (3).

$$\textit{Fat content}\ (\%) = \frac{W_3 - W_1}{W_2}\ \text{x}\ 100 \quad (3)$$

Where W_1= weight of the aluminum cup (g),
W_2= weight of the sample (g), and
W_3= weight of the aluminum cup plus dried fat (g)

Determination of ash content

About 2 grams of each sample was weighed into preconditioned porcelain crucibles that were pre-heated in an oven set at 105 ± 2 °C for 2 h and cooled in a desiccator for 2 h. The samples were placed in a temperature-controlled muffle furnace (Nabertherm GmbH, Lilienthal, Germany) and incinerated at 550 °C for 5 h. The crucibles were transferred to a desiccator, cooled to 29 ± 2 °C, and reweighed. The ash content of the samples was calculated on a dry matter basis using equation (4).

$$\textit{Ash content}\ (\%) = \frac{W_3 - W_1}{W_2 - W_1}\ \text{x}\ 100 \quad (4)$$

Where W_1 = weight of the crucible (g),
W_2 = weight of the crucible and sample before incineration (g), and
W_3 = weight of the crucible and sample after incineration (g).

Determination of crude fibre

Fibre content was determined following Foss Fibertec system instructions. Fibre crucibles were first preheated in an oven set at 105 °C for 2 h and then filled with 2 g of sample and weighed. The fibre crucibles containing the samples were then fixed underneath glassier columns (Foss Fibertec™ 1020). Then, 100 ml of hot H_2SO_4 (1.25 %) was added to the glassier columns to hydrolyze organic substances (e.g., protein, carbohydrate) with occasional auto-heating for 30 min. Resultant residues were washed with hot deionized water followed by adding hot NaOH (1.25 %) to affect the saponification of fat in the sample over 30 min. The sample residues were further washed with hot water and then dried for 2 h in a hot air oven at 130 °C. The crucibles containing the dried sample residues were ignited in a muffle furnace at 550 °C for 5 h and weighed again after cooling following incineration. The crude fibre content of samples (dry matter basis) was then calculated using Eq. (5).

$$\textit{Crude fibre content}\ (\%) = \frac{W_3 - W_2}{W_1}\ \text{x}\ 100 \quad (5)$$

Where W_1= weight of the sample cup (g),
W_2= weight of the sample after drying (g), and
W_3= weight of the sample after incineration (g).

Determination of calcium, zinc, and iron

Half a gram (0.5 g) of each sample was digested with 10 ml nitric acid and 5 ml hydrogen peroxide at 200 °C for 90 min for complete digestion. After cooling to room temperature, the digest was filtered and made up to 100 ml with distilled water and analyzed for Ca, Zn, and Fe using an Inductively Coupled Plasma Optical Emission Spectrometer (ICP-OES) (iCAP 6300 England). The concentration of each mineral was expressed in parts per million (ppm).

Statistical analysis

Minitab Statistical software version 17 was used for analysis in which all data were reported as means +

standard deviation of duplicate determinations. One-way ANOVA was used to compare means of collected data and the significant difference between means was determined by Turkeys test. Differences were considered to be significant when $p<0.05$.

Results and discussion

Proximate composition

The proximate composition of the raw and dried sardines with different methods is presented in Table 1. Fresh fish is highly perishable and also cannot be consumed without cooking. Therefore, subjecting foods, especially meat and fish, to cooking makes them edible and enhances their digestibility. Fish is thus a product that needs proper handling and processing to preserve nutrients and its functional components that promote good health (Sulieman and Mustafa, 2012). However, the nutritional composition of fish is affected by processing temperature and time (Abraha *et al.*, 2018). Drying is a common practice for meat, fish, and other animal protein, as it preserves the quality of the product for an extended time, with minimum deterioration and insignificant changes in the product (Aberoumand and Karimi reza abad, 2015).

Moisture content

It is well understood that moisture content occupies the largest part of the fish body. In this study, moisture content of fresh samples was 72.61%, compared to 17.22%, 9.82%, and 9.45% for the SSD at 120 °C for 60 minutes, OD at 100 °C for 90 minutes and OD at 120 °C for 60 minutes, respectively. There was a significant difference ($p<0.05$) in the moisture content of the fresh and SSD sardines ($p<0.05$), however, there was no significant difference ($p>0.05$) between the oven-dried samples. The moisture content of the fresh sample is similar to that reported by Feng *et al.* (2012) who found that most fish contain 60 % to 80 % moisture content. According to Sheeba *et al.* (2021), two species of sardines (*S. fimbriata* and *S. longiceps*) had a moisture content of 69.8 and 78.2 %, respectively. It was also previously reported by Bagthasingh *et al.* (2016) that the value of the moisture content of sardine (*Sardinella gibbosa*) ranged from 70.79-78.16 %. In the present study, the highest moisture content was recorded in the fresh sardine sample (72.61%) and the lowest in the oven-dried sardine samples. The lowest moisture content in OD sardine samples is due to the high processing temperature applied which facilitated heat transfer. It is well understood that the drying process results in a significant decrease in moisture content while increasing other nutrients (protein, ash, lipids) (García-Arias *et al.*, 2003), as observed in this study. Among the dried sardine samples, SSD sardines had the highest moisture content (17.22%) because superheated steam retains more moisture than other processing methods. Similarly, Yu *et al.* (2017) reported the lowest moisture loss (46.84%) in superheated steam oven-cooked fillet when compared to convection oven cooking (50.13%).

Protein content

The protein content for the fresh and dried sardine samples is presented on a % dry matter basis (Table 2). Protein forms the largest quantity of dry matter in fish (Bagthasingh *et al.*, 2016). The protein content of the studied sardine samples ranged from 75.77 to 78.40 %, and there was no significant difference between them. The protein content of the fresh sardine sample was 78.17 %. The present study is in agreement to Owaga *et al.* (2010) who reported high protein content in the fresh fish sample (74.4 % dry weight basis) and the lowest in the retail market (62.5 % dry weight basis). According to Wisuthiphaet *et al.* (2015), the protein content of the fresh sample was 72.1 %. Daramola *et al.* (2007) also reported the protein content in five fish species ranging from 54.71 to 72.78 %. The highest value of protein was observed in OD at 100 °C, 78.40 %, followed by SSD, 76.05 %, and then OD at 120 °C, 75.77 %. It was reported by Immaculate *et al.* (2012) and Aberoumand (2020) that the increase of protein was due to the dehydration of water molecules present between the proteins causing aggregation of protein and therefore resulting

Table 1. Proximate composition (% dry matter basis) of both fresh and dried sardine samples.

Sample	Moisture	Protein	Fat	Ash	Fibre
FRESH	72.61±0.030^{a}	78.17±1.100^{a}	8.10±0.019^{d}	11.99±0.062^{b}	0.59±0.828^{a}
OD 100 °C	9.82±0.816^{c}	78.40±0.027^{a}	10.63±0.022^{c}	10.24±0.017^{c}	0.12±0.011^{a}
OD 120 °C	9.45±0.381^{c}	75.77±1.064^{a}	11.38±0.001^{b}	12.48±0.041^{ab}	0.015±0.021^{a}
SSD 120 °C	17.22±0.072^{b}	76.05±1.994^{a}	11.81±0.001^{a}	13.60±0.406^{a}	0.13±0.177^{a}

Results expressed as mean (n=3) ± standard error of the mean; samples with different superscript letters across the column indicates statistical difference according to Turkey's Honest Significance difference test ($p<0.05$).

Table 2. Mineral content (% dry weight basis) of fresh and dried sardine samples.

Sample	Ca	Zn	Fe
FRESH	24.94±0.947[b]	0.24±0.025[a]	0.11±0.025[a]
OD 100 °C	30.35±0.269[a]	0.42±0.024[a]	0.00±0.000[b]
OD 120 °C	13.67±0.147[c]	0.29±0.019[a]	0.00±0.000[b]
SSD 120 °C	25.24±0.177[b]	0.36±0.042[a]	0.02±0.000[b]

Results expressed as mean (n=3) ± standard error of the mean; samples with different superscript letters across the column indicates statistical difference according to Turkey's Honest Significance difference test ($p<0.05$).

in the increase in protein content of dried fish. The lowest protein content in OD at 120 °C might be due to denaturation as a result of the high processing temperature. However, there was no significant differences ($p<0.05$) between the three drying methods. The study of Steiner-Asiedu *et al.* (1991) reported the protein content of flat sardine (g/100 g dry matter basis) in fresh, cooked, fried, and smoked samples as 84.1, 82.0, 56.7, and 84.7, respectively. Flowra *et al.* (2012) reported the protein content of sun-dried fishes ranging from 60 to 80 %. Sablani *et al.* (2001) reported the highest protein content of 71 % dry matter basis in freezer-dried sardines and the lowest was 50-65 % dry matter basis in traditionally dried sardines. Sultana *et al.* (2011) reported the protein content of the dried SIS fish ranged from 52.66 to 72.45 %. According to Ayinsa and Maalekuu (2013), different fish processing presents different effects on the nutritional quality of the final product. According to Sultana *et al.* (2011), good quality dried fish can provide 52-73 % of human protein requirements, suggesting that eating 100 g of dried fish in a day provides the required protein for the body.

Fat content

The fat content of the fresh and dried sardine samples varied significantly ($p<0.05$) with the highest value found in SSD (11.81 %) and the lowest in the fresh sample (8.10 %). It has been reported that fat content is inversely proportional to moisture content (Palani kumar *et al.*, 2014) and this was similarly observed in this study. This could be the reason for low-fat content (8.10 %) in the fresh sample compared to the dried samples.

According to Sablani *et al.* (2001), sardines processed in the freeze dryer had a 10 % crude fat content. In the present study, the values of crude fat in the sardines are lower than those reported by Owaga *et al.* (2010) in the fresh sample (14.8 %) and the market sample (13.9 %). According to Shija *et al.* (2019), different cooking processes could lead to biochemical changes which include oxidation during heating. Moreover, the fat content may be reduced with the evaporation of moisture and increase during heat treatment (Immaculate *et al.*, 2012). It has been previously reported that cooking releases bound lipids as free lipids making them easier to extract (García-Arias *et al.*, 2003; Yu *et al.*, 2017). However, this is dependent on the method of cooking used. One advantage of using superheated steam for food drying is that the procedure has little impact on the fat content of sardines. The crude fat content of the sardine samples was 11.81 %, 11.38 % and 10.63 % for SSD at 120 °C, OD at 120 °C and OD at 100 °C, respectively.

Superheated steam drying normally operates under anoxic conditions which means oxidation and combustion reactions are prevented. Sutikno *et al.* (2019) reported that the superheated steam system was better than traditional cooking methods in reducing lipid oxidation and preserving food nutrient substances, colour, and texture. In contrast, fish processed in the oven presented low-fat content (32.99 %) compared to frying (37.33 %) (García-Arias *et al.*, 2003). According to the level of fat content fish can be grouped into four: lean fish (<2 %); low fat (2-4 %); medium fat (4-8 %); and high fat (>8 %) (Ackman, 1990). In the present study, sardines are grouped as medium-fat fish with 8.10 % fat content (fresh sardines). Bagthasingh *et al.* (2016) reported that the fat content of sardine (*Sardinella gibbosa*) varied from 1.25 % to 6.77 %. Sheeba *et al.* (2021) reported the fat content of *Sardinella fimbriata* and *Sardinella longiceps* as 2.7 % and 22.9 %. The variation in lipids has been explained by Bagthasingh *et al.* (2016) who reported that variation is due to season, temperature, feed intake, age, sex, and size.

Ash content

There was a significant difference ($p<0.05$) between the ash values. The ash content of the fresh, OD at 100 °C, OD at 120 °C, and SSD at 120 °C were 11.99 %, 12.48 %, 10.24 %, and 13.60 %, respectively. The study by Sablani *et al.* (2001) reported an ash content of 15 %

in freeze-dried sardines. It is well known that ash content increases as the moisture content decreases. This was true for all samples except the SSD sardine sample which despite the highest moisture content (17.22 %), presented the highest ash content of 13.60 %. This study is in contrast with Yu *et al.* (2017) who reported an ash content of 1.22% in superheated steam oven cooked fillet which was significantly lower ($p<0.05$) than that found in convection oven cooked fillet (1.43 %). However, all the fresh and dried sardine samples in this study presented high ash content. According to Steiner-Asiedu *et al.* (1991), the higher ash content (13.1 %) in the fresh sardine samples is due to the presence of bones. The total ash content in the fresh sardine (10.3 % dry weight basis) was significantly lower ($p<0.05$) than the values in the sun-dried market samples (13.5 % dry weight basis) (Owaga *et al.*, 2010). In addition, marine fish show higher values of ash content due to the different content of seawater (García-Arias *et al.*, 2003) which includes mineral salts and other contaminants. According to Islam *et al.* (2013), the ash content of the dried fish ranged from 29.34-34.49 % on a dry matter basis and associated this with sand and dirt contamination. The ash content of the five dried fish species reported by Flowra *et al.* (2012) ranged between 11.21 and 28.15 %.

Crude fibre

The crude fibre content of the fresh, OD at 100 °C, OD at 120 °C, and SSD at 120 °C sardine samples were 0.59 %, 0.12 %, 0.02 %, and 0.13 %, respectively. There was no significant difference ($p>0.05$) among them. According to the literature, the amount of crude fibre in fish is very low or sometimes absent (Effiong and Fakunle, 2011; Olopade, 2015). The fresh sample had the highest crude fibre content (0.59 %) as compared to the processed samples, which is consistent with the findings of Okpanachi *et al.* (2018). This is attributed to the effect of different cooking methods that affected the concentration of proximate composition (Abraha *et al.*, 2018).

Mineral elements

Minerals represent 0.2–0.3 % of the total intake of all nutrients in the human diet and are so important that without them, the remaining 99.7 % of food intake would be difficult to utilize (Yetunde, 2016). Minerals in sardines are stored mainly in the skeleton (Bouderoua *et al.*, 2011), therefore, when eaten whole they are good sources of these minerals. The results of calcium, zinc, and iron for the present study are shown in Table 2.

Calcium content

The present study noted a significant difference ($p<0.05$) in calcium content between fresh and dried sardine samples. The highest value was observed in OD at 100 °C (30.35 ppm) and the lowest in OD at 120 °C (13.67 ppm). The lowest levels of calcium in OD at 120 °C might be due to leaching as explained by Kirk (1984) and also destruction by high processing temperatures. The study by Shija *et al.* (2019) reported that processing methods have little or no effect and sometimes may increase the mineral content. Small pelagic fish are a rich source of high bioavailable calcium compared to larger fish (Reksten *et al.*, 2020).

Zinc content

There was no significant difference ($p>0.05$) in zinc content between the fresh and dried samples. However, there was an increasing trend due to processing (Table 2). The amount of zinc was highest in OD at 100 °C (0.42 ppm), then in SSD (0.36 ppm), and lowest in OD at 120 °C (0.29 ppm). Zinc plays an important role in the promotion of normal growth and development and is an element in the enzymes that work with red blood cells, which move carbon dioxide gas from tissues to the lungs (Ekweagwu *et al.*, 2008). In malnourished children zinc deficiency contributes to growth failure and susceptibility to infections since it is associated with complications of childbirth (Ekweagwu *et al.*, 2008).

Iron content

There was a significant variation ($p<0.05$) in iron content among the fresh and dried samples. However, sardines treated in the oven and SSD did not show any significant difference ($p>0.05$) in iron content. The concentration of iron in the present study was higher in the fresh sample (0.11 ppm) compared to SSD (0.02 ppm). In OD the iron was not detected in samples treated under either of the two temperatures. This might be due to the leaching of the element during processing. Iron is an important component for the synthesis of hemoglobin in red blood cells (RBCs) which helps to transport oxygen to all parts of the body. The deficiency of iron can cause anemia, impaired brain function, and in infants, it causes poor learning ability and improper behavior (Mishra, 2020).

Conclusions

The suitability of a superheated steam dryer for drying sardines was studied by investigating the proximate composition and mineral contents of the dried

sardines. The study observed that using a superheated steam in drying fish resulted in better preservation of nutrients, especially protein and lipids, with lipids being highly susceptible to oxidation due to their long-chain carbon bonds. In addition, protein constituted a large portion of the fish studied. Although all methods were good in the preservation of nutrients in terms of protein, fat, and crude fibre, SSD is highly recommended because apart from reducing lipid oxidation, it maintains the silvery colour, aroma, and texture of the sardines. In addition, little or no breakage of SSD sardines was observed. This study recommends more testing to be carried out on the SSD technique for its efficiency in other food drying applications. Moreover, more research is needed on the use of other environmentally friendly and cost-effective energy sources apart from liquefied petroleum gas (LPG). Consuming sardines regularly for all age groups will reduce the complications of protein-calorie malnutrition which is a problem in Tanzania and in developing countries at large.

Acknowledgments

The authors are grateful to the Ministry of Livestock and Fisheries for its financial support and the Government Chemist Laboratory Authority (GCLA) for allowing the authors to access their laboratory for analyzing samples.

References

Aberoumand A, Karimi reza abad M (2015) Influences of drying methods processing on nutritional properties of three fish species, Govazym stranded tail, Hamoor and Zeminkan. International Food Research Journal 22 (6): 2309-2312

Aberoumand A (2020) Effects of traditional fish processing methods on the proximate composition and pH of fish black pomfret (*Parastromateus niger*). Journal of Food Sciences 14: 271-276

Abraha B, Admassu H, Mahmud A, Tsighe N, Shui X, Fang Y (2018) Effect of processing methods on nutritional and physico-chemical composition of fish: a review. MOJ Food Processing and Technology 6 (4): 376-382

Ackman RG (1990) Seafood lipids and fatty acids. Food Reviews International 6 (4): 617-646

Alfy A, Kiran B, Jeevitha G, Hebbar H (2016) Recent developments in superheated steam processing of foods—a review. Critical Reviews in Food Science and Nutrition 56 (13): 2191-2208

Ayinsa HK, Maalekuu BK (2013) Effect of traditional fish processing methods on the proximate composition of red fish stored under ambient room conditions. American Journal of Food and Nutrition 3 (3): 73-82

Bagthasingh C, Aran S, Vetri V, Innocen A, Kannaiyan S (2016) Seasonal variation in the proximate composition of sardine (*Sardinella gibbosa*) from Thoothukudi coast. Indian Journal of Geo-Marine Sciences (IJMS) 45 (6): 800-806

Bouderoua K, Mourot J, Benmehdi-Tabet-Aoull F, Selselet-Attou G (2011) The effects of season and site of catch on morphometric characteristics, mineral content, and fatty acids of sardines (*Sardina pilchardus*) caught on the Algerian coast. Journal of Aquatic Food Product Technology 20 (4): 412-420

Daramola J, Fasakin EA, Adeparusi EO (2007) Changes in physicochemical and sensory characteristics of smoke-dried fish species stored at ambient temperature. African Journal of Food, Agriculture, Nutrition and Development 7 (6): 1-16

Effiong BN, Fakunle JO (2011) Proximate and mineral composition of some commercially important fishes in Lake Kainji, Nigeria. Journal of Basic and Applied Scientific Research 1 (12): 2497-2500

Ekweagwu E, Agwu A, Madukwe E (2008) The role of micronutrients in child health: a review of the literature. African Journal of Biotechnology 7 (21): 3804-3810

Feng Y, Ma L, Du Y, Fan S, Dai R (2012) Chemical composition analysis of three commercially important fish species (sardine, anchovy and mackerel). Advanced Materials Research (554-556): 900-904

Flowra F, Nahar D, Tumpa A, Islam T (2012) Biochemical analysis of five dried fish species of Bangladesh. University Journal of Zoology, Rajshahi University 31: 9-11

García-Arias M, Álvarez Pontes E, García-Linares M, García-Fernández M, Sánchez-Muniz F (2003) Cooking-freezing-reheating (CFR) of sardine (*Sardina pilchardus*) fillets. Effect of different cooking and reheating procedures on the proximate and fatty acid compositions. Food Chemistry 83 (3): 349-356

Hoffman JR, Falvo MJ (2004) Protein - Which is best? Journal of Sports Science and Medicine 3 (3): 118-130

Idrus NFM, Yang TA (2012) Comparison between roasting by superheated steam and by convection on changes in colour, texture and microstructure of peanut (*Arachis hypogaea*). Food Science and Technology Research 18 (4): 515-524

Immaculate J, Sinduja P, Jamila P (2012) Biochemical and microbial qualities of *Sardinella fimbriata* sun dried in different methods. International Food Research Journal 19 (4): 1699-1703

Isaacs M (2016) The humble sardine (small pelagics): Fish as food or fodder. Agriculture and Food Security *5* (27): 1-14

Islam T, Ahmed S, Sultana A, Tumpa A, Flowra F (2013) Nutritional and food quality assessment of dried fishes in Singra Upazila under Natore District of Bangladesh. Trends in Fisheries Research 2 (1): 14-17

Kasozi N, Degu G, Asizua D, Mukalazi J, Kalany E (2014) Proximate composition and mineral contents of Pebbly fish, *Alestes baremoze* (Joannis, 1835) fillets in relation to fish size. Uganda Journal of Agricultural Sciences 15 (1): 41-50

Kirk JR (1984) Biological availability of nutrients in processed foods. Journal of Chemical Education 61 (4): 364-367

Kripa V, Mohamed K, Padua S, Jeyabaskaran R, Prema D (2019) Similarities between Indian Oil Sardine *Sardinella longiceps* Valenciennes, 1847 and global sardine fisheries and its management. Journal of the Marine Biological Association of India 61 (1): 5-18

Kweka L (2017) Motivational strategies and staff retention in Mafia District Council , Tanzania. Masters Thesis Dissertation, Mzumbe University

Mishra SP (2020) Significance of fish nutrients for human health. International Journal of Fisheries and Aquatic Research *5* (3): 47-49

Njinkoue JM, Gouado I, Tchoumbougnang F, Ngueguim JHY, Ndinteh DT, Fomogne-Fodjo CY, Schweigert FJ (2016) Proximate composition, mineral content and fatty acid profile of two marine fishes from Cameroonian coast: *Pseudotolithus typus* (Bleeker, 1863) and *Pseudotolithus elongatus* (Bowdich, 1825). Nutrition and Food Science Journal 4: 27-31

Okpanachi M, Yaro CA, Bello OZ (2018) Assessment of the effect of processing methods on the proximate composition of *Trachurus trachurus* (Mackerel) sold in Anyigba market , Kogi State. American Journal of Food Science and Technology 6 (1): 26-32

Olopade O (2015) Effect of poor handling on the nutritional composition of some imported frozen fishes in Nigeria. Food Science and Technology 72 (1): 20-26

Owaga E, Onyango C, Njoroge C (2010) Influence of selected washing treatments and drying temperatures on proximate composition of dagaa (*Rastrineobola argentea*), a small pelagic fish species. African Journal of Food, Agriculture, Nutrition and Development 10 (7): 2834-2845

Palani kumar M, Ruba AA, Jeya SR, Shanmugam SA (2014) Proximate and major mineral composition of 23 medium sized marine fin fishes landed in the Thoothukudi Coast of India. Journal of Nutrition and Food Sciences 4 (1): 1-7

Reksten A, Somasundaram T, Kjellevold M, Nordhagen A, Bøkevoll A, Pincus L, Rizwan A, Mamun A, Thilsted S, Htut T, Aakre I (2020) Nutrient composition of 19 fish species from Sri Lanka and potential contribution to food and nutrition security. Journal of Food Composition and Analysis 91: 1-13

Sablani S, Myhara R, Al-Attabi Z, Al-Mugheiry M (2001) Water sorption isotherms of freeze dried fish sardines. Drying Technology 19 (3-4): 673-680

Sehrawat R, Nema P, Kaur B (2016) Effect of superheated steam drying on properties of foodstuffs and kinetic modeling. Innovative Food Science and Emerging Technologies 34: 285-301

Sehrawat R, Nema PK (2018) Low pressure superheated steam drying of onion slices: kinetics and quality comparison with vacuum and hot air drying in an advanced drying unit. Journal of Food Science and Technology *55* (10): 4311-4320

Sekadende B, Scott L, Anderson J, Aswani S, Francis J, Jacobs Z, Jebri F, Jiddawi N, Kamukuru AT, Kelly S, Kizenga K, Kuguru B, Kyewalyanga M, Noyon M, Nyandwi N, Painter SC, Palmer M, Raitsos DE, Roberts M, Sailley SF, Samoilys M, Sauer WHH, Shayo S, Shaghude Y, Sarah FW Taylor SFW, Wihsgott J, Popova E (2020) The small pelagic fishery of the Pemba Channel, Tanzania: what we know and what we need to know for management under climate change. Ocean Coastal Management 197 (May): 1-18

Sheeba W, Immaculate J, Jamila P (2021) Comparative studies on the nutrition of two species of sardine , *Sardinella longiceps* and *Sardinella fimbriata* of South East Coast of India. Food Science and Nutrition Technology 6 (4): 1-12

Shija SMY, Shilla DA, Mihale MJ (2019) Variation of proximate contents in selected marine fish from Tanzanian Coast due to seasonality and processing methods. Huria Journal 26 (1): 30-49

Steiner-Asiedu M, Julshamn K, Lie Ø (1991) Effect of local processing methods (cooking, frying and smoking) on three fish species from Ghana: Part I. Proximate composition, fatty acids, minerals, trace elements and vitamins. Food Chemistry 40 (3): 309-321

Stephen NM, Shakila JR, Jeyasekaran G, Sukumar D (2010) Effect of different types of heat processing on chemical changes in tuna. Journal of Food Science and Technology 47 (2): 174-181

Sulieman A, Mustafa W (2012) Quality characteristics of dried fish obtained from Eldeim Area, Central Sudan. International Journal of Food Science and Nutrition Engineering 2 (1): 1-6

Sultana S, Parween S, Hossain MA (2011) Biochemical analysis of some dried Sis fishes of the River Padma in Rajshahi. Journal of Life and Earth Science 6: 39-43

Sutikno LA, Bashir KMI, Kim H, Park Y, Won NE, An JH, Jeon JH, Yoon SJ, Park SM, Sohn JH, Kim JS, Choi JS (2019) Improvement in physicochemical, microbial, and sensory properties of common squid (*Todarodes pacificus* Steenstrup) by superheated steam roasting in combination with smoking treatment. Journal of Food Quality: 1-15

SWIOFP (2012). Mainstreaming biodiversity in fisheries management: a retrospective analysis of existing data on vulnerable organisms in the South West Indian Ocean. A specialist report. A SWIOFP Retrospective Analysis, Durban, South Africa. 206 pp

Tavares J, Martins A, Fidalgo LG, Lima V, Amaral RA, Pinto CA, Silva AM, Saraiva JA (2021) Fresh fish degradation and advances in preservation using physical emerging technologies. Foods 10 (780): 1-20

Wisuthiphaet N, Kongruang S, Chamcheun C (2015) Production of fish protein hydrolysates by acid and enzymatic hydrolysis. Journal of Medical and Bioengineering 4 (6): 466-470

Yetunde K (2016) Biochemical composition of *Micromesistus poutassou* from agbalata market, Badagry Lagos West, Nigeria. Food and Applied Bioscience 4 (1): 12-24

Yu L, Zzaman, W, Akanda J, Yang T, Easa A (2017) Influence of superheated steam cooking on proximate, fatty acid profile, and amino acid composition of catfish (*Clarias batrachus*) fillets. Turkish Journal of Fisheries and Aquatic Sciences 17: 935-943