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Physicochemical, microstructural, and microbial qualities of dehydrated Tuna chunks: Effects of microwave power and drying methods

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Abstract

Boneless Tuna chunks were marinated using spices and were dried in a microwave vacuum dryer at different powers (600 W [T1], 650 W [T2], and 700 W [T3]) for 2 hr. Another two batches were prepared by hot air drying (55 ± 5°C) (HAD) and sun drying (SD) to a comparable moisture content obtained by sample T2. The moisture content was 44.69 g/100 g, 39.26 g/100 g, 24.40 g/100 g, 32.80 g/100 g, and 38.45 g/100 g for T1, T2, T3, SD, and HAD, respectively. Increasing microwave power level resulted in reduced moisture content and water activity in dried tuna chunks. Analysis of *SEM* indicated a tough morphology in SD and HAD whereas a smooth morphology in microwave vacuum dried samples. Results of FTIR analysis indicated higher protein denaturation with an increase in microwave power. Oxidation of lipids increased significantly ($p < .05$) with microwave power as displayed by higher peroxide value (PV) and thiobarbituric acid reactive substances (TBARS) values in T3 and T2 samples. Microbial spoilage was faster in T1 samples compared to T2 and T3. On the other side, sun-dried and hot air-dried samples have shown poor rehydration and color attributes but better oxidative stability than microwave vacuum dried samples.

Practical applications

Conventional methods of fish drying have several drawbacks including longer duration of drying, poor sensory properties, low rehydration abilities, etc. Microwave vacuum drying is a novel drying technology that enhances the end product quality of dried fish by using the advantages of both microwave and vacuum for rapid dehydration. It is very essential to evaluate the properties of food products developed by any processing method and the present study gives information on the influence of microwave power on the product quality during drying. The present study also provides the information on effects of different drying methods on the physico-chemical qualities of dried Tuna chunks. The results of the study will definitely benefit fish processing entrepreneurs in developing high-quality dried fish and fish products at a rapid rate compared to conventional drying.

1 | INTRODUCTION

Microwaves are part of the electromagnetic spectrum which lies between 300 MHz and 300 GHz frequencies. Microwave heating has a broad range of applications in the food industry such as cooking, pasteurization, drying, sterilization, baking, etc. (Chandrasekaran et al., 2013). Recently in the food industry, drying with microwave energy is gaining more importance owing to its advantages over conventional drying methods. Conventional drying requires more energy and longer processing time as the heat energy needs to be transferred from the surface to inside by conduction and convection methods. On the contrary, in microwave heating, heat is generated volumetrically inside the food within a shorter time and transferred to the outer surface. Apart from rapid heat transfer, microwave heating minimizes the temperature difference between interior and exterior surfaces of food material. Researchers have proven that microwave drying is a short drying process resulting in high thermal efficiency, absence of case hardening, and improved product quality (Fu et al., 2015; Monteiro et al., 2018; Ozdemir, 2008).

A recently developed innovative drying process is microwave vacuum drying technology. In this dehydration process, microwave energy is applied to produce heat in the absolute pressure range from above the triple point of water to less than atmospheric pressure (0.61–101.33 kPa), (Scaman et al., 2015). By combining vacuum with microwave, we can avoid the high temperature produced by microwave, while retaining the speed of heat transfer. Microwave vacuum drying produces a porous structure inside the dehydrated product that enhances the product quality by reducing hardness and shrinkage and by increasing crispiness and rehydration properties (Monteiro et al., 2018). Open sun drying, mechanical drying using solar dryer, hot air drying, tunnel drying, vacuum drying, and fluidized bed drying are the commonly used drying practices in the seafood industry (Qiu et al., 2019; Sen, 2005). However, these processes are time-consuming and often result in poor quality products because of case hardening which is difficult to control during long drying processes. There are only a few reports on the application of microwave vacuum drying for the dehydration of fish and fish products (Darvishi et al., 2013; Fu et al., 2015; Hu et al., 2013). In our previous studies, (Pankyamma et al., 2019; Viji et al., 2019), physicochemical and sensorial qualities of microwave vacuum-dried products were found surpassing to those produced by conventional drying methods.

Kawa kawa or mackerel tuna (Euthinnus *affinis*) is an abundantly caught Tuna species off the east coast of India. Locally, it is used for making value-added products like fish pickle, fish balls, cutlets, etc. In the present study, our aim was to investigate the effect of increasing microwave power levels on the quality of dehydrated tuna chunks using microwave vacuum drying and to compare its quality with those produced by conventional drying methods.

2 | MATERIALS AND METHODS

Fresh kawa kawa (average weight 0.9 kg) was purchased from Visakhapatnam fishing harbor and brought to the laboratory under chilled condition. Ingredients for marination were procured from a local grocery shop. All chemicals used in the experiment were procured from local dealers of Merck, India and the glasswares used were purchased from Borosil, India and Tarsons, India.

2.1 | Preparation of sample and drying

The tuna fish was thoroughly washed in potable water and skinless fillets were prepared. Central muscle bones were removed and the boneless fillet was cut into chunks of 2 × 2 cm manually using a knife. The chunks were marinated with salt (3 g/100 g wt/wt), chilli powder (1 g/100 g), turmeric powder (0.3 g/100 g), and pepper powder (0.15 g/100 g) and kept in a chiller for 30 min. After marination, the sample was divided into five batches of 1 kg each. Batch No. 1, 2, and 3 were dried in a microwave vacuum dryer (Ragatech, Pune, India) at 600 W (T1), 650 W (T2), and 700 W (T3), respectively for 2 hr. The vacuum was maintained at 700 mmHg (93.3 kPa) during all operations. The microwave power and vacuum used in the present study were decided based on our previous experiments (Pankyamma et al., 2019; Viji et al., 2019). Batch No. 4 was dried by open sun drying on a bamboo rack at an average temperature of 36°C (SD). Sun drying was continued for three days (nearly 18 sunny hours) to reduce the moisture content comparable to that of the T2 sample. Batch No. 5 (HAD) was dried for 16 hr in a hot air oven maintained at a temperature of 55 ± 5°C.

2.2 | Analysis of dried tuna chunks

2.2.1 | Physicochemical evaluation

The yield of drying was calculated from the weight difference of marinated chunks before and after drying. Estimation of moisture, protein, ash, and fat contents of raw and dried tuna chunks was done by AOAC (1990) method. Water activity (a_w) of the five dehydrated samples was determined in a water activity meter (Aqua lb model CX3, Washington). Rehydration properties of the dried samples were determined as per Duan et al. (2011) with a slight modification of the procedure. The pre-weighed samples were rehydrated in warm water (1:20 ratio (wt/vol)) maintained at 40°C for a period of 1 hr and an increase in weight was recorded at periodic intervals (5, 10, 20, 30, 40, 50, and 60 min). Color attributes (L^*, a^*, and b^*) of the samples were analyzed in Color Flex EZ colorimeter (HunterLab, USA). Lipid oxidation of the samples immediately after drying and after 2 months storage at ambient temperature was evaluated by measuring peroxide value (Yildiz et al., 2003) and thiobarbituric acid reactive substances (TBARS) by the method of Tarladgis et al. (1960).

2.2.2 | Microstructural analysis

Cross-section of the dried chunks was examined in a JSM-6400 scanning electron microscope (JEOL, Tokyo) at 20 kV at different

magnifications. IR Prestige21 FTIR spectrometer (Shimadzu, Japan) was used to generate the Fourier transform infrared (FTIR) spectra of the samples after making pellets by KBR method.

2.2.3 | Microbiological analysis

Fish samples were homogenized with Butterfield's phosphate-buffered water (1:10 wt/vol) in a stomacher blender and analyzed for aerobic plate count (APC) by pour plate method using plate count agar under incubation conditions of 35 ± 1°C for 48 hr; and mold and yeast count (MYC) by spread plate method using dichloran rose bengal chloramphenicol agar under incubation conditions of 25°C for 5 days (BAM, 2001).

2.3 | Statistical analysis

All the analyses were done in triplicate and the data was analyzed by one-way ANOVA using SPSS version 16 (IBM, USA). Tukey test at 5% level of significance was performed to determine the significant difference among the treatment means.

3 | RESULTS AND DISCUSSION

3.1 | Yield, proximate composition, and water activity

Yield and proximate composition of different samples are depicted in Table 1. With increasing microwave power, moisture was reduced from an initial value of 76.64 g/100 g to 44.83, 39.24, and 23.05 g/100 g in T1, T2, and T3 samples, respectively after 2 hr of drying. Accordingly, the yield of drying varied markedly among the treatments as T1 had 50.32 g/100 g and T3 had 37.33 g/100 g yield after 2 hr. In order to get an optimum moisture content as that of T2, the HAD and SD samples were dried for 16–18 hr and the respective moisture content and yield of drying in SD and HAD samples were 32.45% and 38.45 g/100 g and 38.6% and 39.5 g/100 g. There is mounting evidence, suggesting that moisture removal during microwave vacuum drying is remarkably faster than conventional drying methods like sun drying or hot air drying (Fu et al., 2015; Pu & Sun, 2017). There are three distinctive drying rate regions that characterize microwave vacuum drying (Scaman et al., 2015). During the "increasing rate region," temperature of the material rises rapidly to reach the boiling point of water, while the pressure controls extensive heating. During the constant rate region, the free water is rapidly diffused and evaporates from the material. In the third stage, i.e., falling rate period, rate of moisture removal slow down as the bound water is removed. In microwave vacuum drying, the falling rate period is reduced because most of the water is removed during the constant rate period whereas in the conventional drying method, two-thirds of total drying time is consumed by falling rate region. Hence, traditional drying processes require longer duration for dehydration in the falling rate period. Accordingly, hot air drying and sun drying processes continued for 16–18 hr to bring down the moisture content to 32–38 g/100 g.

Drying for 2 hr at 600 W reduced the moisture content to 44.69 g/100 g only, while drying at 700 W could reduce the moisture content to 24.4 g/100 g in tuna chunks. In microwave drying, the rate of dehydration is fundamentally decided by the ratio of microwave power to the quantity of moisture to be removed (Scaman et al., 2015). Hence, the greater the microwave power, the faster the moisture removal. Plenty of literature proves that the drying rate increases with an increase in microwave power (Chahbani et al., 2018; Doymaz et al., 2015). Ganesapillai et al. (2012) observed a threefold reduction in the drying time of ginger slices when the microwave power was increased from 100 to 300 W. Similarly, by increasing the power from 120 to 240 W, 80% reduction in drying time of ginger slices was recorded by Mohanta et al. (2014). In our study, though the drying time was kept constant for the microwave vacuum process, an increase in power lead to significant variation in the moisture content of the dehydrated sample.

Significantly higher ($p < .05$) protein content was noticed in T3 (56.59 g/100 g) followed by SD (49.67 g/100 g) sample, while the lowest protein value was with T1 (38.77 g/100 g). The variations in protein owe to the differences in the moisture content of the samples. Different microwave power levels and drying methods did not significantly influence the ash content whereas the fat content of the T1 sample was significantly lower ($p < .05$) among all the samples. The elementary principle of drying is to bring down the water activity of food to the required value where the growth of

TABLE 1 Yield, proximate composition, and water activity of the dehydrated Tuna chunks

Parameter	T1	T2	T3	SD	HAD
Yield (g/100 g)	50.32	42.66	37.33	38.6	39.5
Moisture (g/100 g)	$44.69^{d} \pm 0.62$	$39.26^{c} \pm 0.51$	$24.40^{a} \pm 0.5$	$32.80^{b} \pm 0.35$	$38.45^{c} \pm 0.42$
Protein (g/100 g)	$38.77^{a} \pm 0.55$	$43.10^{b} \pm 0.65$	$56.59^{e} \pm 0.48$	$49.67^{d} \pm 0.49$	$45.30^{c} \pm 0.49$
Fat (g/100 g)	$2.20^{a} \pm 0.201$	$3.78^{b} \pm 0.4$	$3.93^{b} \pm 0.17$	$3.86^{b} \pm 0.154$	$3.37^{b} \pm 0.43$
Ash (g/100 g)	13.39 ± 0.33	13.27 ± 0.15	13.52 ± 0.27	13.03 ± 0.17	13.44 ± 0.39
Water activity	$0.890^{e} \pm 0.004$	$0.856^{d} \pm 0.005$	$0.78^{a} \pm 0.003$	$0.823^{b} \pm 0.004$	$0.844^{c} \pm 0.002$

Note: Values represent mean ($n = 3$) ± standard deviation. Different superscripts in a row indicate the values are significantly different.

microorganisms is inhibited to extend the shelf life (Qiu et al., 2019). Water activity is an important quality parameter deciding the microbial spoilage of dried food. Water activity values 0.98–0.99 is best for the growth of microorganisms, but the majority of the microbes stop growing at $a_w < 0.90$ (Sen, 2005). There is a direct relationship between moisture content and water activity. Accordingly, T1 with 44.69 g/100 g moisture had the highest water activity (0.89) and T3 with 24.40 g/100 g moisture had the lowest water activity (0.78). Most spoilage bacteria and spoilage yeast require a water activity of 0.91 and 0.88, respectively but the spoilage mold can survive up to 0.8 a_w (Sen, 2005). According to this profile, all the dried tuna chunks except T1 and T2 can hinder the growth of spoilage bacteria and yeast but not mold. The T1 and T2 samples are susceptible to both bacterial, yeast and mold growth. Consequent upon the lower moisture content, water activity of SD and HAD samples was lower than that of T1 and T2 samples.

3.2 | Rehydration properties

Rehydration ability of dried fish is very important in deciding its quality as the dried products are mostly rehydrated before final preparation. Rehydration rate (RR) of the dehydrated tuna chunks prepared in the present study is given in Figure 1. The tuna chunks dried at 600 W (T1) displayed the lowest rehydration rate. It is clearly noticeable that the RR of HAD and SD samples were significantly ($p < .05$) lower to T2 and T3 samples. Rehydration ability can also be considered as an index of cell damage that occurred during the drying process (Wang et al., 2013). Generally, during microwave vacuum drying, a porous structure is developed in the tissue aided by the fast removal of moisture. These pores enable rapid rehydration by faster diffusion of water. In conventional drying methods such as sun drying or hot air drying, case hardening is a limiting factor influencing the rehydration properties (Viji et al., 2019). Closure of surface capillaries supported by case hardening during the prolonged drying period might have led to poor rehydration rate of sun dried and hot air-dried tuna chunks. Our results were consistent with those reported for fruits and vegetables dried by microwave vacuum drying (Giri & Prasad, 2007; Monteiro et al., 2018; Pu & Sun, 2017). RR of chunks dried at 600 W was the lowest among all samples owing to its higher moisture content and a tight microstructure which limits further diffusion of moisture into the muscle. After 30 min of rehydration, RR of chunks dried at 700 W started declining and remained lower to that of the chunks dried at 650 W. Similar to our finding, Mohanta et al. (2014) also observed less rehydration ability in ginger slices when the microwave power increased from 120 W because of shrinkage of cell structure caused by faster drying rate.

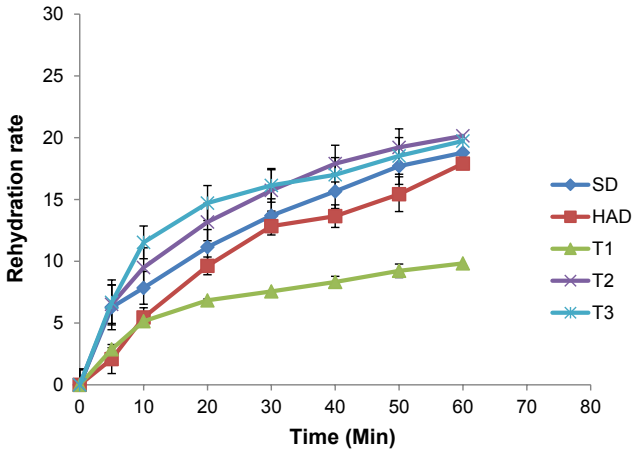


FIGURE 1 Rehydration rate of the dried Tuna chunks

3.3 | Color

The hunter color values (L^*, lightness, a^*; redness [+a] or greenness [−a] and b^* yellowness [+b] or blueness [−b]) were used to evaluate the color attributes of tuna chunks dried by different methods. As shown in Table 2, there was no significant difference ($p > .05$) between the lightness (L^*) value of tuna chunks dried in microwave vacuum drier at 600 and 650 W. However, hot air drying and sun drying process markedly affected the color of tuna chunks by imparting significantly lower ($p < .05$) L^* values compared to the microwave vacuum drying process. During drying, color of food materials changes depending on the factors including pigment degradation, enzymatic and non-enzymatic browning (Ling et al., 2015). In the present work, since the tuna chunks were marinated with spices before drying, the final color owes to a combination of all these factors. Microwave heating has been proven to be the supreme cooking method to retain the color of fruits and vegetables (Akdas & Bakkalbas, 2017; Armesto et al., 2016). In our study too, microwave drying preserved the color of tuna chunks compared to hot air and sun drying methods. The difference could be attributed to higher degree of the denaturation of protein and myoglobin that occurred during an extended drying period in sun-dried and hot air-dried products. Guo et al. (2017) in their review on microwave processing technique states that there is a reduction in the denaturation of myoglobin and other protein during microwave heating because of low exposure time. Similar results were observed in our previous studies with microwave vacuum drying of mackerel and squid shreds. In contrary to the results of Perez-juan et al. (2012), increasing power level could not significantly affect the lightness of dried tuna chunks which could be attributed to the same exposure time (2 hr) given at each power level.

3.4 | FTIR spectra and *SEM* image

All dehydrated samples displayed similar spectra irrespective of the drying method. However, little variations among the amplitude of the major peaks were identified (Figure 2). FTIR spectra are chiefly used as a tool to assess the extent of protein denaturation in muscle foods. The major peaks are amide I (wavelength 1600–1700), amide II (1500–1600) and amide III (1200–1300), and amide I and

TABLE 2 Color attributes of the dehydrated Tuna chunks

Sample	T1	T2	T3	SD	HAD
L^*	$49.02^{c} \pm 0.28$	$49.48^{c} \pm 0.47$	$50.85^{d} \pm 0.56$	$43.86^{a} \pm 1.01$	$45.94^{b} \pm 0.18$
a^*	$12.04^{c} \pm 0.12$	$8.09^{a} \pm 0.10$	$12.72^{d} \pm 0.07$	$8.375^{b} \pm 0.16$	$13.37^{e} \pm 0.07$
b^*	$37.40^{c} \pm 0.31$	$30.23^{b} \pm 0.31$	$31.24^{b} \pm 0.44$	$26.44^{a} \pm 0.87$	$31.10^{b} \pm 0.25$

Note: Values represent mean ($n = 5$) ± standard deviation. Different superscripts in a row indicate the values are significantly different.

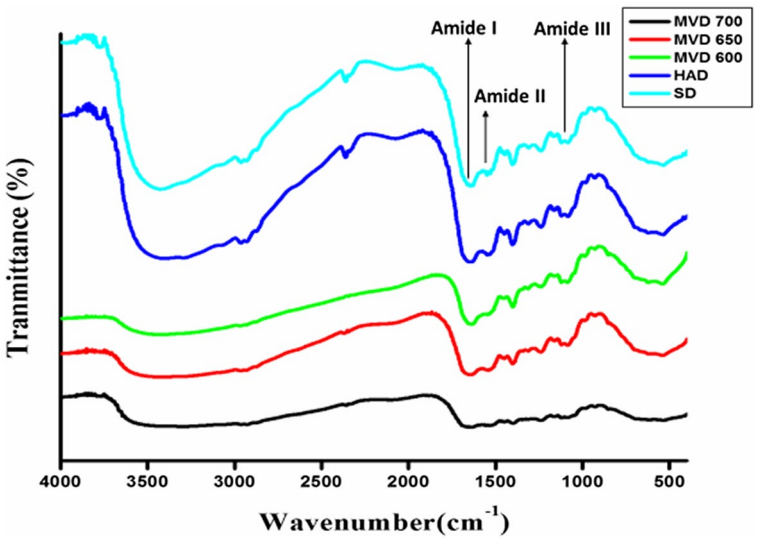


FIGURE 2 FTIR spectra of the dehydrated Tuna chunks

amide II bands are generally used to indicate the protein denaturation (Barth, 2007). As suggested by Carbonaro and Nucara (2010), amide I is the most reliable indicator of the secondary structure of protein. Figure 2 displays an apparent widening and shifting of all the major peaks affected by drying methods which indicate the protein denaturation was more with microwave vacuum-dried samples. Within the microwave vacuum-dried samples, the amplitude of major peaks increased with an increase in power level. It has been proven that microwave treatments accelerate protein degradation (Jiang et al., 2018) by altering the tertiary structure. Plagemann et al. (2014) opined that microwave heating has a significant impact on the secondary structure and activities of protein as the proteins have higher dielectric constant. According to these hypotheses, the SD and HAD samples have undergone lesser degree of protein denaturation compared to MVD samples. Similar to our findings, Jaya (2009) observed a difference in the peak of yogurt dried by microwave vacuum drying compared to those dried by air.

Scanning electron microscopy images of food is useful to assess the microstructural changes induced by any treatment/process. *SEM* images of the cross-section of dried tuna chunks are given in Figure 3. Various dehydration methods used in the study had a remarkable influence on the microstructure of the products as shown in Figure 3. In the samples dried at 600 W, the muscle fibers were intact and arranged in an orderly manner. As the power increased, a loosening of the muscle fiber was visible and in the sample dried at 700 W, the space between the fibers is more. The conventionally dried samples had a tough morphology with a tight arrangement of the muscle fibers. It is assumed that the changes in the microstructure of microwave vacuum-dried sample are associated with the rate of water vapor evaporation. Rapid evaporation of water caused loosening of muscle at increased microwave power level. However, an increase in microwave power above 650 W resulted in structural damage as revealed from the fractures of the muscle fiber. Li et al. (2019) reported that low microwave power was beneficial for controlling the muscle structure damage during the cooking of yak meat. Results of the present study were consistent with our earlier research on squid flakes (Pankyamma et al., 2019) as microwave vacuum drying led to a spongy and smooth muscle fiber alignment against the tough and tight arrangement of muscle fibers of hot air-dried squid flakes.

3.5 | Lipid oxidation

Oxidation of food lipids results in the development of unpleasant odor and flavor, loss of nutritional value, and shortening of storage life (Secci & Parisi, 2016), and hence, lipid oxidation is of great concern in dried fish and fish products. Peroxide value is useful to assess the primary oxidation products, while TBARS value gives an idea of the extent of secondary oxidation. As given in Figure 4 a, PV of microwave vacuum-dried samples were higher than SD and HAD samples at 0 month with T3 showing a significantly higher ($p < .05$) amount of PV than all other samples. After 2 months, PV increased in all samples irrespective of the drying methods. Similarly, TBARS also increased after 2 months of storage in all samples with significantly higher ($p < .05$) values in samples dried by microwave vacuum

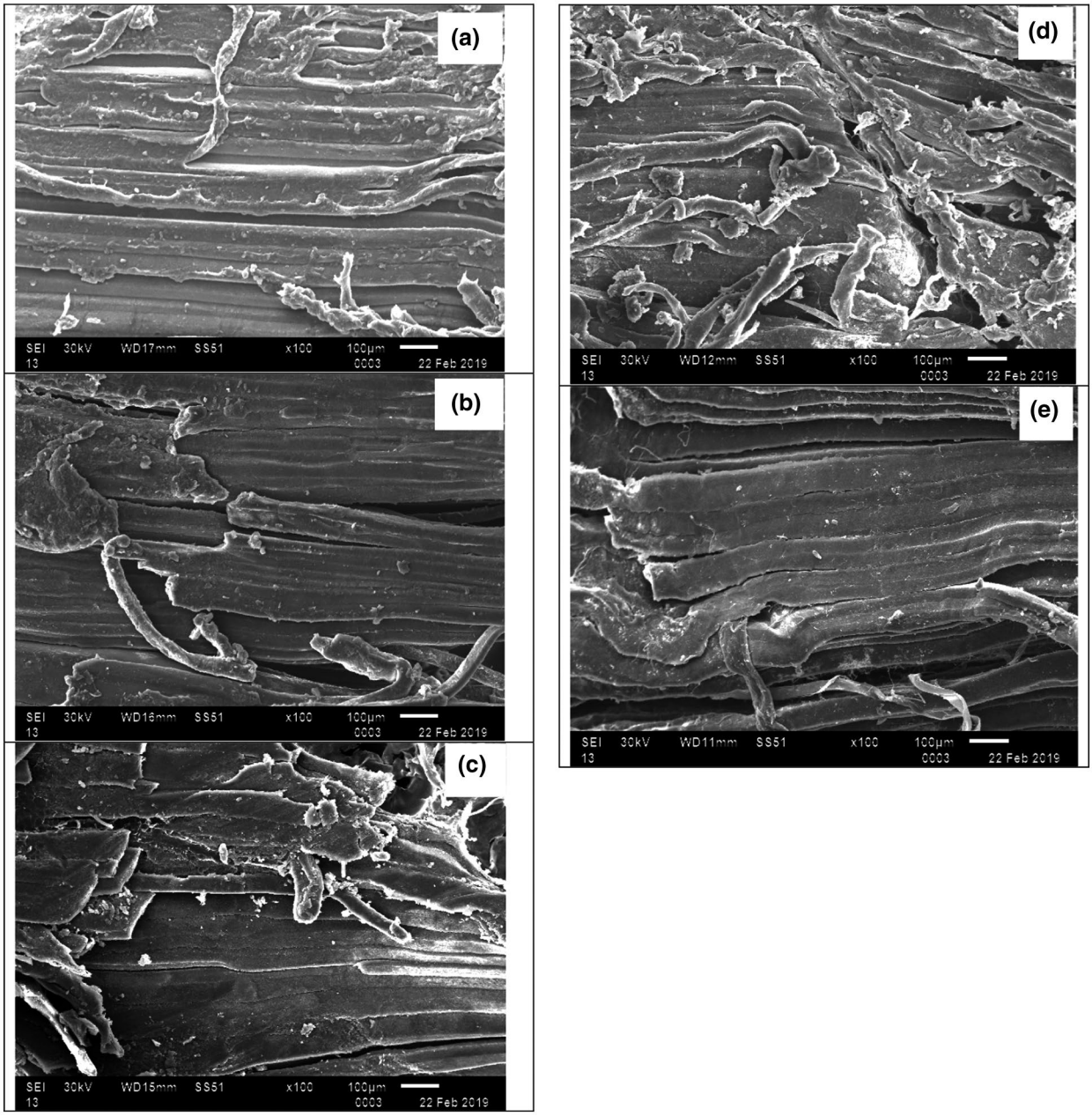
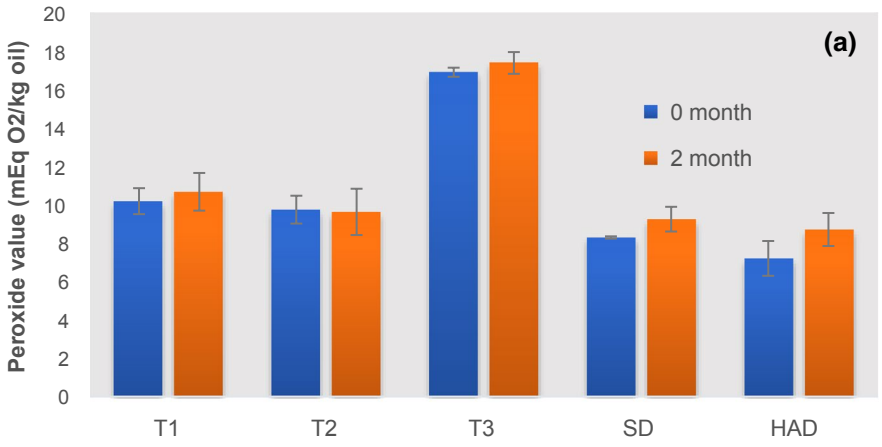


FIGURE 3 *SEM* images of the dehydrated Tuna chunks ((a) T1, (b) T2, (c) T3, (d) HAD, and (e) SD)

drying process (Figure 4b). As in the case of PV, T3 sample displayed a significantly higher ($p < .05$) TBARS value among all the dried tuna chunks at 0 and after 2 months storage. Among the sun-dried and hot air-dried samples, lipid oxidation was higher with SD samples as shown by its higher PV and TBARS values when compared to that of HAD sample. The results also point out that the degree of lipid oxidation intensifies with an increase in microwave power level.

During sun drying, oxidation of fish lipids is facilitated by direct exposure to sunlight for a longer duration. Selmi et al. (2010) compared the oxidative stability of silverside fish during sun drying and hot air drying and Tir et al. (2017) compared the oxidation of sun-dried and hot air-dried cuttlefish. In both studies, significantly higher amounts of TBARS, PV, and free fatty acids were observed in sun-dried samples. The authors assume that the formation of singlet oxygen is accelerated by sun light and hence, fasten the rate of oxidation during sun drying process. Additionally, the longer drying time of sun drying resulted in increased oxidation compared to hot air drying process. In agreement with our previous studies, microwave vacuum drying has increased lipid oxidation significantly. Many researchers support our finding that microwave heating accelerates lipid oxidation (Dominguez et al., 2014; Fu et al., 2015). Researchers suggest that high electromagnetic field separates fat cells from the muscle and hence, it becomes exposed to oxidation (Yarmand & Homayouni, 2009). In the research of Abbas et al. (2016), corn oil was heated at low and medium power settings in a domestic microwave oven for different time duration to study its quality degradation. The results revealed that the degradation rate as measured by peroxide value, p-anisidine



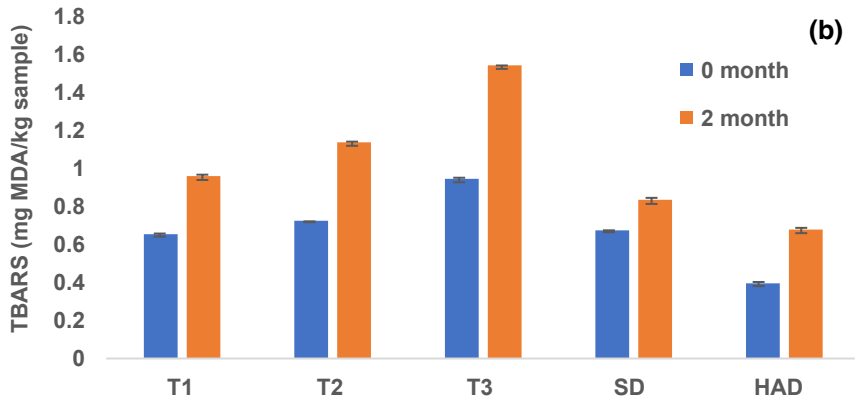
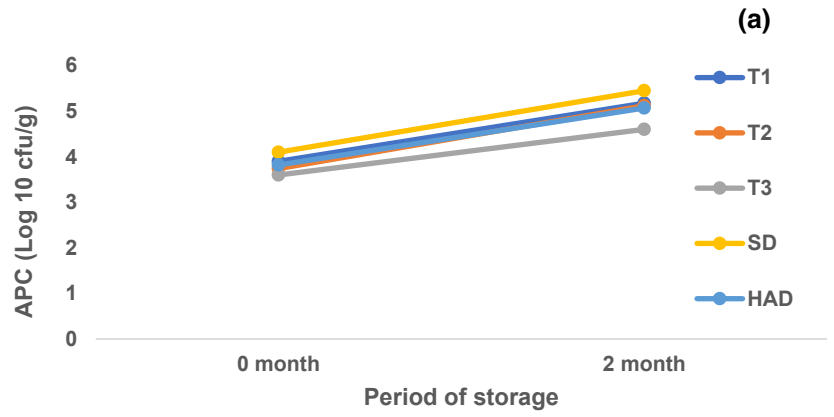


FIGURE 4 Peroxide value (a) and TBARS (b) of dehydrated Tuna chunks



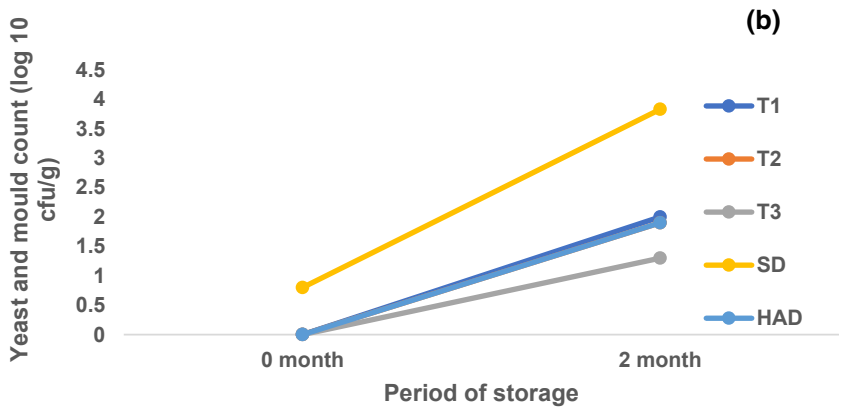


FIGURE 5 Aerobic plate count (a) and yeast and mold count (b) of dehydrated Tuna chunks

content, free fatty acid content, etc., was higher when corn oil was heated at medium power compared to lower power settings. Qiu et al. (2019) pointed out that a rise in the product temperature and drying time is responsible for lipid oxidation during microwave drying. In our study, rate of oxidation increased with increase in microwave power at a given time of dehydration.

3.6 | Bacterial and mold growth

All the dehydrated samples were stored at room temperature for 2 months and evaluated its total aerobic plate count and mold count. The results are shown in Figure 5. Immediately after drying, the APC was found to be lower with microwave vacuum-dried samples irrespective of the microwave power, compared to sun-dried and hot air-dried samples. Among the MVD samples, the T3 sample had the lowest bacterial count and T1 had the highest APC which reveals that increase in microwave power led to more destruction of bacteria. Microwave treatment inactivates the microorganisms by two mechanisms; heats generated by microwaves denature the microbial protein and at molecular level, reorientation of microbial DNA by microwaves (Sen, 2005). The sun-dried sample had the highest APC probably due to its prolonged exposure to open-air during the drying process, making the sample susceptible to bacterial contamination. Since T5 samples are dried in a closed chamber, its APC was lower that of T4, the sun-dried counterparts. Except for the sun-dried samples, the presence of mold was not detected in any other samples immediately after drying. Many researchers point out that open-air sun drying is prone to higher levels of microbial contamination (Eze & Agbo, 2011).

Aerobic plate count of all samples had shown a marked increase over two months storage. In contrary to the initial load of bacteria, the T1 and T2 samples had distinctly higher bacterial count than the T3 sample and T5 sample at the end of two months storage. This huge variation is possibly due to higher moisture content and high water activity of those two samples (T1 and T2) compared to other samples which might have facilitated the proliferation of bacteria during storage. However, sun-dried sample (T4) registered the maximum bacterial count during storage owing to its initial higher microbial load. In harmony with the bacterial growth, mold growth was also higher in the samples dehydrated using lower microwave powers (T1 and T2). Sun-dried samples had a huge load of mold after 2 months storage, lead to an unpleasant appearance of the samples. Reduced water activity is often reported as an effective way to inhibit mold growth (Sautour et al., 2001). Reduced a_w detain the process of spore germination and mycelium growth in food products and hence, T3 samples which had the lowest water activity among the dried samples showed lesser growth of mold during storage. Though T1 and T2 samples recorded higher a_w than that of sun-dried sample, the growth rate of mold was lower in former samples on account of the initial low load of mold in the same. Food safety and standards authority of India has recommended the maximum acceptable level of APC and mold count in dried fish is 5 log cfu/g and 1 log cfu/g, respectively (FSSAI, 2017). All the products except T3 had crossed the limit for TPC after 2 months storage period. Though the sample T3 had acceptable level of TPC, it had an objectionable odor because of fat oxidation. Hence, the shelf life of all the dried tuna chunks was considered as 2 months.

4 | CONCLUSION

In the present study, marinated Tuna chunks were dehydrated using microwave vacuum drying at different power levels and compared its quality to that of sun-dried and hot air-dried counterparts. Rate of moisture reduction augmented with increasing microwave power levels. Among the microwave dehydrated samples, the samples dried at 700 W exhibited good rehydration properties. Microbial spoilage was higher in sample dehydrated at low microwave power level because of higher moisture content. Though higher microwave power level increased the microbial stability, the lipid oxidation was higher in the same. The sun-dried and hot air-dried samples had poor rehydration properties and color attributes compared to microwave dehydrated samples. Microstructural analysis indicated a smooth and spongy arrangement of muscle fiber in samples dehydrated at 700 W, while a tight muscle fiber arrangement was noticed in sun-dried and hot air-dried samples. Though sun-dried Tuna chunks had lower water activity than microwave dehydrated samples at 600 and 650 W, the former was more susceptible to microbial spoilage due to its high initial load of bacteria and mold. Among the samples, lipid oxidation was lowest in hot air-dried Tuna chunks. Shelf life of the Tuna chunks was determined as 2 months at ambient temperature storage based on the microbiological analysis.

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CONFLICTS OF INTEREST

The authors have declared no conflicts of interest for this article.

AUTHOR CONTRIBUTIONS

Conceptualization; Data curation; Formal analysis; Investigation; Writing-original draft; Writing-review & editing: Pankyamma. *Formal analysis; Project administration*: Badireddy Rao. *Formal analysis*: Debbarma. *Formal analysis; Software*: Pallela Panduranga Naga.

DATA AVAILABILITY STATEMENT

The research data are not shared.

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