Intl. J. Food. Ferment. Technol. 5(2): 201-211, December, 2015

DOI Number: 10.5958/2277-9396.2016.00010.6

RESEARCH PAPER

Effect of drying in Solar-Biomass hybrid Tunnel dryer on Biochemical, Microbial and Sensory Properties of Mackerel (*Rastrilliger Kangurta*)

B.R. Chavan[1], A. Yakupitiyage[2], S. Kumar[2] and V.B. Sutar[3]

[1]Marine Biological Research Station, (DBSKKV) Zadgaon, Ratnagiri-415612, MS.
[2]School of Environment, Resources and Development, Asian Institute of Technology, P.O. Box 4, Klong Luang, Pathumthani 12120, Thailand.
[3]College of Fishery Science (MAFSU), Udgir, Latur, MS

Corresponding author: brc15672@gmail.com

Paper No. 99 Received: 16 Jan 2015 Accepted: 07 Dec 2015 Published:

Abstract

Drying of mackerel was conducted using solar biomass hybrid tunnel dryer (S-BHTD) and open sun drying (OSD) at air temperatures 32.4-57.7°C, relative humidity of 23.9-85.8% and air flow rate 0.20-0.6 ms^{-1}. Solar radiation ranged between 287-898 Wm^{-2} during the experimentation. During the night time, drying was carried out by combusting biomass**.** The fresh mackerel dried in experimental dryer and in open sun drying achieved the final moisture content <17% (w.b.). The drying time required in S-BHTD was 21 h. The overall drying efficiency of the solar-biomass hybrid tunnel dryer was estimated to be about 5.42 during fish drying. S-BHTD significantly influenced the biochemical properties of dried mackerel. Mackerel dried by using S-BHTD showed very high corresponding coefficients of determination, where all R^2 were greater than 0.85, except histamine value. In experimental dryer, microbial growth was not found except TPC (<30 cfu/g) which was within the acceptable limit. Contour plots of dried mackerel in S-BHTD dryers also showed that for all the sensory attributes examined, panelists preferred more the fish dried with S-BHTD than OSD. The optimum points for all sensory attributes of dried mackerel evaluated at temperatures ranged from 45-55 °C for 20-30 h. Biochemical, microbial analysis and sensory evaluation showed that the dried mackerel remained acceptable after 120 days of storage at ambient temperature. The data showed that the drying in S-BHTD resulted in high quality dried mackerel. The study suggests that the experimental dryer could be used successfully to produce high quality dry fish.

Keywords: Solar Biomass Hybrid Tunnel Dryer, Mackerel Drying, Open Sun Drying, Dried Mackerel, Fish Dying

Drying of fish is mainly carried out by the traditional method of open sun drying in India but the process is not hygienic and the fish is vulnerable to infestation with insect larva besides contamination with microorganisms. The net result is in 10-40% post harvest loss as supported earlier (Wall *et al.* 2001). The losses of dried reportedly fish occurred mainly because of inadequate drying in open sun (Gopakumar, 1998), employing a wooden horizontal racks resulting in a very slow drying process and such drying method makes dried fish not only unhygienic but less nutritious by partial destruction of the proteins content of the fish through oxidation and bacterial or enzyme degradation (Braguy, 2007). Solar drying can be considered as an elaboration of sun drying (Bala and Mondol, 2001). Njai, (1987) tested three types of solar dryer tent, house, and dome shaped for drying fish. It was found that the dryers did not reduce drying time significantly but quality of the dried product was improved in terms of reduced contamination by dirt and infestation by blowflies.

The research performed so far on solar drying at various institutes has revealed that to meet the increasing demand for food preservation in developing countries, simple, cheap but efficient solar dryers, supplied with a fan for ventilation and supplementary heat sources need to be developed (Arata and Sharma, 1991). Several designs of solar dryers have recently been proposed for drying applications of fish in developing countries though still a good deal of work is being continued on this aspect (Ratti and Mujumdar, 1997).

Drying of fish like mackerel is commonly practiced during the glut production of fish in the coastal areas of various countries (Gopakumar, 1998). Therefore, to ensure the production of a high quality dried mackerel, a pre-requisite for a proper and safe preservation, the existing fish processing technology must be optimized in terms of hygiene and adapted to the specific requirements of a solar dryer. The quality characteristics of the dried mackerel on one hand is affected by the composition of the chemical components, the moisture content of the product after harvesting, contamination by microorganisms with the drying parameters (temperature, relative humidity and velocity of the drying air as well as the drying time). On the other hand, the objective of this study was to investigate the effect of solar biomass hybrid tunnel dryer on physic-chemical, biochemical, microbiological and sensory properties for improvement of quality characteristics of dried mackerel. Mackerel (*Rastrilliger kangurta*) using solar biomass hybrid dryers. The results are reported in this communication.

Materials and Method

Raw materials: Fresh mackerel (*Rastrilliger kangurta*) were purchased from Mahachai fish landing centre, Mahachai, Thailand. These were then, transferred to the laboratory in polystyrene boxes with crushed ice within 2 hours of purchase. The fishes were washed with potable water and packed in 200 gauge high-density polythene sacks and stored in -20^{o}C, till use.

Solar biomass hybrid tunnel dryer

The dryer (Fig. 1) consists of a flat plate air-heating solar collector, integrated with a drying chambers. The tunnel dryer has a width of 1.8 m and a total length of 8.25 m. The first 4 meters served as a solar air heater, and the remaining 4.25 meters constituted the drying tunnel. The side height for the air flow was 0.07 m to accommodate the trays with the products. In order to have flow rate variation from about 300 m^3/h to more than 600 m^3/h, five AC- driven fans of 14 W capacity, were placed in front of the collector. However, in our drying experiment we had used only three AC-driven fans. Glass wool insulation with thickness of 4 cm to reduce the heat losses (Fig. 1).

Fig. 1: Solar biomass hybrid tunnel dryer

A 0.2 mm thick UV stabilized polyethylene sheet was used as a glazing material for the dryer. The transmissivity of the plastic cover was about 0.89 for beam radiation and the covering sheet was tilted like a roof to prevent water entering or even flooding during the rain fall. The roof supports by the side frames and metal string running from the collector inlet to the dryer outlet was connected so that the covered plastic did not sag. The plastic cover consisted of two pieces, one each for the collector and the dryer. The part of the collector was fixed at all four edges. For spreading out the drying material inside the tunnel dryer, the cover foil had to be removed by rolling up the foil on a crank made of galvanized pipe that was riveted to one end of dryer cover. At the end of the dryer, an alluminium mesh was established to avoid any insect entering in the dryer. The support for the collector dryer unit was made of small brick pillars. Ten pillars, each of 0.3* 0.3 m^2 were piled to a depth of 0.2 m below the surface. The height of the brick work was 0.8 m above the ground (Fig. 2) (AIT solar tunnel dryer, construction manual, 1997).

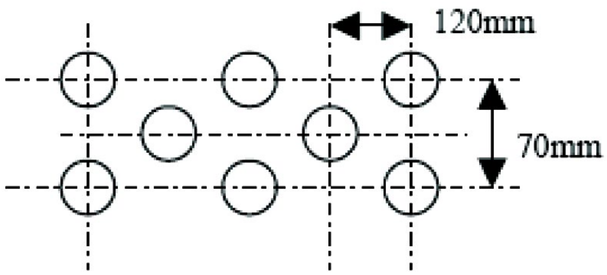

Fig. 2. Arrangement of tubes in the heat exchanger

Biomass stove-heat exchanger assembly

A biomass stove-heat exchanger assembly was fitted at one end of the tunnel, at the collector side, which was used as an alternate heat source for the dryer when solar energy was not available. Several trays were provided inside the drying chamber, on which the products were loaded in a thin layer. During day time, the dryer was operated as a solar dryer. In cloudy weather conditions or at night, the biomass stove was used. For hygienic reason, the drier stands on a 75 cm high brick plinth. Both the collector and the tunnel were covered with a 0.2 mm thick, UV-stabilized polythene sheet. The collector was painted black to act as an absorber. Mackerel to be dried were placed in perforated aluminium trays and loaded inside the drier. Easy loading and unloading of the materials was facilitated by rolling one side of the plastic cover up or down using a hand-operated pipe and crank arrangement.

Steel stove

A mild steel stove was fabricated with a width of 0.3 m, length of 0.275m, and height of 0.4 m. A grate punched with 44 holes of 1.5 cm diameter was used to increase the efficiency and quality of combustion (Mastekbayeva *et al.* 1998). The stove used a high chimney to produce hot flue gas in natural draught. The chimney was designed for a flue gas flow rate of about 139 m^{-3}.hr. A rectangular shape was chosen for the chimney design with a cross section of 0.275 m×0.16 m and the height of chimney was calculated to be about 1m (Fig. 1).

A rectangular shape of shell side to connect the heat exchanger with the solar tunnel dryer, with the dimensions: length: 1.72m, width: 0.6m and height: 016m was used. To provide an estimated total required heat transfer area of 1.74m^2, eight galvanised iron (GI) pipes with outer diameter 50mm and inner diameter 44mm were used. Tubes were arranged in a staggered manner, as shown in figure 2.

Preparation for salt-drying

Fresh mackerels were dressed by removal of fins, scales and viscera and were split open in a butterfly style by cutting along the backbone from head to tail, the guts and gills were removed and the cut made under the backbone to open out the thick part of the flesh and exposed the greater surface area for salt-drying. Dressed fishes were soaked in separate containers containing 25% (w/v) brine solution of NaCl for 4 h (Sankat and Mujaffar, 2004). A fish-to-brine ratio of 1:4L was used. Following brining the fishe were placed skin side down in aluminum tray and washed lightly with tap water, drained and loaded in the experimental dryer.

Experimental Design

Eight drying trials were carried out in solar biomass hybrid tunnel dryer (S-BHTD) with an open sun drying (OSD) as a control treatment for evaluating the effect on quality characteristics of mackerel. This study was conducted using locally available, freshly caught marine fish, mackerel. Which was dried in a solar-biomass hybrid tunnel dryer and open sun. Two batches of 25 kg dressed and salted mackerel were prepared and one was placed in the solar-biomass hybrid tunnel dryer at 08.00 hr. and the other was placed under open sun for a particular trial. Both batches were dried until 17.00 hr. The first batch was dried using the rise of internal temperature by solar collector until evening (17.00) and during the night time, the drying was continued by using the burning of eucalyptus wood biomass to raise the internal temperature until the next morning. Care was however, taken to prevent internal temperatures to exceed 58 °C. Fish that were placed under open sun (OSD) was stored in sealed plastic bags during the night-time and placed under sun in the next day.

Dryer operating procedure

Openings of the dryer were closed in the early mornings in order to raise internal temperature as quick as possible. Temperatures measurements and recordings were made by the air probe sensors K-type thermocouples (JB10) connected to a data logger (Campbell CR10KD). Thermocouples were calibrated before fixing them in the experimental dryer. Dry and wet bulb temperatures in drying area and outside the drier were measured at hourly intervals. Relative humidity (RH) of tunnel dryer was determined by using the psychometric chart. The air flow rate was measured with hot wire anemometer at the outlet of the drying chamber. The solar radiation and other meteorological data were obtained from the meteorological station at AIT. A top-loading balance with 50 kg capacity was used to measure the weight of fresh and dry fish. Each batch of fish was weighed at intervals of three hours during the drying process in S-BHTD and open sun drying. The air temperature in the drying chamber was less than 58°C and was considered suitable for drying of mackerel. The fish were dried until the final moisture content reached <17% (w.b.).

Physicochemical, Biochemical and microbiological analysis

The water activity (a_w) was measured by using Tripette and Renaud Agro CX-2, France and salt content of fresh and salt-dried mackerel were determined by the volumetric method of AOAC (2000).

Free fatty acid (FFA), Thiobarbituric acid (TBA) value and Peroxide value (PV) were analyzed by standard method (AOAC, 2000) and changes in biogenic amines such as total volatile bases nitrogen (TVB-N), trimethylamine (TMA-N) and histamine were also analyzed by using standard AOAC method (AOAC, 2000). Twenty-five gram samples were aseptically added into stomacher bag containing 225 ml of sterile peptone water (PW) (0.1% w/v) (Merck Darmstadt, Germany) and homogenized in a stomacher for 2 min. Further serial dilutions were prepared in sterile peptone water solution for microbial enumeration. Total plate counts were determined by using plate count agar (PCA) (Hi media, Bombay) incubated at 37°C for 24 hours; Coliforms on Mac-Conkey Agar (Merck Darmstadt, Germany), incubated at 37°C for 24 hours; moulds by using potato dextrose agar (PDA), incubated at 30°C for 48 hours; Staphylococci by using Baird-Parker agar (bioMerieux, Marcy l Etoile, France), incubated at 37°C for 48 hours. For the halophilic bacterial counts, the samples were prepared similarly with homogenizing solution including 15% NaCl and were plated on to standard PCA containing 15% NaCl in duplicate and incubated at 37°C for 48 hours (Andrews, 2000).

Sensory evaluation

Sensory attributes of dried fish including taste, texture, odor, appearance, and overall acceptability were evaluated to determine the optimum point of drying. The evaluation was conducted by using a 7-point hedonic scale (1= dislike extremely, 7= Like extremely) by ten semi-trained panelists selected from students, staff and faculty of AIT, having same ethnicity (Larmond, 1977). Response Surface Methodology (RSM) was used to determine the optimum condition for drying of mackerel as RSM has been reported as a suitable method for product optimization including the sensory evaluation field (Giovanny, 1993).

Statistical analysis

All data were expressed as mean and standard deviation (S.D.). Statistical analyses were performed by non-linear regression using statistical software, SPSS. In all the cases, $P<0.05$ was taken as the significance level. Data of sensory analysis were analyzed using SIGMA PLOT, computer software.

Results and Discussions

Physical parameters of food: The mean weight and length of the fish were 78.22±1.19g and 18.27±0.80cm, respectively.

Characteristics of drying condition

During drying of mackerel fish, eight experimental runs in experimental dryer were carried out. Drying temperature in the solar biomass hybrid tunnel dryer values of 34.2-57.20°C was recorded. Open sun drying temperature ranged from 31-40°C. The temperature profile showed that during day time the collector was heated by the solar radiations reached higher temperatures at the collector outlet and the drying chamber outlet. The higher temperature of drying chamber could be due to the direct and indirect heating. However by the solar radiation collector's heated air, which was blown into the drying chamber, might have contributed to the indirect heating.

During the solar-biomass hybrid tunnel, at night time the biomass stove was used for heating the drying air, due to the heat exchange, heated air was passed first in the collector unit, before entering the drying chamber which might have resulted in some heat lost. The maximum temperatures during night time were found to range between 40.6-55.7°C, which is suitable for drying of fish. The drying, temperature profile did not show any constant temperature during the day and night time which could be due to the fact that during day time the tunnel dryer temperature is based on the solar radiation, which is never constant, while at night time due to the more distance between biomass stove heat exchanger duct and the drying chamber and small the size of biomass stove, (only 2-3 kg of wood chips was accommodated in the stove at a times), in every two hours, the temperature usually falls, hence lot of variations was documented.

The relative humidity inside the drying chamber varied between 15.1-61.2, and 37-56 % of SBHTD and OSD respectively and the ambient relative humidity ranged from 41.7-76.4 % during day and 41.2-67.6 % during night time of fish drying (Fig. 3), further the ambient relative humidity decreased with increase in ambient temperature. The relative humidity of drying air is a critical factor controlling the drying rate of the product. The lower the relative humidity, the greater is the absorbing capacity of drying air. The relative humidity of air at the outlet of the dryer showed that the air still had a considerable drying potential, implying that the rated capacity of the dryer had not been fully utilized.

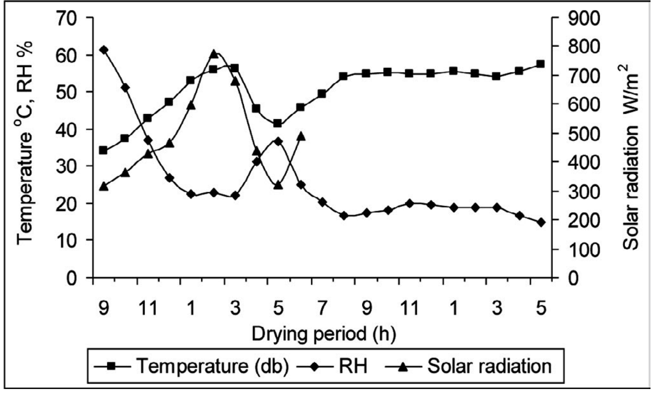

Fig. 3: Variation of temperature, humidity and solar radiations during mackerel drying in S-BHTD (Solar biomass hybrid tunnel dryer).

The solar radiation also varied by day–to–day and ranged from, 318-772 and 236-758 w/m^2 of S-BHTD and OSD, during drying process, respectively. The average air flow rate of S-BHTD, and OSD were 45.36-395.31 and 535.12 m^{-3}.h, respectively. The air flow rate was not constant and depended on the wind velocity and solar radiation as well. The variation of the air flow rate helped to regulate the drying temperature.

During high insulation period more energy was received by the collector which was intended to increase the drying air temperature, but it was compensated by the increase of the air flow rate. However, during low solar insolation period, less energy was received by the collector and air flow rate was low. Hence, the decrease in temperature due to low solar insolation was compensated by the increase in temperature due to low air flow rate. This resulted in minimum variation of the drying air temperature throughout the drying period and saved the dried fish from partial cooking due to excess temperature.

Simillar results were obtained during the drying of silver jew fish in a solar tunnel dryer (Bala *et al.* 2001).

Drying and drying rate curves

The initial moisture content of processed fish (brine treated) was 72.80 which was reduced to 16.56 within 21 hours of drying time in S-BHTD, while OSD took 44 hours of drying to bring down the moisture content of similar sample of mackerel to 16.22%. This could be due to the fact that the brine treated mackerel in the experimental dryer might have received energy both from the collector and from incident solar radiation, while the open sun dried samples received energy only from the incident radiation and could have loss a significant amount of energy to the environment. During drying, the salted fish suffered greater moisture lost at the initial stage of drying than during the subsiquent stage. This can also be seen from the drying rate of the salted fish, where a higher drying rate was observed at the initial drying stage, which implies that a greater amount of moisture was removed during that stage. This was caused by higher moisture contents in and lower salt content in fish, thus, allowing the faster moisture removal at the initial stage of drying.

Drying efficiency of S-BHTD and Open sun drying

The average drying efficiency of the solar-biomass hybrid tunnel dryer is estimated to be about 6.30% during fish drying. Performance of the solar-biomass hybrid tunnel dryer during its solar and biomass operation, during drying fish is shown in table 1.

Table 1: Drying efficiency of solar-biomass hybrid tunnel dryer

Parameters	Solar	Biomass	Overall
Initial weight of Mackerel (kg)	25.0	11.55	25.00
Final weight of Mackerel (kg)	11.55	8.10	8.10
Initial Moisture content (% wb)	72.8	41.13	72.80
Final Moisture content (% wb)	41.13	16.56	16.56
Water evaporated (kg)	13.45	3.45	16.90
Latent heat of Evaporation(kJ)	2272	2272	2272
Energy used to evaporate water (kJ)	30558.4	7838.4	38396.80
Amount of wood cheap used (kg)	—	38	38
Calorific value of the wood chips used (KJ)		16970	16970
Duration that got the energy (min)	540	720	1260
Fuel consumption rate kg/h	—	3.17	3.17
Energy supplied by biogass (kj)	—	644860	644860
Average solar radiation (w/m^2)	487.8	—	487.8
Collector area (m^2)	4	—	4
Energy from solar collector (kJ/m^2)	63218.88	0.0	63218.88
Total energy suplied to the system (kj)	63218.88	644860.0	708078.88
Drying Efficiency (%)	48.3	1.2	5.42

The drying efficiencies of S-BHTD showed 48.3% in solar operation only and 1.2% is obtained in biomass operation only, whereas in open sun drying, it was found 38.55, 10.87, 5.29, 2.64 and 2.32% during first, second third, fourth and fifth days, respectively. The overall drying efficiency of open sun drying was 12% (table 2).

Quality Characteristics of Dried Mackerel

Physicochemical, biochemical characteristics of mackerel

The fresh mackerel had salt content and water activity of 0.85±0.31% and 0.994±0.03, respectively. On salting, there was an increase in the salt content in the mackerel. During the salting, salt uptake was found to be higher because of the large surface area in the eviscerated mackerel for exposure to the salt solution. The salt concentration in the salted fish before drying was 11.19±0.32%. On the drying in the experimental dryer, the drying methods had significant effect on the NaCl content and a_w measured. The S-BHTD and

Table 2: Drying efficiency of open sun drying

Parameters	1 day	2 day	3 day	4 day	5 day	Overall
Initial weight of Mackerel (kg)	25.0	14.6	11.3	9.8	9.0	25.0
Final weight of Mackerel (kg)	14.6	11.3	9.8	9.0	8.5	8.5
Initial Moisture content (% wb)	71.58	51.29	36.85	27.65	21.32	71.58
Final Moisture content (% wb)	51.29	36.85	27.65	21.32	16.22	16.22
Water evaporated (kg)	10.40	3.30	1.49	0.79	0.52	16.50
Latent heat of Evaporation(kJ)	2272.0	2272.0	2272.0	2272.0	2272.0	2272.0
Energy used to evaporate water (kJ)	23628.8	7497.6	3385.3	1794.9	1181.4	37488.0
Duration that got the energy (min)	540.0	540.0	540.0	540.0	480.0	2640.0
Average solar radiation (w/m^2)	473.0	532.0	494.0	524.0	442.0	493.0
Air flow rate(m^3/ h)	41.42	34.27	45.63	42.59	38.22	40.41
Drying area (m^2)	4.0	4.0	4.0	4.0	4.0	4.0
Energy from solar collector (kJ/m^2)	61300	68947	64022	67910	50918	312364
Total energy suplied to the system (kj)	61300	68947	64022	67910	50918	312364
Drying Efficiency (%)	38.55	10.87	5.29	2.64	2.32	12.00

BTD drying methods had significant effect ($p< 0.05$) both on water activity and salt.

The variation of FFA, PV, TBA, TVB-N, TMA-N and histamine contents of fresh mackerel were also determined. Results showed that the fresh mackerel had free fatty acid (FFA), Peroxide value (PV) and Thiobarbituric acid (TBA) of 3.48±1.20, 3.95±0.57% and 0.99±0.20, respectively. The formation of FFA, PV and TBA is the measurement of the lipid quality. The formation free fatty acid and peroxide values is the result of the reaction between the enzyme and tri-glycerides and lead to enzymatic deterioration known as the lipid oxidation. Result shows that there was not much variation of the lipid oxidation. The TVB-N, TMA-N and histamine values were found 1.26±0.37 mg N/100g, 1.4±0.48 mg N/100g, respectively. Histamine values were found 2.55±0.58 ppm.

On salting, the FFA, PV, TBA, TVB-N, TMA-N and histamine were increased and the values of 4.08±1.20 g oleic/100g fat, 4.58±0.57 meq. Peroxide/ kg fat, 1.05±0.20 mg malonaldehyde/kg, 2.1±0.87 mg N/100g, 1.82±0.54 mg N/100g, respectively were obtained. Histamine was increased 7.78±1.25 ppm. The formation of TVB-N, TMA-N in the fish occurs due to the proliferation of the bacterial growth. The TMA-N and TVB-N is produced by the bacterial reduction of the trimethylamine oxide present in the fish flesh (Lakshmanan, *et al.* 2002). Histamine content in salted mackerel increased during salting and reached a maximum value of 7.78±1.25 mg/100g at the end of salting process. This could be due to the growth of halophilic histamine forming bacteria. The histamine forming bacteria produce histidine decaboxylase enzyme which reacts with the histidine amino acid and produce histamine (Lakshmanan, *et al.* 2002).

Drying, in S-BHTD, and OSD significantly influenced the biochemical properties of dried mackerel. Mackerel dried by using S-BHTD and OSD showed very high corresponding coefficients of determination, where all R^2 were greater than 0.90, except TBA value. Variations in bio-chemical properties of mackerel dried in S-BHTD and open sun are shown in figure 4.

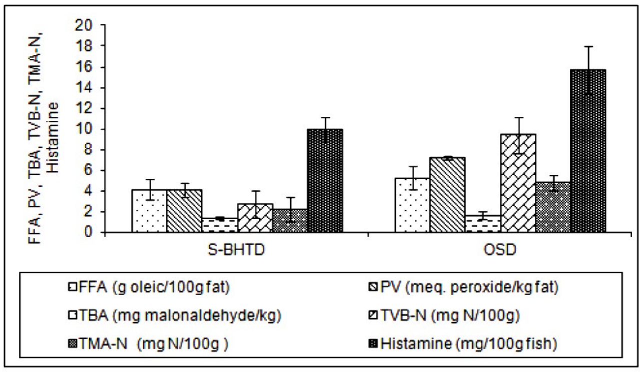

Fig. 4: Variations of bio-chemical properties of mackerel dried in S-BHTD and open sun

The intensity calibration curve of histamine determination of mackerel dried in solar tunnel dryers are shown in figure 5. High levels of histamine in dried fish can pose a health risk to consumers, where histamine can cause scombroid fish poisoning is a potent mutagen precursor. The presence of high levels of amines in salted fish showed that the products lacked necessary hygiene during production. Therefore, quality control programs in the fish industries must recommend removing contaminated fish and improving the quality of dried fish (Karmi, 2014).

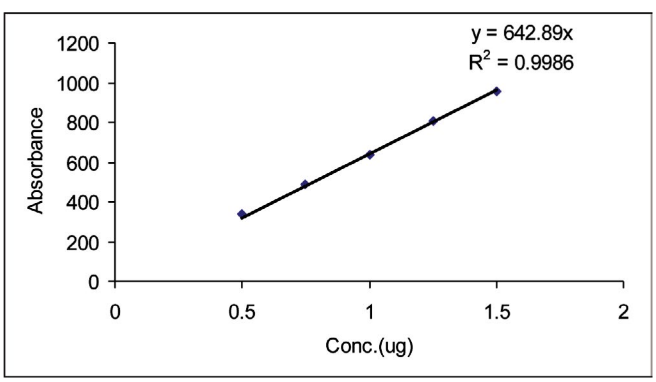

Fig. 5. Intensity curve of histamine of mackerel dried in S-BHTD and open sun

Microbial growth changes

Variation in microbial growth on fresh and dried mackerel: total plate count, coliforms, *Staphylococcus aereus*, halophilic bacterial counts and molds were observed. The initial count of the TPC, coliforms, *Staphylococcus aereus*, and total halophilic bacteria was 5.68±0.97, 3.75±0.57, 4.69±0.9, 2.8±0.39 and 3.61±0.69 cfu/gm, respectively. During the salting stage, the total halophilic bacterial count increased and reached at a level of 7.23±0.82 cfu/g, while the TPC and coliforms, *Staphylococcus aereus* were decreased, slightly. The difference in initial and salting stage bacterial count was statistically significant ($P > 0.05$). The presence of high level of total bacterial count in fresh mackerel was mainly because the visceral region of the fish is known to harbour a large number of bacteria. On drying in experimental dryer, the total bacterial count were not detected except that the total plate count (TPC) that decreased and reached a level of 0.11±0.03, and 0.12±0.01 cfu/gm of S-BHTD and OSD, respectively. After the final drying the bacterial load were almost identical.

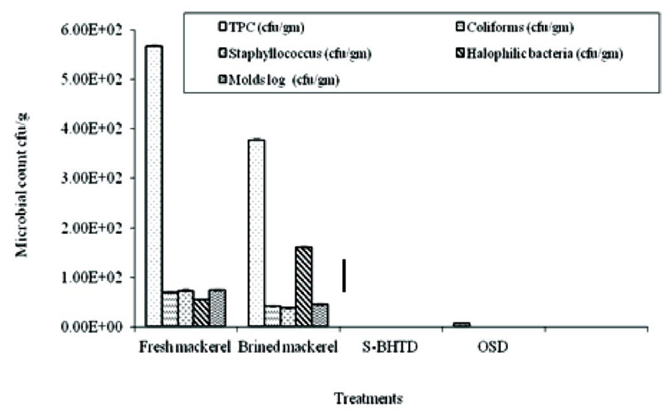

Fig. 6. Variation in microbial population of fresh, brined and dried mackerel

Sensory evaluation of dried mackerel

With respect to total halophilic amine forming bacteria in the mackerel, the initial counts were lower than 2.8±0.39 cfu/gm, which was increased on the salting stage but the microorganisms got eliminated after drying in the experimental dryers. The result showed that the total halophilic amines forming bacterial count was high at the salting stage but decreased at the final drying stage. Thus, the proliferation of halophilic amine forming bacteria was favored when the water activity was above the value of 0.75. Further, the drying of mackerel

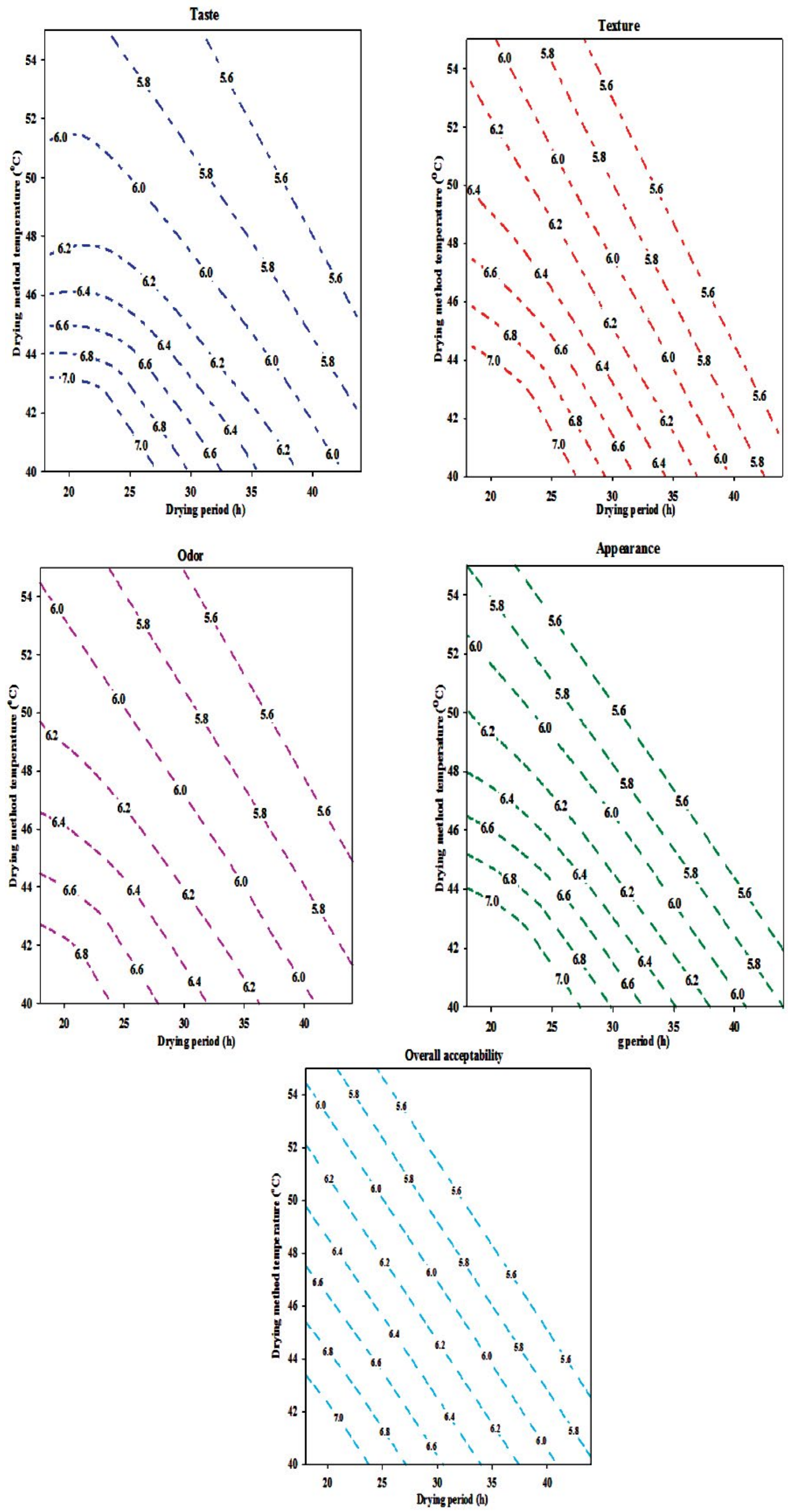

Fig. 7. Contour plot on the effect of drying and time of drying on sensory properties (Temperature <40 °C =OSD, 45-50 °C =S-BHTD)

caused a decrease in amine forming bacteria, which indicated that their growth is retarded by reduction in water activity. After drying in an experimental dryer, there were no amine forming bacteria in salt-dried mackerel. Also no histamine forming bacteria were detected in the dried mackerel (Fig. 6) since most of the bacteria that decarboxylate histidine cannot tolerate high salt concentration and reduced moisture content (Lakshmanan *et al.* 2002) and with decrease in moisture content, the activity of the decarboxylase was also reduced.

Sensory evaluations of the dried samples at various dryer temperatures were also analyzed. The regression coefficients for sensory attributes of drying methods with their coefficients of determination (R^2) showed that the drying in S-BHTD, all the sensory responses gave R^2 greater than 0.900. The R^2 values were 0.9461, 0.999, 0.9938, 0.9368, and 0.9039 of S-BHTD, for taste, texture, odor, appearance and overall acceptability scores given by sensory evaluators, respectively. In open sun drying, the R^2 values of 0.9738, 0.878, 0.9857, 0.9574, and 0.9939 for taste, texture, odor, appearance and overall acceptability scores given by sensory evaluators, respectively, were recorded. The R^2 values obtained from experimental dryers were statistically adequate for prediction. Henika (1982) stated that R^2 greater than 0.75 was used for prediction purpose.

Contour plots of S-BHTD and OSD dried mackerel showed that for all sensory attributes examined, the panelists preferred fish dried with experimental dryer. Initially, the optimum points for all attributes evaluated were at temperatures ranging from 43-50 °C for 18-29 h. Analysis showed the drying methods had asignificant effect (P<0.05) on taste, texture, odor, appearance and overall acceptability scores (Fig 7).

Conclusion

The drying behavior of mackerel drying in solar-biomass hybrid tunnel dryer and in open sun drying was studied to achieve the final moisture content <17% (w.b.). The drying time required in S-BHTD was 21 h. The overall drying efficiency of the solar-biomass hybrid tunnel dryer was estimated to be about 5.42 % during fish drying. Solar drying methods S-BHTD significantly influenced the biochemical properties of dried mackerel. Mackerel dried by using S-BHTD showed very high corresponding coefficients of determination, where R^2 were greater than 0.85, except for histamine value. In the experimental dryers, microbial growth was not recorded except TPC which was <30 cfu/g. Contour plots of dried mackerel in both the dryers also showed that for all sensory attributes examined, panelists preferred fish dried with S-BHCD. The optimum points for all sensory attributes of dried mackerel evaluated were at a temperatures ranging from 45-55 °C for 20-30 h. The analyzed data showed that the S-BHTD gave positive results for production of high quality dried mackerel. However, by improving the design (large size) of biomass stove could help to utilize the complete biomass energy.

Acknowledgements

Authors are thankful to the Co-coordinator, Aquaculture and Aquatic Resources Management, SERD, Asian Institute of technology, Thailand for providing necessary facilities to carry out the research work. The authors are also thankful to the authorities of Government of Maharashtra and Dr. Balasaheb Sawant Konkan Agriculture University, Dapoli, Ratnagiri for providing fellowship and study leave for doctoral program at AIT, Thailand.

References

A.O.A.C. 2000. Association of Official Analytical Chemists. Microbiological methods *Official Methods of Analysis.* Hortwitz, W., 13th edn. Washington, D.C. ch. 17, P 1-57.

AIT, solar tunnel dryer, construction manual. 1997. Report submitted to Swedish international cooperation development agency (SIDA). School of Environment, Resources and Development, Energy Program, Asian Institute of Technology, Thailand.

Andrews, W.H. 2000. Microbiological methods, AOAC official methods of analysis. Chapter 17: 1-57. Application. In: Skjak- Braek, G. *et. al.* eds. Chitin and chitosan: sources, chemistry, biochemistry, physical properties and applications. London, UK. *Elsevier Applied Science*. 373-382.

Arata, A. and Sharma, V. 1991. Performance evaluation of solar assisted dryers for low temperature drying applications. *Renewable Energy* **1(**5-6): 729.

Bala, B.K. and Mondol, M.R.A. 2001. Experimental investigation on solar drying of fish using solar tunnel dryer. *Drying Technology*, **19**(2): 427- 436.

Braguy, S. 2007. *Fish drying: an adaptable technology, Sustainable fisheries livelihoods programme* (SFLP). Bulletin-13, pp. 1-26.

Giovanny, M. 1993. Response surface methodology in sensory evaluation. *Food technol.* Nov: pp. 96-101.

Gopakumar, K. 1998. Dried and smoked fish products, Fish drying and smoking production and quality. *Technomic publication*, pp. 47-87.

Henika, R.G. 1982. Use of response surface methodology in sensory evaluation. *Food Tech.* November, pp. 96-101.

Karmi, M. 2014. Determination of Histamine and Tyramine Levels in Canned Salted Fish by Using HPLC. *Global Veterinaria* **12**(2): 264-269.

Larmond, Elizabeth 1977. *Laboratory Methods for Sensory Evaluation of Food*. Research Branch, Canada Department of Agriculture, Publication, p. 1637.

Lakshmanan, R., Jeya Shakila, R. and Jeyasekaran, G. 2002. Changes in the halophilic amine forming bacterial flora during salt-drying of sardines (*Sardinella gibbosa*). *Food Research International* 35(6): 541–546.

Mastekbayeva, Gauhar A., Augustus, Leon and Kumar, S. 1988. Performance evaluation of a Solar Tunnel Dryer for Chilli Drying, Paper Presented at the 'ASEAN Seminar and Workshop on Drying Technology', 3-5 June, 1988, Phitsanulok, Thailand.

N'Jai, A.E. 1987. Outlook for solar drying of fish in the Gambia. Conference Workshop on Solar Drying in Africa, Dakar (Senegal).

Ratti, C. and Mujumdar, A. 1997. Solar Drying of Foods: Modeling and Numerical Simulation. *Solar Energy* **60**(3/4): 151.

Sankat, C.K. and Mujaffar, S. 2004. Sun and solar cabinet drying of salted shark fillets. Proceedings of the 14th International drying symposium, Brazil, August 22-25, pp. 1584- 1591.

Wall, R., Howard, J.J. and Bindu, J. 2001. The seasonal abundance of blowflies infesting drying fish in south- west India. *Journal of Applied Ecology*, **38**: 339-348.