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Editorial

The current Kenya Aquatica Vol. 6(1) features application of local technology on coral reef rehabilitation; performance of locally manunfactured fish dryers, some aspects of Blue Economy, and the role of the ocean in climate change mitigation and adaptation in Kenya.

Many thanks to members of the Kenya Aquatica Editorial Board and the unwevering support we continue to receive from KMFRI, Pwani University and the Technical University of Mombasa. This year we have been fortunate to receive additional financial support from Pew Fellowship programme based at KMFRI. We are most thankful to Dr. James Kairo, Pew Fellow (2019), for providing this support that led to the successful production of the current Volume.

Volume 6(1) contains two papers on the restoration of degraded coral reef and the socio-economic impact of reef rehabilitation. Two more papers feature comparison between the solar tunnel dryer and the traditional rack dryer as well as the performance of two dryers - solar tunnel and open air rack. This Volume also features a short communication and a commentary on emerging areas of sea floor mapping and inclusions of ocean climate solutions in Kenya's Climate Change Agenda.

The Editorial Board acknowledges various reviewers of the manuscripts led by Prof. Leonard Chauka of University of Dar-es-Salaam - Institute of Marine Sciences based in Zanzibar, Tanzania.

About Kenya Aquatica

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Submitting Articles

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Comparative Drying Performance of Mackerel (*Rastrelliger kanagurta*) in a Solar Tunnel Dryer and an Open-air Raised Drying Rack

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Abstract

A sand base solar tunnel dryer was fabricated at Gazi, Kwale – Kenya and its effectiveness in drying mackerel (*Rastrelliger kanagurta*) was compared to that of an open air drying rack. The dryer consisted of a collector, drying cabinet and a photovoltaic system. The collector was covered with UV stabilized polyethylene while the drying cabinet's roof was made of glass. Direct Current fans, one for driving air in and another for extracting air were used. The drying rack measuring 10m by 1m made of mangrove poles with timber support for the nylon mesh on which the fish were laid.

The starting weights of the mackerel were 95.0 ± 18.02g and 96.7 ±5.77g in the solar dryer and drying rack respectively. The net drying time was 28 hours over a period three days. There was a significant difference ($p<0.05$) in the rate of the mackerel's weight loss in the solar tunnel dryer and on the drying rack. The moisture in the fresh fish reduced from 70.6%±0.9 (2.40kg/kg, db) to 14.5%±6.6 (0.17kg/kg, db) in the solar dryer and to 39.3%±3.4 (0.65kg/kg, db) on the rack. The drying rate constants for the solar- and rack-dried mackerel were 0.0772 h^{-1} and 0.0436 h^{-1} respectively. Drying was more uniform with the solar tunnel dryer compared to the rack dryer with drying coefficients (R^2) of 0.7544 and 0.4116 respectively. The mean temperature during the entire drying period was 57.6°C in the solar tunnel dryer and 35.6°C in the drying rack respectively. The mean humidity during the entire drying period was 46.4% in the solar tunnel dryer and 47.2% for the drying rack.

This study provides information for design engineers in the food industry in the design and operation of post-harvest fish drying facilities using low cost solar energy systems

Key Words: Solar tunnel dryer, Drying rack, Moisture content, Humidity, Temperature

Abbreviations: db = dry basis, DR = Drying Rack SD = Solar Tunnel, Dryer

INTRODUCTION

In the coastal region of Kenya, very little fish is landed by artisanal fishermen between the months of April to early September while October to March is characterized by glut and it is not possible to process the excess harvest which results in massive spoilage losses of fish by fishermen. The fishermen sell some of the fish cheaply to middlemen with the rest going to waste (Kimani *et al.,* 2018). Therefore, there is need to improve on the post harvest techniques to reduce losses by fishermen, and improve their earnings, in addition to contributing to food security.

Open sun drying is a common post harvest preservation method in the fish industry. The fish is laid on the ground or on rocks by the shores of the ocean (Kimani *et al.,* 2018). The drying process is slow and unhygienic, and is subject to dust contamination, insect infestation, and exposure to harmful human and animal handling and destruction by rodents among other pests. If drying is near homes, the fish has to be brought inside every time it rains and each evening to avoid dew and consequences such as moulds. The process results in very low quality fish with possible high moisture and limited demand in the market, high spoilage rates, higher labour in put and low income for the fishermen, in addition to loss of the fish as a source of proteins, community food security is also lost (Bala & Mondol, 2001; Sankat & Mujaffar, 2004; Mujaffar & Sankat, 2005; Sablani *et al.,* 2003). There is need to improve the quality of dried fish through technology advances in order to reduce post harvest losses and create a wider appeal for the cured fish market.

Drying racks, which are raised ventilated platforms, have been used widely in the drying of fish. The racks rely on air circulation around the product to evaporate the excess moisture, and their use reduces soiling of fish during drying. However, infestation by insects, rain and aerial contamination remain a problem during rack drying. Attempts to use improved solar drying technologies such as solar dryers in Kenya were carried out by Shitanda and Wanjala (2006) and Uluko *et al.,* (2004) but none addressed fish drying. The use of solar dryers provides an improved environment where temperatures are raised and fish is secured from most contaminating agents (Bala, 1997; Bala, 1998; Bala, 2009; Doe et al, 1977; Ahmed *et al.,* 1979; Rao *et al.,* 1987; Curan & Trim, 1982). One of the disadvantages of such dryers is the problem of internal air convection (Bala & Woods, 1994, 1995; Bala & Mondol, 2001). For effective drying, hot and dry moving air is employed. These factors are inter-related and it is important that each is correct. For instance, cold moving air or hot, wet moving air are each unsatisfactory. Attempts to utilize improved dryers with forced air convection have been made in the drying of various food products such as fruits, cereals grain legumes, oil seeds, and spices (Esper & Mühlbauer, 1993; Bala, 1997; Bala & Mondol, 2001; Bala *et al.,* 2005; Hossain *et al*, 2005, Reza *et al,* 2009). Most of these dryer designs expose the drying material to direct sun light.

A solar tunnel dryer has the capacity to improve on the quality of the dried fish as it has a partially dark drying chamber which secures material from exposure to direct sunlight in addition to elimination of most of the contaminants from accessing the drying fish. The objective of this study was to evaluate the performance of a sand base tunnel dryer against that of an open sun-drying rack in the drying of mackerel (Rastrelliger kanagurta).

METHODS

Solar tunnel Dryer construction

The, solar tunnel dryer (Fig. 1), was a modification of a solar tunnel dryer described by Bala and Mondol (2001). It was designed and fabricated at the Jomo Kenyatta University of Agriculture and Technology (JKUAT) in consultation with Kenya Marine and Fisheries Research Institute (KMFRI). The dryer consists of a solar collector chamber, a drying chamber and a photovoltaic system.

Fig. 1: Solar tunnel fish dryer

Solar Collector

The solar collector was a 7m long, 2m wide and 0.3m tunnel raised 0.4m above the ground. The maximum height at the center was 450mm above the collector base. The top outer cover was made from two layers of UV (Ultra Violet) treated polythene sheet of 500G (0.5mm). The base of the collector was made up of a 2mm thick metal plate painted black for heat absorption and encased in a sand layer for refractory and heat storage purposes. Below the sand layer was a 5mm thick wooden layer followed by a 20mm thick coconut fibre layer, both for insulation purposes. At the bottom were a 2.5mm wooden layer and a 0.5mm polythene layer for encasing the collector. The sides of the collector were made of a 2mm thick black painted metal for heat absorption, and lined by a 50mm thick coconut fibre layer for insulation. The outer surface of the collector wall was a 25mm thick black painted wooden layer for absorbing heat. To facilitate the forced air convection in the drying chamber, a 2m by 0.6m galvanized sheet plenum mounted with a 40W DC fan was fixed onto the collector.

Drying Chamber

The drying chamber was a cabinet measuring 2m wide, 2m long and 1.4m high and 0.5m above the ground surface. The maximum height of the dryer was 1.55m above the base of the cabinet. The sides of the dryer were made from 25mm thick plywood, which was lined with 0.05mm galvanized iron sheet for reflection and painted black on the outside for heat absorption. The base of the dryer cabinet was lined with 0.05mm aluminium sheet for heat reflection and ease of cleaning. A 5mm thick wooden layer, followed by a 50mm coconut fibre layer and finally a 2.5mm wooden layer for insulation encased the aluminium sheet. The roof of the drying cabinet was made from 4mm thick glass to allow for solar radiation into the cabinet and ease of inspection during the drying process. The chamber had three shelf layers for holding twelve wire mesh trays measuring 1m by 1m, and spaced 200mm apart with a maximum capacity of 200kg of fish. These were accessed from the side of the dryer cabinet via hinged doors, which could be opened wide to allow for sliding the trays into and out of the drying cabinet during loading or offloading of fish. At the outlet of the dryer cabinet an exit plenum 2m wide by 1.4m wide and fitted with a chimney 30mm in diameter and encased with a 40W DC fan was fitted to facilitate the removal of moist air from the drying chamber. The power supply system for the solar dryer was a photovoltaic system consisting of a 100W solar panel and a 100Ah deep cycle battery. This power system was used to power two axial 40W DC axial fans with a capacity of 0.46 m^3/h.

The drying rack

The traditional drying rack (Fig. 2) consisted of mangrove support frames. The rack was 10m long, 1m wide and 1m high. The top was covered by nylon mesh to avoid rust and therefore ideal for use by the sea.

Fig. 2: Raised rack fish drying

Site selection

The site selection was purposive. Gazi area was selected due to the presence of an organized community-based group (*Mpaaji ni Mungu*) who showed interest in running the project. Gazi is located in Kwale District in the south coast of Kenya. It is set on a mangrove filled bay just off the road towards the south and about 50km from Mombasa. The village lies 4°25'S, 39°30'E, and has its major landing seasons as October and March.

Drying of Mackerel

A total of 240 fresh mackerel were purchased from the local fishermen in Gazi a day before solar drying in late November 2012. The selection of the fish samples was such that only sound, wholesome fish, free from adulteration and organoleptically detectable spoilage, and of relatively the same size were subjected to further processing. After selection, the fish were de-scaled, de-gilled, split open and eviscerated. They were washed thoroughly and salted at a ratio of 1:10 salt to fish in a wooden trough for a period of 16 hours, from early evening to the following day before drying. The fish were layered alternately with salt first at the bottom of the trough followed by fish. Salt and fish layers alternated with the salt layer finally at the top. The fish were washed to remove excess salt, and placed in trays, under a shade where they were held at an angle for 1 hour to drain excess water.

After the preparation, half of the fish were distributed randomly and laid in single layers on the drying trays in the drying chamber of the solar tunnel dryer. The other half were also distributed randomly on the drying rack lying next to the solar tunnel dryer and with the drying rack kept the same height as the drying trays of the solar tunnel dryer. Three (3) representative samples of fish were taken at random from the solar tunnel dryer and traditional rack and weighed using a digital field balance (SALTPETERSK 2000-BLACK & DECKER, USA), to give the average starting weight of the fish before drying started. Every 2 hours during the period of drying, fish weight, moisture content, drying air temperature and humidity for the drying inside the drying cabinet and on the drying rack. On day-one, measurements were taken at 2 hours interval from 09.30am to 05.30; that is, at 0, 2, 4, 6, 8 hours. On day-two measurements continued from 08.15am to 06.15pm at two hour intervals i.e. (23, 25, 27, 29, 31, 33 hours from day-one). On day-three measurements continued from 8.15am to 2.15pm at two hour intervals i.e. (47, 49, 51, 53 hours from day-one). Temperature and humidity during drying was measured every 2 hours using a DICKSON TH300 (USA). Fish weight was determined by randomly weighing three (3) representative pieces of fish from the solar tunnel dryer and dryer rack every two hours and returning the fish in the dryer. Three randomly selected fish were also sampled for moisture content determination every two hours during the drying period. They were removed and wrapped in aluminium foil, and put in seal lock bags, before being labeled and placed on ice in ice boxes, after which they were taken to the laboratory in KMFRI and stored at -18°C till analysis.

Moisture content was determined according to Helrich, (1990), while moisture loss as weight loss during drying after every 2 hours was evaluated by getting the difference between starting and subsequent weight. The moisture ratio was evaluated using the equation 1 (Henderson, 1976; Kituu *et al,* 2008; Uluko *et al*., 2006).

$$MR = \frac{M}{M_0} = \exp(-kt) \quad (1)$$

RESULTS

Weight loss

The weight loss for mackerel in the solar tunnel dryer was from 95.0 ± 18.0g mean initial weight to 20.0±13.2g (Fig. 3) in day-one, which was equivalent to 78.9% loss, while in the drying rack the weight loss was from 96.7 ± 5.8 to 26.7 ± 2.9, equivalent to 64.4%. In day-two, the weight loss in the solar tunnel dryer and drying rack were from 23.3 ± 17.6g to 13.3 ± 7.6g, from 28.3 ± 5.7g to 16.7 ± 2.9g, equivalent 42.9%, and 40.9% loss, respectively. In day-three the weight loss was 13.3±7.6g to 8.3±2.9g or 37.6%, and 16.7±2.9g to 10.0±0g or 40.1% respectively for the solar tunnel dryer and the drying rack. There was no significant weight loss in day-three; therefore, the experiment was stopped after 53 hours from day-one. The relationship between weight loss and drying time for the rack drying and tunnel dryer is presented in Fig. 3.

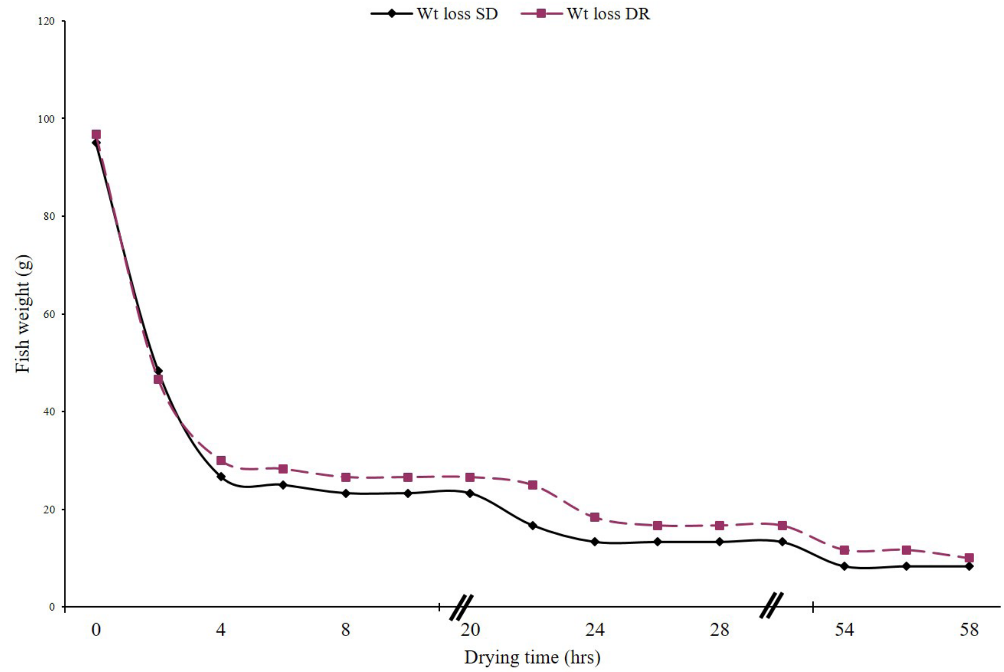

Fig. 3. Weight loss of mackerel each day in SD and DR

The overall moisture loss was 91.2% for the fish dried in the solar tunnel dryer and 89.6% for the fish dried in the drying rack at the end of the drying period. There was a statistically significant difference in weight loss ($p < 0.05$) between the solar tunnel dryer and the drying rack.

The variation in moisture content with time during drying of mackerel in the solar tunnel dryer and rack dryer is shown in Fig. 4. The initial moisture content of fresh mackerel was 2.40 kg/kg (db), or 70.6% ± 0.9 which decreased to 0.17 kg/kg (db) or 14.5% ± 6.6 and 0.65kg/kg (db) or 39.4% ± 3.4 respectively in the solar tunnel dryer and the drying rack at the end of drying.

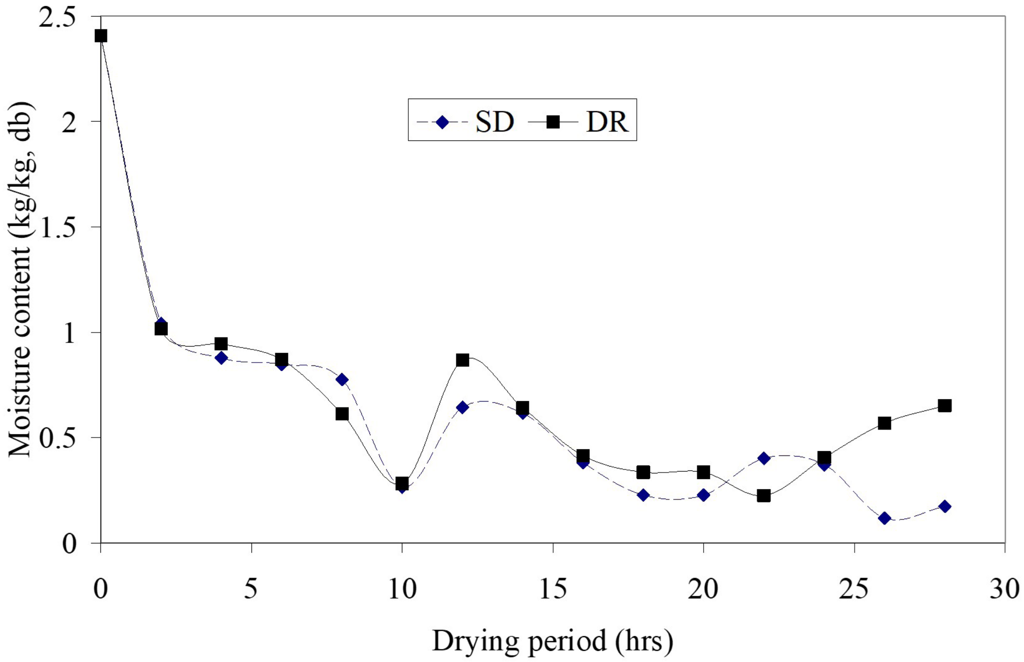

Fig. 4. Variation of moisture content against time for mackerel dried SD and DR

The moisture ratio for mackerel dried in the solar tunnel dryer and drying rack was presented as a reduction in moisture ratio with time for both types of drying environment (Fig. 5).

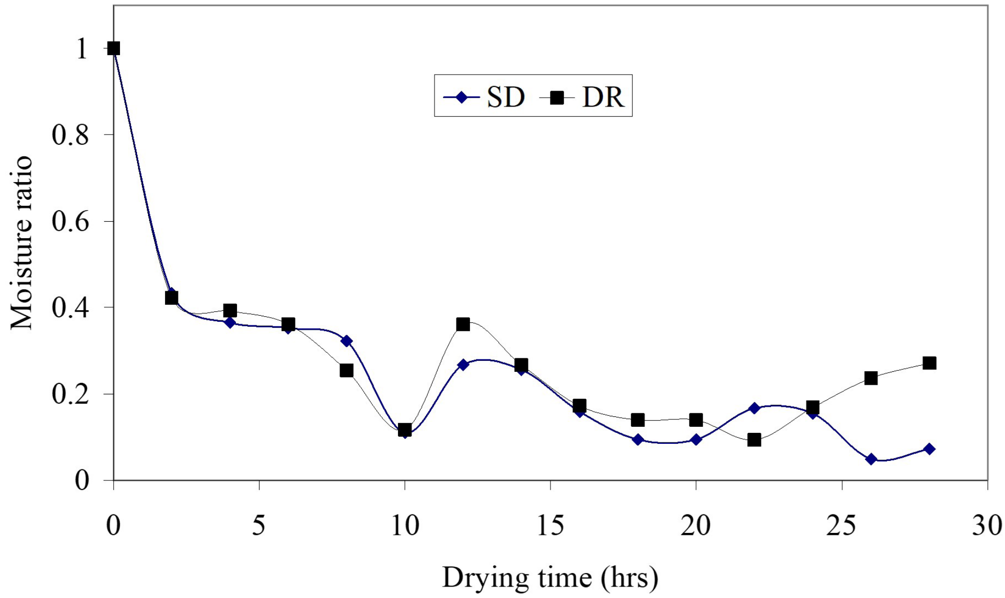

Fig. 5. Change in moisture ratio with time for drying mackerel in a SD and a DR

The change in the natural log of moisture ratio (MR) versus time for the mackerel dried in the solar tunnel dryer and drying rack is as presented in Fig. 6. The figure also presents the best curves of fit for the relationship, the equation describing the best curves of fit and the corresponding coefficients of determination (R^2).

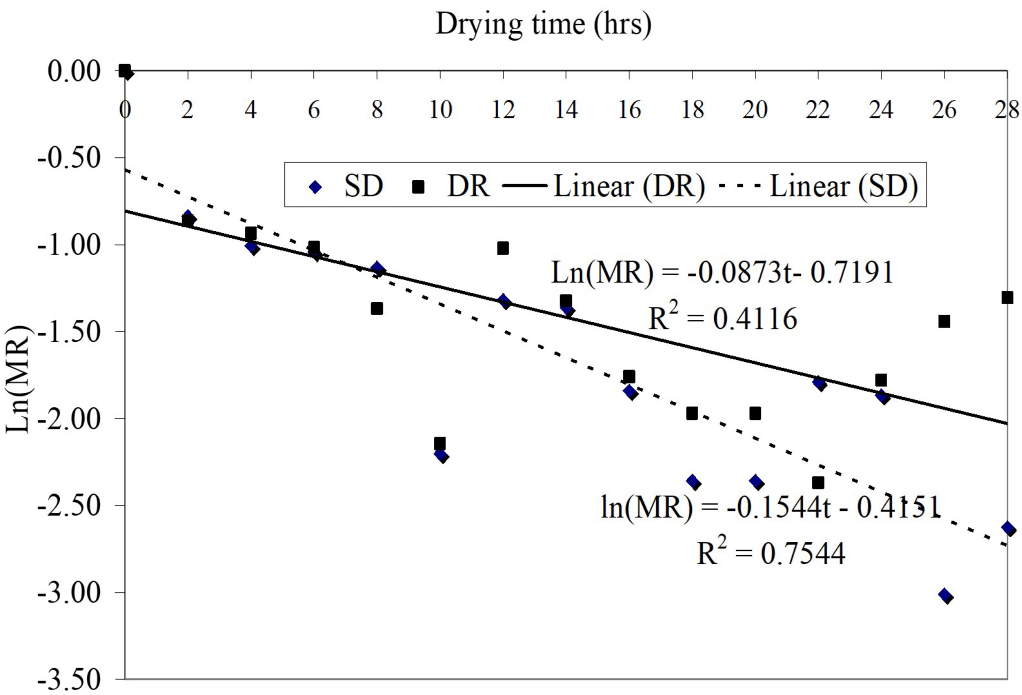

Fig. 6. Relationship between natural log of MR and time for mackerel dried in SD and DR.

The drying rate in the solar tunnel dryer and drying rack are shown in Fig. 7. More variations in drying patterns were observed in the drying rack than in the solar tunnel dryer.

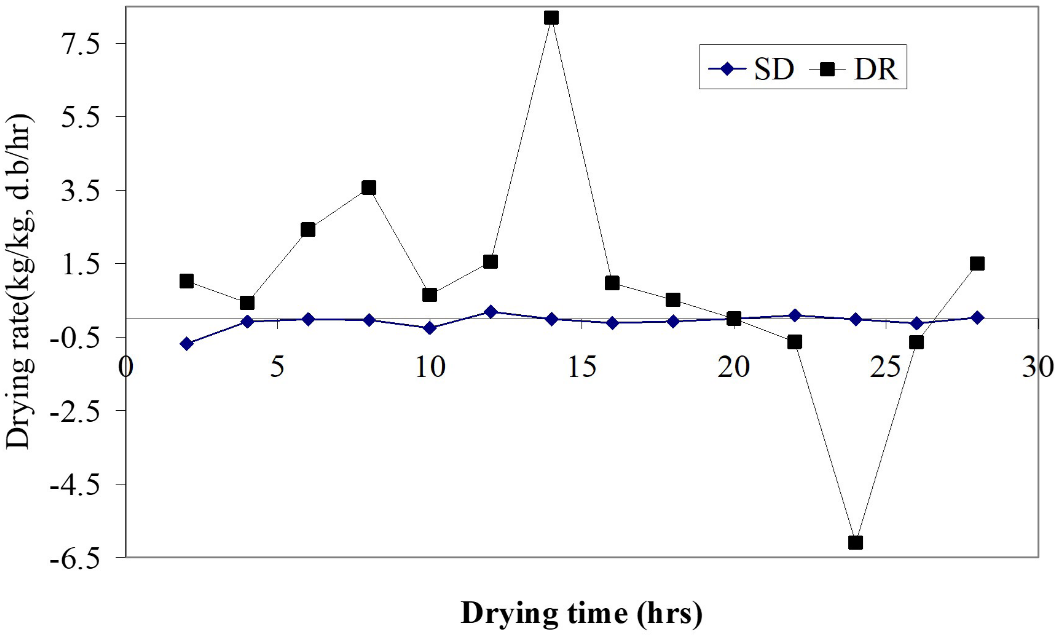

Fig. 7. Drying rate of mackerel in SD and DR

The drying rate constants for the drying of fish in the solar tunnel dryer and rack dryer are presented in Table 1. The drying rate constant for the solar dried mackerel was 0.0772 h^{-1} and for the rack dried 0.0436 h^{-1}.

Table 1: Drying equation parameters for mackerel drying in both SD and DR

	k (hr^{-1})	Coefficient of determination (R^2)
Solar Dryer	0.0772	0.7544
Drying Rack	0.0436	0.4116

Changes in temperature and humidity during the drying period are shown in Fig. 7. The mean daily and overall mean values for temperature and humidity during the drying period are presented on Table 2. Temperature increased in both the dryer and rack as the day progressed peaking between 10.00 hours and 14.00 hours. The mean temperatures in the solar tunnel dryer in da-one, day-two and day-three were 56.2°C and 56.3°C and 60.3°C respectively, while in the drying rack they were 35.3°C, 33.8°C and 37.5°C respectively for day-one, day-two and day-three. The mean temperature during the entire drying period was 57.6°C in the solar tunnel dryer and 35.6°C in the drying rack. Humidity decreased more in the solar tunnel dryer as drying progressed and was lowest in the solar tunnel dryer between 10.00 hours and 14.00 hours. The mean humidity in the solar tunnel dryer in day-one, day-two and day-three was 48.4%, 44.7% and 46%. In the drying rack it was 47.9%, 47.0% and 46.8% in day-one, day-two and day-three. The mean humidity during the entire drying period was 46.4% in the solar tunnel dryer and 47.2% in the drying rack.

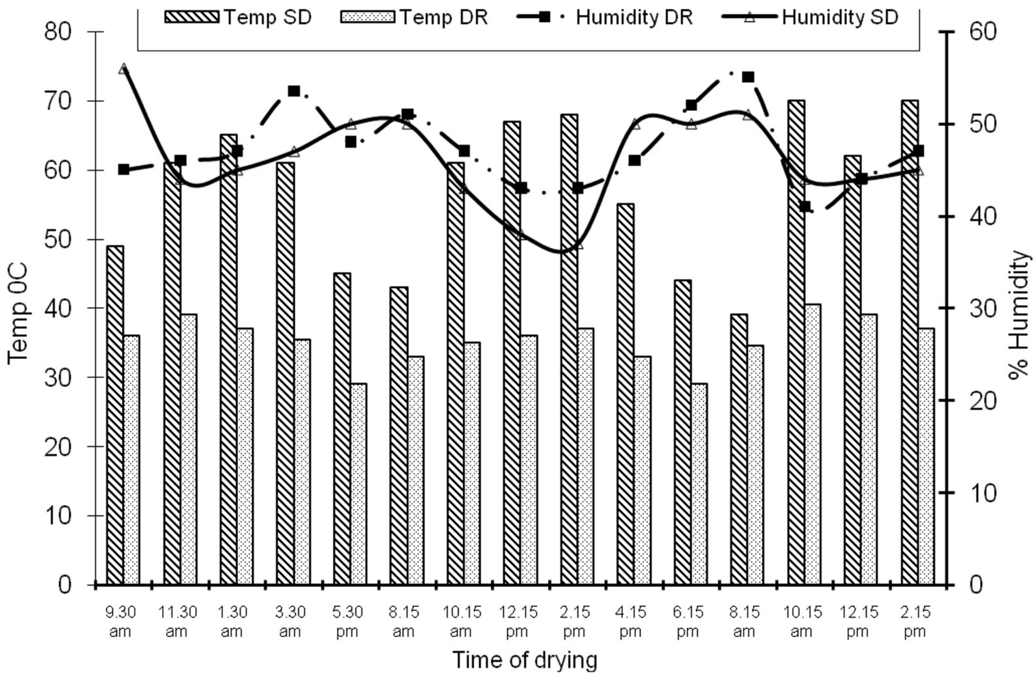

Fig. 7: **Humidity and temperature in SD and DR**

Table 2: Mean daily Temperature and % Humidity in solar tunnel dryer and drying rack

	Solar tunnel dryer		Drying rack	
	%Humidity	Temperature°C	%Humidity	Temperature°C
Day 1	48.4±4.8	56.2±8.6	47.9±3.3	35.3±3.8
Day 2	44.7±6.2	56.3±10.1	47.0±3.8	33.8±2.9
Day 3	46.0±3.4	60.3±14.7	46.8±6.0	37.8±2.6
Mean	46.4±1.9	57.6±2.3	47.2±0.6	35.6±2.0

DISCUSSION

Drying of fish in both the solar tunnel dryer and rack dryer was identified to be within the falling rate period, during which, the surface of the substance is still fairly dry, with drying resulting from moisture migration from the fish flesh to the surface and subsequent evaporation. The predominant factor that contributes to drying is heat, which causes evaporation of water from the fish, while the contribution of air in drying is effective when the moisture is at the surface. The fish in the solar tunnel dryer was at higher temperatures. This allowed the drying process to continue as any resistance against the water vapour flow to the surface was reduced by the effect of higher temperatures compared to the drying rack (Sankat & Mujaffar, 2004). The lower the humidity and the higher the temperature, the faster is the rate of drying (Mujaffar & Sankat, 2005).

Dryers that give better drying rates have lower humidity and higher temperatures inside the drying units (Sablani *et al.* 2003). Drying temperatures of 50°C and humidity of up to 50% have been considered ideal in the drying of fish (Bala & Mondol, 2001; Sablani *et al.*, 2003). In this study, the mean temperature in the solar tunnel dryer was 57°C and in the drying rack 35°C. The mean humidity was 46.4% in the solar tunnel dryer and 47.2% in the drying rack. During peak heat periods in this study between 10.00 hours and 14.30 hours, humidity varied inversely to temperature during drying. It can be postulated that higher temperatures maintained inside the solar tunnel dryer as a result of solar insulation on the collector, followed by subsequent transfer of the heated air by forced convection over the fish, coupled with direct radiation into the cabinet dryer and lower humidity were responsible for the faster drying rate of the fish.

During the drying period on the drying rack, ambient temperatures ranged from 33°C to 37°C, and were not as high as those developed inside the tunnel dryer. Such temperatures are however not ideal for drying of fish unless aided by another factor. Mujaffar and Sankat, (2005) describe such an occurrence where Shark fillets dried at 30°C in an oven without air movement were discarded after 16 hours due to spoilage. The rack was located by the sea side where wind is quite strong. The seaside wind increased the drying rate by removing more surface moisture and creating room for more moisture migration to the surface. However, the drying potential still needed to be increased by heat, which was lower in the drying rack and hence the low drying in the rack. Although wind alone can cause surface drying and might not influence the internal water content of the fish significantly, the rapid drying rate was occasioned by strong air currents at the height of the raised rack that passed freely over and below the fish, picking up moisture and thereby increasing moisture migration from the surface of the fish (Chamberlin & Titili, 2001).

The initial moisture content in fresh mackerel on dry basis was 2.40kg/kg. This decreased to 0.17kg/kg (db) in the solar tunnel dryer and to 0.65kg/kg (db) at the end of drying in the drying rack. There was a greater decline in moisture content in mackerel dried in the solar tunnel drier than on the drying rack. The moisture content declined rapidly with time from the initial values of 2.40 kg/kg (db) to 0.776 kg/kg (db) on day-one for the fish dried in the solar tunnel dryer and to 0.61 kg/kg (db) for fish dried in the drying rack. During this time, there was no distinct difference in decline in moisture content between the fish in the solar tunnel dryer and the drying rack.

After this rapid initial change in moisture content, the reduction in moisture content became gradual to a final moisture of 0.17 kg/kg (db) and 0.65 kg/kg (db) in the solar dryer and drying rack respectively Such observations were also made by Bala and Islam, (2001), Sablani *et al.,* (2003), Sankat and Mujaffar, (2004), Mujaffar and Sankat, (2005), Sereno *et al,* (2001), Mujaffar and Sankat, (2006).The drying rate constant (k) for the drying period was 0.0772 $h^{-1}$for the fish dried in the solar tunnel dryer and 0.0436 h^{-1} for the fish dried in the drying rack. These constants were higher in the solar dried fish than for the fish dried on the rack, implying superior performance of the solar tunnel dryer compared to the drying rack when used to dry mackerel.

Moisture content is affected by drying time according to Sablani *et al.,* (2003). The decline in moisture content (db kg/kg) in the solar tunnel dryer was more uniform and regular than in the drying rack. This is seen in the best line of fit relating moisture content and moisture ratio with time (Fig. 6). The coefficient of determination (R^2) was 0.7544 for solar tunnel dried fish and 0.4116 for fish dried on the drying rack. This observation implies that a strong relationship exists between moisture ratio and time for fish dried in a solar tunnel dryer than in a rack dryer. This then translated to better uniformity in the drying process for fish dried in a solar tunnel dryer (Fig. 7).

The non uniform moisture decline in the drying rack was due to the absence of control in the drying parameters including wind, temperature variations and humidity (Mujaffar and Sankat, 2005). Any changes in humidity in the atmosphere may lead to reabsorption of moisture since dry fish muscle is quite hygroscopic (Daramola *et al.,* 2007; Wood, 1981) and fish shape is heterogenous. The fish contained up to 2.4 kg/kg (db) moisture content. When moisture content is reduced to 0.33kg/kg (db) contaminating agents cannot survive, and autolytic activity is greatly reduced (Bala & Mondol, 2001). However, to prevent mould growth during storage moisture must be reduced to 0.18 kg/kg, (db) (Bala & Mondol, 2001). In this study the final moisture content of the mackerel was 0.17kg/kg, (db) for fish dried in the solar tunnel dryer and 0.65 kg/kg (db) for those dried in the drying rack. The fish dried in the solar tunnel dryer therefore contained the desirable moisture content for storage that would prevent mould growth.

CONCLUSIONS

The initial moisture content of the mackerel (2.4 kg/kg, db) was reduced to 0.17kg/kg (db) and 0.65 kg/kg (db) in the solar tunnel dryer and the rack dryer respectively in three drying days. The drying rates for the fish drying in the tunnel dryer and rack dryer respectively were 0.0772 and 0.0436 per hr. The relationship between moisture content and drying time for both tunnel drying and rack drying was exponential. A strong relationship exists between moisture content and drying time for solar tunnel dried mackerel since the coefficient of determination was high (R^2=0.7544), in comparison, the rack dried fish demonstrated a weak correlation with a low coefficient of determination (R^2=0.4116). The final moisture content for solar-tunnel and rack dried mackerel respectively were 0.17 kg/kg (db) and 0.65kg/kg, (db). The final moisture content for solar tunnel dried fish was within the acceptable rage for stored dried fish. Rack dried mackerel did not meet the threshold. Drying was more uniform and the fish dried to a lower moisture content (14.5%) ideal for longer shelf life for fish dried in the tunnel dryer. The higher drying rate constants confirmed superiority of the solar tunnel dryer over the drying racks. Humidity did not very much in both the tunnel dryer and rack and may not have been crucial in drying differences. Temperature range between the dryer and the rack was wide and could have contributed more to the drying process. This study concludes that the sand base solar tunnel dryer provides a good alternative for drying mackerel fish earmarked for storage especially during seasons of fish glut along the coastal region.

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REFERENCES

Ahmed ATA, Ata A, Mustafa G, Rahman H (1979) Solar Drying of Silver Jew Fish, Johnins Argentatus (houttuyn) in Polythene Tent Drier. *Bangladesh J. Biol. Sci*, *8*(1), 23–30.

Bala BK (1997) *Drying and storage of cereal grains*. Wiley Online Library.

Bala BK (1998) Solar drying systems: Simulations and optimization. Agrotech Publishing Academy.

Bala BK, Ashraf MA, Uddin MA, Janjai S (2005) Experimental and neural network prediction of the performance of a solar tunnel drier for drying jackfruit bulbs and leather. *Journal of Food Process Engineering*, *28*(6), 552–566.

Bala BK, Islam MN (2001) Solar drying of fish using solar tunnel drier. *1st Nordic Drying Conference, NDC*, *1*. Trondheim, Norway

Bala BK, Janjai S (2009) Solar drying of fruits, vegetables, spices, medicinal plants and fish: Developments and Potentials. *International Solar Food Processing Conference*, 14–16.

Bala BK, Mondol MRA (2001) Experimental investigation on solar drying of fish using solar tunnel dryer. *Drying Technology*, *19*(2), 427–436.

Bala BK, Woods JL (1994) Simulation of the indirect natural convection solar drying of rough rice. *Solar Energy*, *53*(3), 259–266.

Bala BK & Woods JL (1995) Optimization of natural-convection, solar drying systems. *Energy*, *20*(4), 285–294.

Chamberlain AI, Titili G (2001) *Seafood Handling* (Vol. 5). University of the South Pacific.

Curran CA, Trim DS (1982) Comparative study of three solar fish dryers. In FAO (Ed.), *Proceedings of the FAO Expert Consultation on fish technology in Africa* (Technical Report No. 268 Suppl.). FAO Fisheries Reports (FAO).

Daramola JA, 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.

Doe PE, Ahmed M, Muslemuddin M, Sachithananthan K (1977) A polythene tent drier for improved sun drying of fish [tests carried out in Bangladesh]. *Food Technology in Australia*.

Esper A, Mühlbauer W (1993) Development and dissemination of solar tunnel drier. Proceedings of Workshop TC-12, Organized during the ISES Solar World Congress at the Technical University of Budapest in Hungary, 1993, 22, 63–74; 127 pp. Budapest, Hungary

Helrich K (Ed.) (1990) *Official Methods of Analysis of the Association of Official Analytical Chemists* (15th ed.). Association of Official Analytical Chemists, Inc. Retrieved from https://law.resource.org/pub/us/cfr/ibr/002/aoac.methods.1.1990.pdf

Henderson SM, Perry RL (1976) Agricultural Process Engineering. The AVI Publ. Co. *Inc, Wesport, Connecticut, USA*.

Hossain MA, Woods JL & Bala BK (2005) Simulation of solar drying of chilli in solar tunnel drier. *International Journal of Sustainable Energy*, *24*(3), 143–153.

Kimani EN, Aura MC, Okemwa GM (Eds.) (2018) The Status of Kenya Fisheries: Towards the sustainable exploitation of fisheries resources for food security and economic development. Kenya Marine and Fisheries Research Institute (KMFRI). 135 pp. Retrieved from https://www.kmfri.co.ke/images/pdf/Status_of_Fisheries_Report_New_31-10-2019.pdf

Kituu GM, Shitanda D, Kanali CL, Mailutha JT (2008) Effect of Brining on the Drying Rate of Tilapia in a Solar Tunnel Dryer. *Proceedings of the 2. IASTED African Conference on Power and Energy Systems (AfricaPES 2008)*, 230.

Mujaffar S, Sankat CK (2005) Air Drying Behaviour of Shark Fillets. *Canadian Biosystems Engineering*, *47*(3), 11–21.

Mujaffar S, Sankat CK (2006) The mathematical modelling of the osmotic dehydration of shark fillets at different brine temperatures. *International Journal of Food Science & Technology*, *41*(4), 405–416.

Rao CCP, Basu P, & Prasad MM (1987) Studies on solar tent drier for drying fish. *Seminar on Diversification of Post-Harvest Technology in Low Cost Fish. Cochin, 10-11 March*, 101. Cochin, India

Reza MS, Bapary MAJ, Islam MN, Kamal MD (2009) Optimization of marine fish drying using solar tunnel dryer. *Journal of Food Processing and Preservation*, *33*(1), 47–59.

Sablani SS, Rahman MS, Haffar I, Mahgoub O, Al-Marzouki AS, Al-Ruzeiqi MH, Al-Habsi NH, Al-Belushi RH (2003) Drying rates and quality parameters of fish sardines processed using solar dryers. *Agricultural and Marine Sciences*, *8*(2), 79–86.

Sankat CK, Mujaffar S (2004) Sun and Solar Cabinet Drying of Salted Shark Fillets. Proceeding of the 14th International Drying Symposium 22-25 August 2004 (IDS 2004). Sao Paulo, Brazil, C, 1584–1591.

Sereno AM, Hubinger MD, Comesana JF, Correa A (2001) Prediction of water activity of osmotic solutions. *Journal of Food Engineering*, *49*(2–3), 103–114.

Shitanda D, Wanjala NV (2006) Effect of different drying methods on the quality of jute (*Corchorus olitorius* L.). *Drying Technology*, *24*(1), 95–98.

Uluko H, Mailutha JT, Shitanda D & Kanali CL (2004) *Simulation of Temperature Distribution in a Rice Solar Dryer Using Finite Element Method* [Master's Thesis]. Jomo Kenyatta University of Agriculture and Technology.

Wood CD (1981) *The Prevention of Losses in Cured Fish* (Technical Paper No.219; FAO Fisheries Reports, p. 87). Food and Agricultural Organization (FAO). Retrieved from https://agris.fao.org/agris-search/search.do?recordID=XF19840037285