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Comparison between Drying Characteristics of Siganids in a Sand-Base Solar Tunnel Dryer and a Traditional Rack Dryer

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Abstract

Solar dryers are seldom used for fish drying at the Kenyan coast despite abundant sunshine. A sand base solar tunnel dryer was fabricated at Gazi in South Coast, Kenya. The dryer was then used to attempt drying Siganids and its effectiveness measured against that of a traditional rack dryer. The dryer was made using steel, timber, glass, wire-mesh, a solar system with two DC fans, UV treated polythene sheet, coconut fibre, sand and black paint. The net drying time of the fish was 30 hours and moisture loss was logarithmic. The starting fresh weight of the Siganids in the solar tunnel dryer was 350 ± 53.0g; by day-one, recorded weight was 165 ± 30.5g, by day-two the weight was 80g ± 17.4 representing a 77.14% loss and 60 ± 21.0g by day-three equivalent to 5.71%.

In the traditional rack, the starting fresh weight was 250 ± 50.6g which reduced to 70 ± 44.2g by day-two then to 60 ± 35.5g by day-three equivalent to 4% loss. Drying was discontinued when no further weight loss occurred. There was a significant difference ($p<0.05$) in weight and moisture loss between the solar tunnel dryer and the traditional rack ($p=0.0001$, $p=0.0038$) respectively. The rate of drying was faster in the solar tunnel dryer compared to the traditional drying rack ($p = 0.0134$). Humidity and temperature varied diversely during drying in the solar tunnel dryer with humidity reaching 22-28% while temperatures ranged from 60-69°C. In the traditional rack, humidity was constant during peak heat drying periods at 60-70% with temperatures of 30-33°C. Lower humidity and higher temperatures inside the solar tunnel dryer caused the faster drying rates. The fish in the solar tunnel dryer attained a final moisture content of 17.9%. No insect infestation was curtailed by design when using the solar tunnel dryer.

It is concluded that the solar tunnel dryer is more effective in drying fish than the traditional drying rack. There is no insect infestation during drying in the solar tunnel dryer and the fish is dried to a low moisture content in the solar tunnel dryer which is more suitable for longer storage. It recommended that fish processors at the beach start migrating to adopt solar drying technologies to reduce drying time, get fish that can be stored for a longer time due to lower moisture content.

Key words: Drying, Moisture, Humidity, Temperature

INTRODUCTION

Traditional fish preservation methods common in Kenya includes sun drying as can be seen by observing the bulk of fish sold in the markets. Drying is used to reduce as much as possible the water content from foods to prevent or inhibit microorganism growth and hence preserve the food. Also, this reduces the bulk weight of food for cheaper transport and storage. Very little fish is landed by artisanal fishermen at the Kenyan coast between the months of April to early October while November and March is characterized by a glut. During this glut, it is relatively difficult to process the excess harvest. The fishermen sell cheaply to middlemen with the rest going to waste (FAO, 2000). Some of the fish is laid on the ground, on sand occasionally covered with fishing nets or on rocks to dry (personal observation). The disadvantage of these natural outdoor drying methods is that the drying process is slow making it unhygienic, tedious because the fish has to be brought inside every time it rains and each evening to avoid dew and its consequences such as mould, dust contamination, insect infestation, and exposure to harm from human or animals. These result in very low-quality fish with limited market circulation hence low income (Mujaffar & Sankat, 2005; Sablani et al., 2003).

The improvement of the quality of cured fish through technological advances is an important intervention that aims to reduce post-harvest losses and to create a wider appeal for the cured fish market. With the abundance of sunlight in this region, improved drying methods can be introduced. Attempts to use improved drying technologies in Kenya have been carried out by Shitanda and Wanjala (2006) and Uluko et al., (2006). However, none has been tried on fish. The use of solar dryers provides one such method of improved drying (Rao et al, 1987; Curran & Trim, 1982). However, these methods have had challenges with air movement inside the dryers (Bala & Mondol, 2001). Drying proceeds efficiently when air is hot, dry and moving. These three factors are inter-related and it is important that each factor is correct so that, cold moving air or hot, wet moving air are both unsatisfactory. Bala and Mondol, (2001), Bala et al., (2005), Hossain et al., (2005) and Reza et al., (2009) have utilized improved dryers with forced air convection to dry various food products including fruits, cereals, grains, legumes, oil seeds, fish and spices. In this study, a sand base solar tunnel was constructed for use in drying Siganids which is one of the commonly landed, popular and abundant species in the South coast area (FAO, 2000; Kimani et al., 2018) When drying is carried out correctly, the nutritional quality, colour, flavour and texture of dehydrated foods are maintained.

The aim of this study was to compare the drying characteristics of Siganus sutor fish in a traditional rack dryer (TR) with a locally fabricated solar tunnel dryer (SD) in Gazi, south coast of Kenya.

METHODS

Solar Tunnel Dryer construction

The dryer was designed and fabricated at Jomo Kenyatta University of Agriculture and Technology (JKUAT) in consultation with Kenya Marine and Fisheries Research Institute (KMFRI) with modifications according to Bala and Mondol (2001). This was a community-based project, and Gazi area of south coast of Kenya was selected. Gazi is set on a mangrove filled bay off the Mombasa-Lunga Lunga-road about 50km from Mombasa and lies 4°25', 39°30'E. It is in Kwale county, Coast region in Kenya. The major landing seasons are between October and March. The area was chosen because the community had identified with its implementation and was therefore easier to get locals to help run the solar tunnel dryer once installed.

Solar Collector

The solar collector was a tunnel 7m long, 2m wide and 0.4m above the ground. The tunnel height was 300mm. 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 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, a double insulation of 5mm thick wood followed by a 20mm thick coconut fibre layer was made. At the bottom a 2.5mm wooden layer was fitted. The collector was encased in a 0.5mm polythene layer. The sides of the collector were fabricated using 2mm thick metal plate painted black for heat absorption and lined by a 50mm thick coconut fibre layer for insulation. The outer surface of the collector wall was made of 25mm thick wooden layer painted black to absorb heat. To facilitate the entry of air into the collector a 2m by 0.6m galvanized sheet plenum mounted with a 40W DC fan was fixed onto the collector (Figure 1).

Drying Chamber

The drying chamber was a cabinet measuring 2m wide, 2m long and 1.4m high set at 0.5m above the ground. 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.

Figure 1. View of designed tunnel dryer

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 in and out of the drying cabinet during loading or offloading. At the outlet of the dryer cabinet an exit plenum 2m wide by 1.4m wide 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 40W DC axial fans with a capacity of 0.46m3/h.

Drying of Siganids

A total of 240 fresh Siganids were purchased from the local fishermen in Gazi a day before solar drying in late October 2012. Only sound, wholesome fish free from adulteration and organoleptically detectable spoilage were subjected to further processing. The fish was sorted to obtain similar sizes where possible. The average weights were recorded after being descaled, de-gilled, split open and eviscerated. Thorough washing was done followed by salting at a salt:fish ratio of 1:10. Alternate layering of the fish and salt was done in a wooden trough with a salt layer applied at the bottom (on top of the wooden layer) and at the top of the final fish layer.

The fish was then stacked in the trough from early evening to the following for approximately 16 hours before drying. The fish was then washed to remove excess salt, transferred to chorkor oven trays, placed under a shade and held at an angle for 1 hour to drain. Half the fish was distributed randomly and laid in single layers on the drying trays in the drying chamber of the solar tunnel dryer (Figure 2). The other half was distributed randomly on the traditional rack lying next to the solar tunnel dryer and with the drying rack kept the same height as the drying rack of the solar tunnel dryer. Three random representative samples of fish each were taken 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 day from 08.30 to 18.30 hours, drying temperature and humidity were measured inside the drying cabinet and on the traditional rack on the drying days. Temperature was measured using a normal mercury thermometer and humidity by a Humidity meter (HYGRO Haar-Synth, USA). Moisture loss was determined by randomly weighing the three representative pieces of fish from the solar tunnel dryer and dryer rack every 2 hours and returned. Two fish were sampled for moisture content determination every 2 hours during the drying period. They were wrapped in aluminum foil put in seal lock bags, labeled, placed on ice in ice boxes, taken to the laboratory in KMFRI and stored at -18°C till analysis.

Figure 2. Fish in the drying chamber laid in single layers

A complete drying period was between 8.30am to 6.30pm (10 hours) every day for three days giving a net drying period of 30 hours. Moisture content was determined by standard Helrich (1990) method, moisture loss as weight loss during drying after every 2 hours by getting the difference between starting weight and subsequent weight divided by starting weight and cumulative weight loss was weight loss every 2 hours as a percentage of fresh starting weight (Uluko et al., 2006). Insect infestation was assessed visually during drying.

DATA ANALYSIS

Rate of drying was compared using ANCOVA

RESULTS

Moisture Loss

The weight loss of Siganids in the solar tunnel dryer was from 350.0 ± 53.0g when fresh to 165.0± 30.5g (Figure 3) in day 1 to 80 ± 17.4g at the end of day-two. This was equivalent to 77.14%. In day-three the weight loss was from 80 ± 17.4g to 60 ± 21.0g which occurred between 20 to 22 hours (8.30am to 10.30am). This represented a weight loss of 5.71%. No further loss in weight was observed.

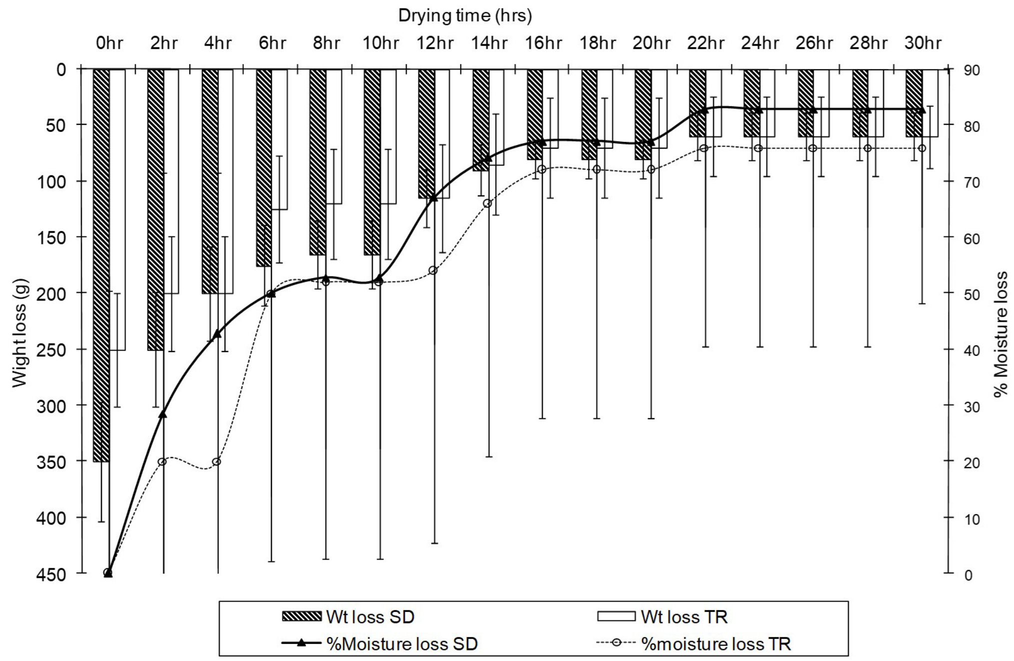

Figure 3. Drop in weight and % moisture loss of Siganids each day in Solar Tunnel Dryer (SD) and Traditional Rack (TR)

In the traditional rack, the weight loss was from 250 ± 50.6g to 70 ± 35.5g at the end of day 2 equivalent to 72%. In day-three the weight loss was from 70 ±42.4g to 60 ±35.5g that occurred between the 20 – 22 hours period (8.30am to 10.30am). This loss in weight was equivalent to 4%. The overall moisture loss was 82.85% for the fish dried in the solar tunnel dryer and 76% for the fish dried in the traditional rack at the end of the three day drying period (Figure 3). There was a significant difference in weight loss and moisture loss ($p<0.05$) between the Siganids dried in the solar tunnel dryer and the traditional rack ($p=0.0001$ and 0.0011) respectively.

The rate of drop in weight of the Siganids during the period was higher in the solar tunnel dryer compared to the traditional rack (Table 1, Figure 4). The weight losses observed indicated that most drying took place during the first 10 hours.

Table 1. Equations for drop in weight of Siganids over time

Day	Siganid in Solar Tunnel dryer	Siganid in Traditional rack
1	$y = -106.66 \ln x$	$y = -78.893 \ln x$
2	$y = -52.809 \ln x$	$y = -39.56 \ln x$
3	$y = -10^{-3} - 14 \ln x$	$y = -1.82 \ln x$

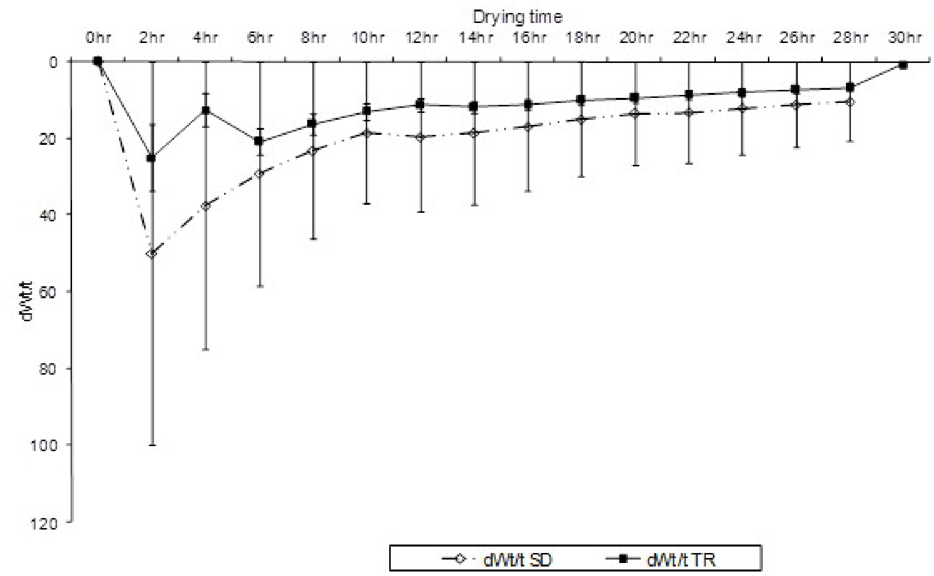

Figure 4. dWt/t of Siganids dried in the solar tunnel dryer (SD) and traditional rack (TR).

There was a statistically significant difference in drying rate (p = 0.0134) between the solar tunnel dryer and the traditional drying rack. Better drying rates were observed for the solar tunnel dryer. In day 1, humidity was 48% (Figure 5) at the start of the drying in the solar tunnel dryer (0 hours) and reduced to 23% between 2 and 6 hours equivalent to 10.30 hours and 14.30 hours (considered peak heat or drying times) and then increased as the evening approached to 80% at 18.30 hours.

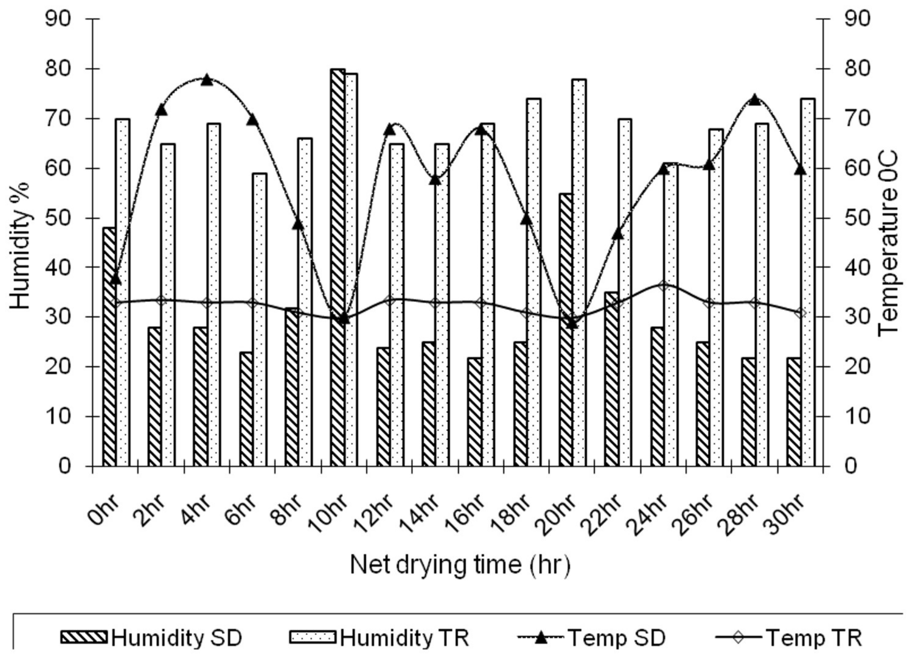

Figure 5 Humidity & Temperature in Solar Tunnel Dryer (SD) & Traditional Rack (TR)

Temperatures followed opposite trends. The temperatures increased from 38°C at the start of drying to a peak of 72°C between 2 and 6 hours drying period equivalent to 10.30 hours and 14.30 hours and finally dropped in the evening to 30°C. The temperature was considered rather high and could initiate cooking. The temperature was however controlled as the day progressed and in subsequent days. In the traditional rack, humidity in day-one was 70% (Figure 5) at the start of drying in the morning (0 hours) and ranged between 59% and 65% during peak drying periods of 10.30 hours and 14.30 hours (2 to 6 hours) and later increased to 79% towards the evening. In day-two, the humidity in the solar tunnel dryer followed the same pattern as in day-one with values of 22-24% being recorded between 10.30 hours to 14.30 hours (14 to 18 hours period). Temperature was more or less the same but this time the range was between 60-69°C during the peak heat periods. On day-two (12 to 20 hours period) in the traditional rack, the humidity was mainly between 65% - 69% during the peak heat period (14 to 18 hours period). The initial humidity was 75% at the start of drying in the morning and 78% by evening. The temperatures were between 30 to 34°C during the drying period. On day-three; the humidity in the solar tunnel dryer was low throughout with values of 22-28% being recorded during peak heat periods. The weather conditions on this day fluctuated unusually. Temperature kept rising most of the day and was between 48 to 70°C in the solar tunnel dryer. However effective drying or moisture loss was not quite evident during the third day. In the traditional rack the humidity was also rather high on this day averaging about 70%. Effective drying was not evident and average temperatures of 32-33°C were recorded.

The initial moisture content in fresh Siganids was 73.9% on a wet weight basis. This dropped to 17.9% ± 0.77 at the end of the three days in the solar tunnel dryer (Figure 6).

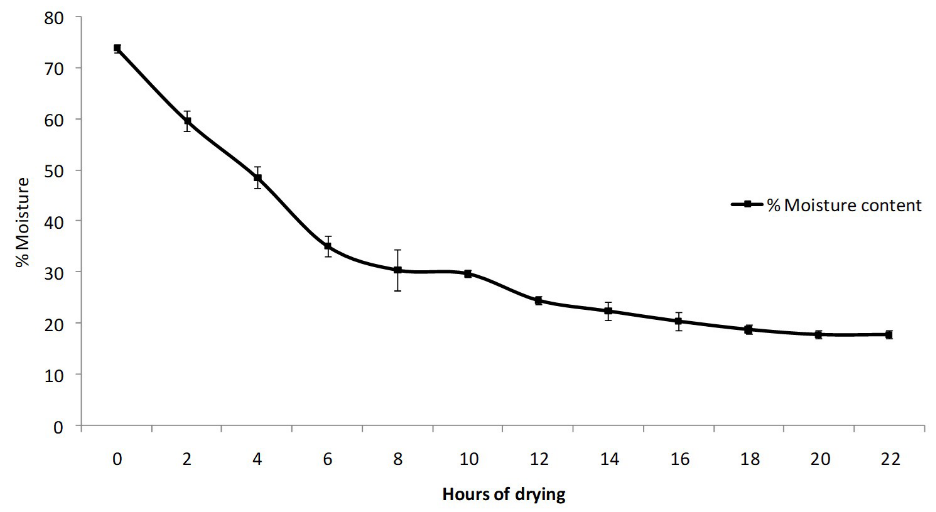

Figure 6. Moisture content (%) of Siganid during drying in solar tunnel dryer.

DISCUSSION

The starting weights of fish in the traditional rack were smaller and by inference thinner than those in the solar tunnel dryer. Thinner or smaller fish would normally dry faster than bigger or thicker ones. The surface area to volume ratio of smaller fish is normally higher resulting in faster drying rates (Mujaffar & Sankat, 2006). Work with shark fillets of various thicknesses showed that the thinner fillets lost moisture faster than the thicker ones (Mujaffar & Sankat, 2005). In this study the fish in the solar tunnel dryer showed more moisture loss despite their size. The factors that varied greatly and could be attributed to drying were temperature and humidity. The lower the humidity the faster the rate of drying (Mujaffar & Sankat, 2006). Dryers that give better drying rates have lower humidity and higher temperatures inside the drying units (Sablani et al., 2003). This trend was conclusively demonstrated using the solar tunnel dryer. The peak heat periods were also recorded as the peak drying periods, between 10.30 hours and 14 30 hours, humidity and temperature varied inversely during drying. It is postulated that higher temperatures maintained inside the solar tunnel dryer as a result of insulation on the collector, subsequent transfer of the heated air by forced convection over the fish coupled with direct radiation into the cabinet dryer and low humidity were responsible for the faster drying rate of the fish. During the drying period on the traditional rack, ambient temperature and humidity did not vary greatly. The daily temperatures were 30 - 33°C. Such temperatures are however not ideal for drying unless aided by another factor. Shark fillets dried at 30°C in an oven without air movement spoilt and discarded after 16 hours (Mujaffar & Sankat, 2005). Humidity was high under the ambient temperature conditions ranging from 60 to 79% mostly and could not have played a significant role. The reason for the relatively fast drying in the traditional open rack was attributed to the strong winds at the beach. The rack was located by the sea where wind speeds and value is quite strong. Although wind alone may result to in surface drying, it may not have much effect in internal water content. The rapid drying rate could also be due to a function of the air currents passing freely over and below the fish owing to the raised rack (Chamberlin & Titili, 2001). During drying, the moisture loss decreased with drying time meaning that the Siganids suffered greater moisture loss at the initial stage of drying. Such observations have been made by Mujaffar and Sankat, (2006), (Sablani et al., 2003). Moisture content is affected by drying time according to Sablani et al. (2003). Fish contains up to 80% water. When moisture is reduced to 25% wet basis, 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 15% (Bala & Mondol, 2001). A report by Sankat and Mujaffar (2004) indicates that moisture contents of 20-40% for dry salted sun dried fish are acceptable. In this study the final moisture content attained for the Siganids was 17.9% after drying for three days in the solar tunnel dryer.

Unfortunately, insect larvae and insect infestation are a common occurrence in the fish dried using the traditional open rack method. This renders the fish unattractive leading to rejection by community members and loss of revenue. The solar dried fish which had no signs of insect infestation were therefore more attractive and acceptable to the community. The lack of infestation was attributed to the higher temperatures in the solar tunnel dryer during the drying process and the enclosed drying cabinet. Results from other studies have also yielded similar results (Bala & Mondol, 2001; Sankat & Mujaffar, 2004; Panduro et al., 2004; Mujaffar & Sankat, 2006; Kituu et al, 2008).

CONCLUSIONS

This study concludes that the sand base solar tunnel dryer provided a good alternative initiative for drying fish. The drying time of three days was also relatively short. The final moisture content of 17.9% was within the suitable range for dried fish storage. Humidity and temperature played a key role in the drying process. Insect attacks seen during drying in the traditional rack negatively affect the community members' perception of dried fish consumption.

RECOMMENDATIONS

The use of solar dryers to be encouraged by policy makers in the fishery industry due to the shorter drying times, improved fish quality and longer storage achievable due to the lower moisture content achieved

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