Greenhouse Solar Drying and Thin Layer Drying Of Fresh Kapenta (*Stolothrissa tanganicae*)

Aduke N. Rhoda, Isaac N. Simate

Abstract— The aim of this study was to carry out an experimental investigation on drying fresh Kapenta in a Greenhouse Solar Dryer and to evaluate a suitable thin-layer drying model for the Kapenta. The nutritional constituents and quality of the Kapenta dried from the Greenhouse solar dryer and the open sun were also examined. To determine thin-layer drying characteristics of fresh Kapenta, drying in a hot air dryer at different air temperatures was carried out. The influence of the drying temperature (35, 45, 55 °C) on the moisture ratio and drying rate has been studied in this paper. The experimental drying data of Kapenta under different temperatures was fitted to three different thin-layer drying models by using non-linear least squares regression analysis in Excel, and the models compared according to three statistical parameters; coefficient of correlation, the reduced chi-square and the root mean square error. The coefficient of correlation values of Page were higher (0.980361- 0.997000), compared to the other models, indicating that the Page model was the best to describe drying curves of fresh Kapenta among the three models.

Index Terms— Drying, Greenhouse, Kapenta (Stolothrissa tanganicae), solar, thin layer, sun

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1 INTRODUCTION

Drying of agricultural products is one of the oldest methods of preservation of food. Drying or dehydration is used to describe any process involving the removal of water from fish or fish product by evaporation [1]. Drying prevents occurrence of undesirable changes due to microbial activity [2]. Although preservation is the primary reason for drying, it also lowers the product mass and volume. The reduction in mass and volume improves the efficiency of packaging, storing and transportation [2].

Fish drying is one of the oldest method of fish preservation using heat from the sun and atmospheric air although it has been limited to certain climatic areas and seasons. In Zambia open sun drying is practiced along the shores of Lake Kariba where 98% [3] of Kapenta *(Stolothrissa tanganicae)* is harvested, an area where air temperatures are remarkably high for prolonged periods.

Kapenta, is a local name for small planktivorous, pelagic, freshwater *clupeid (Limnothrissa miodon and Stolothrissa tanganicae)*, were introduced into Lake Kariba, a man-made reservoir on the Zambezi shared between Zambia and Zimbabwe, in the late 1960s from Lake Tanganyika. [4]

Open sun drying is the most commonly used method of drying Kapenta at the local fishermen level, but the process contaminates fish by exposing it to dust, excreta from birds and animals, and subjects it to destruction by birds, blowflies' Larvae and animals. The drying process is slow and the fish dries to unstable moisture content that is favorable for micro-organisms proliferation, and therefore the fish becomes a source of food poisoning [5]. Additionally, the direct exposure of fish to sunlight destroys light sensitive nutrients in the fish [5].Consequently, alternative affordable, hygienic and ecologically friendly methods must be developed and adopted for the drying of fish in this case fresh Kapenta. The Greenhouse solar dryer provides a hygienic and environmental friendly fresh Kapenta dryer design capable of enclosing fish away from contaminants and a reliable means for thin layer drying of Kapenta.

Thin layer drying is the drying of one layer of sample particles or slices [6]. Thin layer drying models that describe the drying characteristics of agricultural materials mainly fall into three categories, namely theoretical, semi-theoretical and empirical [6]. The theoretical approach is mainly concerned with either the diffusion equation or simultaneous heat and mass transfer equation and it only takes into account the internal resistance to moisture transfer while the semi-theoretical approach deals with approximated theoretical equations and considers only the external resistance to moisture transfer between the product and air. Semi-theoretical models are developed by simplifying general series solution of Fick's second law and they offer a compromise between theory and ease of use. But they are only valid within the temperature, relative humidity, and airflow velocity and moisture content range for which they were developed [5].

The most commonly used semi-theoretical thin layer drying models include; the Newton model, Page model, the Modified Page model, the Henderson and Pabis model, the Logarithmic model, the Two-term model, the Two-term exponential, the Diffusion approach model, the modified Henderson and Pabis model, the Verma et al. model and the Midilli–Kucuk model. In this study the Page model, Logarithmic model, and the Midilli–Kucuk model were used for the mathematical modelling of the thin layer drying equation.

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Several studies on thin layer drying and mathematical modelling of biological products, using conventional or solar tunnel dryers { [7], [4], [8]} have been reported. However, no detailed studies were found in literature on thin layer drying and the drying of fresh Kapenta in a Greenhouse solar dryer. The objectives of this study were: (a) To carry out an experimental investigation on drying fresh Kapenta in a Greenhouse Solar Dryer; (b) to evaluate a suitable thin-layer drying model for fresh Kapenta; and(c) To compare the quality of Kapenta dried in a Greenhouse Solar Dryer and that dried on the open sun.

2 MATERIALS AND METHODS

2.1Description of the Solar Greenhouse Dryer System

The solar Greenhouse natural convection drying system was located at the University of Zambia; Lusaka; School of Agricultural Sciences Field Station: Latitude; 15°23'39.50"S; Longitude; 28°20'7.96"E on a site that was well drained, nearly level, and with full exposure to sunlight away from shading of trees. The Greenhouse solar dryer had an east -west orientation to ensure the fish receive maximum exposure to sunlight.

The Greenhouse Solar Dryer design; Kainji Solar Tent Dryer described by Olokor and Samuel (2009) was adopted for this study. Materials used in the construction of the Greenhouse solar dryer were;200 µm thick greenhouse plastic, wooden frame, 20mm diameter plastic pipes, black polythene sheet spread out on the base of the tent, black stones, a drying rack, mosquito net and a zip.

The length, width and height of the Greenhouse solar dryer were 1.5 metres by 1metre by 0.5 metres, respectively. The Greenhouse Solar Dryer frame was constructed using straight wooden poles each measuring 1.5m long. A rectangular wooden frame measuring 1.5m by 1m was fabricated and 20 mm diameter plastic pipes clamped on opposite ends to form the Greenhouse frame as shown in figure 1. Pieces of rocks were spread within the base of the wooden frame and covered with black polythene.

Figure. 1. Greenhouse solar dryer for Fresh Kapenta

The Greenhouse plastic was fitted onto the entire Greenhouse framework as shown in Figure 1 above. On one of the longer sides of the polythene cover, a 1metre long zip was fitted to serve as an access opening into the tent for loading and unloading the Kapenta on the drying rack during the drying process. At the extreme narrow top part of the tent, an opening of 0.1 m x 0.5 m was made and covered with mosquito net to serve as outlet of moist air from the dryer. On the opposite end of the Greenhouse Solar Dryer at the bottom of the tent another opening measuring 0.1 m by 0.5 m was made to serve as the air inlet into the solar tent. The drying rack was a wire mesh framed with steel (0.9 m by 1m) and placed at a height of 0.20 m from the surface of the rocks.

2.2Experimental procedure

2.2.1 Greenhouse Solar and Open Sun Drying

Drying experiments of the fresh Kapenta in the Greenhouse dryer were carried out in November and December in 2015.Freshly harvested Kapenta (*Stolothrissa tanganicae*) was obtained from fish traders at Lake Kariba, Siavonga, Zambia. The samples were stored at -40 ^{0}C in a freezer before the experiments. In order to determine the initial moisture content of the Kapenta, samples were dried in an oven (JeioTech, Model ON-02G, and accuracy ±0.5%) at 105 ^{0}C for 4 hours [9].

Fifteen kilograms of fresh Kapenta was dried in the Greenhouse solar dryer to investigate the drying characteristics of Kapenta and develop a thin layer drying equation for Kapenta drying. A total of eight experimental runs were conducted in the Greenhouse Solar dryer and a total of twelve experiments in the hot air dryer during the period of November – December, 2015.

Kapenta (*Stolothrissa tanganicae*) dried in each experimental drying run weighed 3 kg. Kapenta was placed in a thin layer on a drying rack inside the Greenhouse solar dryer. The experiments were started at about 9.00 am and ran until constant moisture content of the samples was reached. Product samples of 50g from the Greenhouse solar dryer were weighed at 30 minutes intervals using a digital balance (Metter, Model PE3000, accuracy, ±0.1 g) and the moisture contents of the product inside the dryer were compared against the control samples (open-air sun dried). The moisture content during drying was estimated from the weight of the product samples and the estimated dried solid mass of the samples.

Solar radiation was measured by a pyranometer (Kipp and Zonen, Model CM11, accuracy, ±0.5%) placed on the roof of the Greenhouse solar dryer. Three thermocouples (Campbell scientific, Model T108, accuracy ± 0.2 ^{0}C) were used to measure air temperatures at different positions of the Greenhouse solar dryer. Thermocouple positions for temperature measurement are shown in figure 1.

Figure. 2. Experimental drying of Kapenta inside the Greenhouse solar dryer and in open sun

2.2.2Thin layer Hot Air Drying Experiments

Three (20 g) samples of fresh Kapenta were dried at different temperatures (35, 45 and 55 °C) [8], using a hot air drier (INNOTECH, Model Hohenheim). The weight of the samples were measured at 20 minute intervals using a digital balance (Metter, Model PE3000, accuracy, ±0.1 g).The drying procedure continued until a constant weight of the samples was achieved. The weight of the samples was converted into moisture content using equation 1 below.

$$M_2 = \frac{100 - W_1(100 - M_1)}{W_3} \qquad (1)$$

Where;
W_1 is the initial weight of the sample
W_3 is the weight at intervals of 20 minutes
M_1 is the initial moisture content
M_2 is the moisture content of the sample at time t

The moisture ratio (MR) was determined using the following formula;

$$MR = \frac{(M_t - M_e)}{(M_0 - M_e)} \qquad (2)$$

Where;
M_t is the moisture content of the fresh Kapenta at time t
M_0 is the initial moisture content of the fresh Kapenta and
M_e is the equilibrium moisture content. This was determined by plotting a graph of moisture content against time and the equilibrium moisture content determined as illustrated in figure 3.

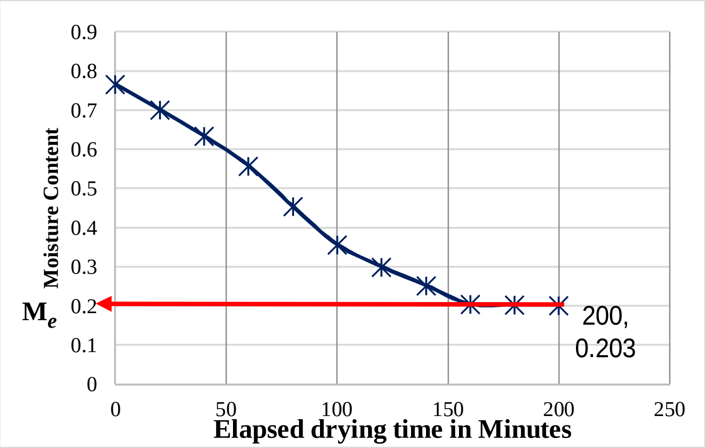

Figure. 3. Determination of Equilibrium Moisture Content

2.2.3Proximate Analysis.

Samples of Kapenta that were dried inside the Greenhouse Solar Dryer and those that dried in the open sun were taken to the Food Science and Nutrition Laboratory at the University of Zambia for qualitative analysis.

Samples were analyzed using the method described by the Association of Official Analytical Chemists [9]. The proximate composition of the samples in the Greenhouse Solar Dryer and the samples in the open sun were analyzed and compared in terms of the following Nutritional content; Moisture content, Protein content, Fibre and Ash Content.

The hygiene indicators such as presence of yeasts and moulds, feacal coli forms and E.coli (Escherichia coli) in both samples were analyzed.

3 RESULTS AND DISCUSSION

3.1 Variation of Solar Radiation with Air Temperature inside the Greenhouse

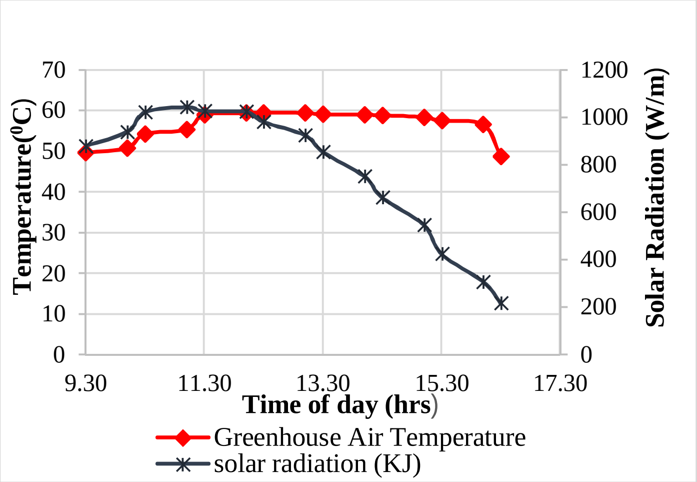

Figure. 4. Mean solar radiation and temperatures at various times during the day (November 2015)

As the solar intensity reduced in the afternoon due to the cloud cover the air temperature inside the Greenhouse solar dryer remained consistently high due to the effect of the black stones covered with black polythene at the base of the Greenhouse solar dryer which acted as a capacitor by absorbing, retaining and releasing radiant energy needed for the Kapenta drying. Olokor and Samuel (2009) found similar behavior in the drying of fish (*Bagrus bayad*) in an improved solar tent dryer.

3.2 Variations of Temperature and Relative humidity at different locations of the Greenhouse Solar dryer

Figure 5 below shows the comparison of air temperature at three different locations on the Greenhouse solar dryer and the ambient air temperature for the experimental runs of solar drying of Kapenta in December 2015. The air entered the dryer at a low temperature and was heated up in the dryer to a higher temperature. At the exit the air temperature is lower than the temperature of the tray due to evaporation cooling by the moisture absorbed from the Kapenta being dried.

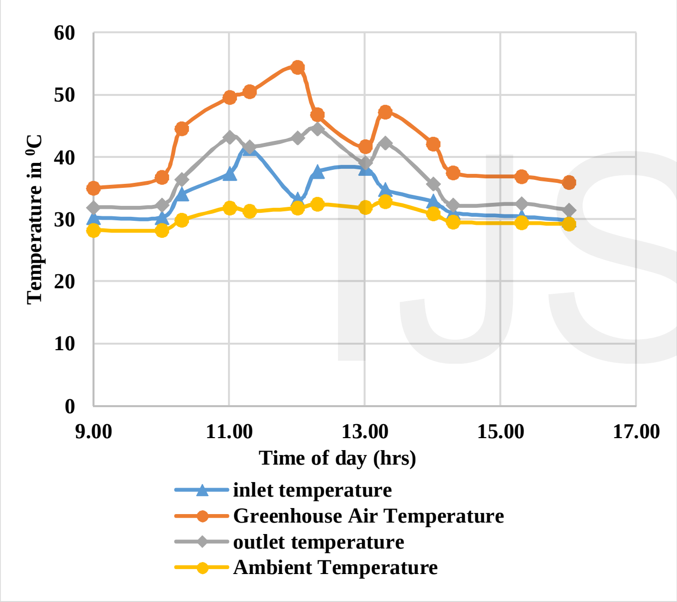

Figure. 5. Mean temperatures at different locations of the greenhouse solar dryer compared to the ambient temperatures (December 2015)

Figure 6 also illustrates relative humidity at two different locations; inside the dryer and ambient air relative humidity during solar drying of Kapenta. There is a significant difference in relative humidity inside the dryer compared to the ambient relative humidity. The relative humidity of the air inside the dryer is lower than that of the ambient air.

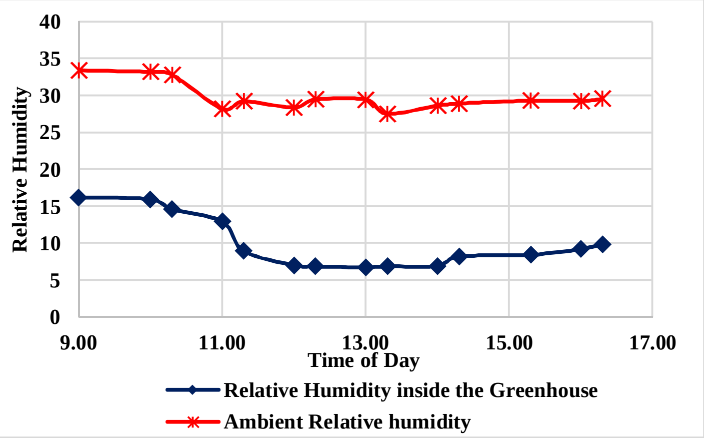

Figure. 6. Air Relative humidity inside the greenhouse solar dryer compared to the ambient relative humidity (December 2015)

3.3 Variations of moisture content of the Kapenta under different drying conditions

The initial moisture content of the fresh Kapenta was obtained as 76.74% wet basis from the oven. The variations in moisture content of the fresh Kapenta that was inside the dryer compared to the control sample dried by natural sun drying are showed in Fig.7.The moisture content of Kapenta in the Greenhouse Solar Dryer was reduced from an initial value of 76.74 % (w.b.) to a final value of 2.14% (w.b.) within 4.5 hours whereas the moisture content of the natural sun-dried samples was reduced to 14.34% (w.b.) in the same period. In addition, the Kapenta dried in this dryer was completely protected from insects, dust, animals and rain. Therefore the Greenhouse Solar dryer is more efficient than open sun drying since within the same amount of time the solar dryer dries the Kapenta to significantly lower moisture content of 2.14% (w.b) compared to open sun drying at 14.34 %(w.b.).This is a major advantage of the Greenhouse Solar Dryer since the fish is completely dried to a stable moisture content which inhibits micro-organism proliferation thus increasing the shelf life of the dried Kapenta.

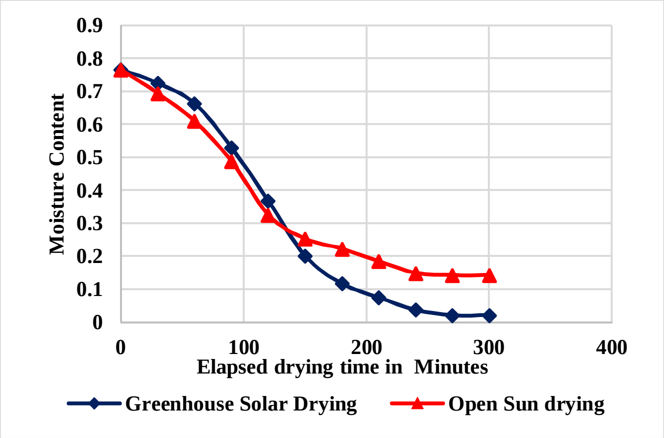

Figure. 7. Shows the variations of moisture content with time during drying of Kapenta both in the Greenhouse solar dryer and open sun drying.

3.4 Thin Layer Mathematical modeling

The moisture content data observed in the drying experiment under different temperatures were fitted to the 3 commonly used thin-layer drying models listed in Table 1 below.

TABLE 1

MATHEMATICAL MODELS GIVEN BY VARIOUS AUTHORS FOR DRYING CURVES

Model name	**Model**	**Reference**
Page	$MR = \exp -\left(Kt^{n}\right)$	[11]
Logarithmic	$MR = a\exp\left(-kt\right) + b$	[7]
Middilli-kucuk	$MR = a\exp\left(-kt^{n}\right) + bt$	[12]

Suitability of each model against the experimental data was checked by using nonlinear least squares regression analysis in Excel, Solver method. [7]The best model describing the drying characteristics of samples was chosen as the one with the highest coefficient of correlation (R^2), and the least reduced chi square (χ^2) and root mean square error (RMSE). [11] These statistical parameters were calculated as follows [7]:

$$\mathrm{RMSE} = \left[\left[\frac{1}{N}\right]\sum_{i=1}^{N}\left(MR_{\exp i} - MR_{pre\, i}\right)^{2}\right]^{\frac{1}{2}} \tag{3}$$

$$\chi^{2} = \frac{\left[\sum_{i=1}^{N}\left(MR_{\exp,i} - MR_{pre\, i}\right)^{2}\right]}{N - Z} \tag{4}$$

$MR_{exp,\, i}$ is experimental moisture ratio
$MR_{pre,\, i}$ is predicted moisture ratio
N is number of observations and
Z is number of constants.

The statistical results of different models such as coefficient of correlation (R^2), the reduced chi-square (χ^2) and the root mean square error (RMSE) values are summarized in Table 2. In all cases, the value of (R^2) was greater than 0.90 indicating a good fit [11] except the Middilli model which gave (R^2) values of 0.7. But the Page model gave comparatively higher (R^2) values in all the drying treatments (0.980361-0.997000), and also the (χ^2) (0.000157-0.001192), and (RMSE) (0.007235-0.034521) values were lower as shown in Table 2 and figures 8 and 9 below. Hence, the Page model was selected as the best model describing the thin-layer drying behavior of fresh Kapenta. Guan, (2013) also reported a similar result for Mathematical Modeling on Hot Air Drying of Thin Layer Fresh Tilapia Fillets.

TABLE 2

VALUES OF MODEL CONSTANTS AND STATISTICAL PARAMETERS

TEMP (°C)	CONSTANTS				R^2	$\chi 2$	RMSE
	K× (10^{-4})	a	b × (10^{-1})	n			
PAGE EQUATION							
35	2.72			1.834	0.996	0.0012	0.0345
35	2.72			1.834	0.996	0.0006	0.0236
45	7.08			1.252	0.997	0.0004	0.0194
45	6.76			1.564	0.993	0.0002	0.0141
55	13.96			1.513	0.980	0.0002	0.0115
55	13.58			1.544	0.988	6.19E-05	0.0072
LOGARITHIMIC EQUATION							
35	73.73	1.426	-3.787		0.980	0.0033	0.0492
35	62.69	1.574	-0.517		0.981	0.0033	0.0488
45	57.53	1.397	-3.565		0.949	0.0009	0.0277
45	63.65	1.359	-3.056		0.941	0.0011	0.0305
55	98.83	1.263	-2.074		0.990	0.0016	0.0341
	113.9	1.223	-1.608		0.987	0.0022	0.0398
MIDILLI EQUATION							
35	1200	1.006	-0.049	0.090	0.734	0.0107	0.0825
35	761.5	1.006	-0.052	0.084	0.740	0.0096	0.0780
45	15.36	1.012	-0.038	0.048	0.975	0.0047	0.0684
45	15.24	1.007	0.0002	1.372	0.988	0.0001	0.0109
55	17.30	1.007	-6.2E-6	1.461	0.999	9.34E-05	0.0097
55	15.37	1.007	-2.1E-5	1.515	0.709	4.39E-05	0.0066

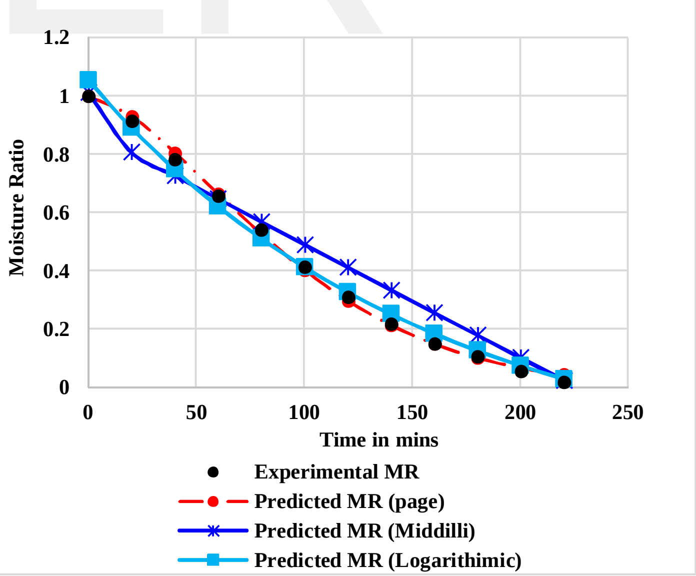

Figure. 8. Variation of the experimental and predicted moisture ratio by the page, Middilli and Logarithmic models with drying time at 45 °C of drying air for fresh Kapenta

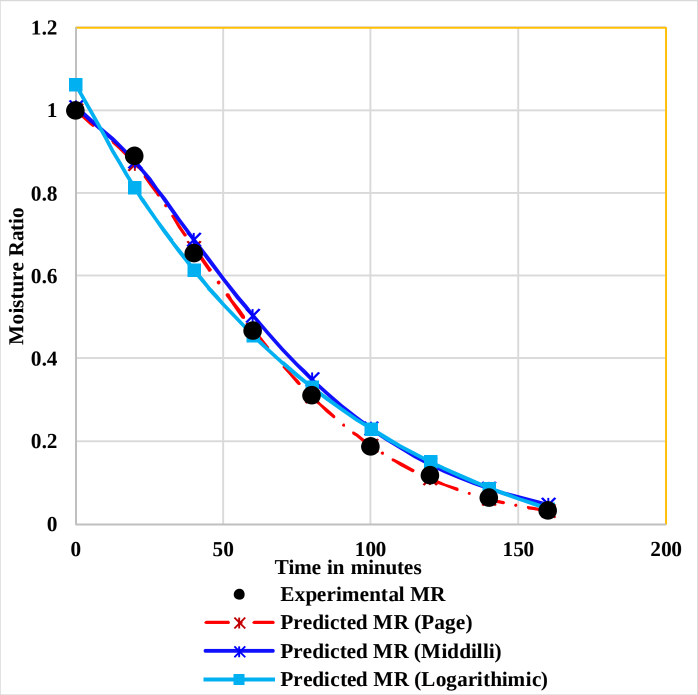

Figure. 9. Variation of the experimental and predicted moisture ratio by the page, Middilli and Logarithmic models with drying time at 55 ^{0}C of drying air for fresh Kapenta

The coefficients of the accepted page model for the thin layer drying of fresh Kapenta (*Stolothrissa tanganicae*) were determined as;

$K = 0.000001258T^2 - 0.00005701T + 0.0007267$ (5)

$n = 0.001286955T^2 - 0.13189801T + 4.8743251$ (6)

Where;

T-Temperature in degrees Celsius (^{0}C)

Figure 10 shows the influence of drying air temperature in moisture ratios Predicted by the Page model. The two expressions (Equations (5) and (6) predicted the moisture ratio (MR) well at three drying temperatures 35, 45, and 55 ^{0}C for the Kapenta (Stolothrissa tanganicae) with an r of 1. These results can be proved consequently from Fig. 10 which plotted the Page Model predicted moisture ratios versus drying time at 35, 45, and 55 ^{0}C. Also from this figure, it can be concluded that the predicted moisture ratio decreased with increase in the drying air temperature and consequently the drying time decreased.

Accordingly, it can be concluded that the Page drying model described adequately the drying behavior of fresh Kapenta (Stolothrissa tanganicae) in the hot air drying process at a temperature range 35–55 ^{0}C.

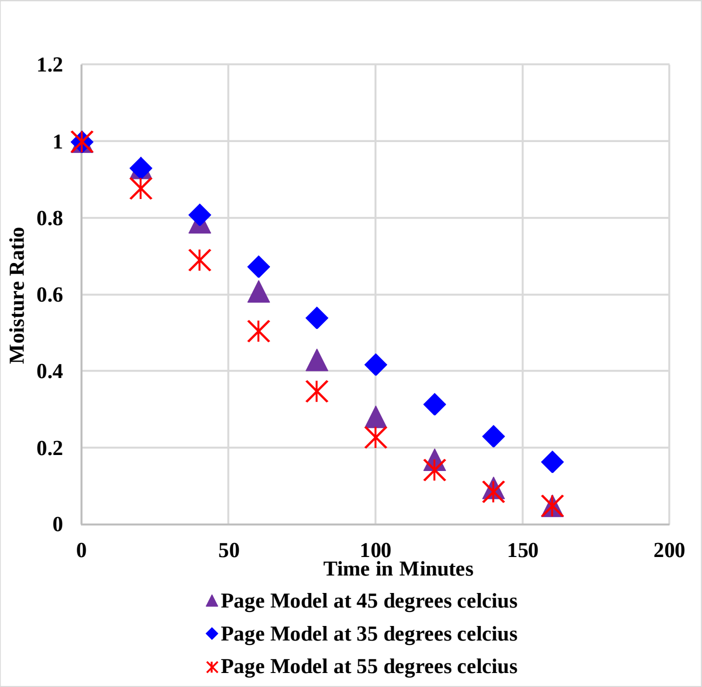

Figure. 10. Influence of drying air temperature in moisture ratios predicted by page model.

3.5 Nutritional Contents

The proximate composition of the products from the Greenhouse Solar Drier and the open sun dried Kapenta is represented in Table 3 below.

TABLE 3

NUTRITIONAL PROPERTIES OF KAPENTA DRIED (STOLOTHRISSA TANGANICAE) UNDER DIFFERENT CONDITIONS

Nutrients	Open sun dried (%)	Greenhouse Solar dried (%)	Student T- test
Moisture content	9.18	6.25	$(P < 0.05)$
Crude Fibre	1.96	2.69	$(P < 0.05)$
Ash content	12.66	13.08	$(P < 0.05)$
Crude Protein	58.10	59.98	$(P < 0.05)$
Crude fat	10.25	11.22	$(P < 0.05)$

The Kapenta dried in the Greenhouse solar drier had a lower moisture content, (6.25%) ($P < 0.05$) as compared to the moisture content (9.18%) of the Kapenta dried in the open sun. Based on the student t-test; nutritional contents of the products significantly differed from one another at 95% level of significance; products from the Greenhouse solar drier were richer in protein (59.98), Crude fat (11.22), crude Fibre (2.69%) and Ash content (13.08%) due to the lower moisture content obtained from Greenhouse solar drying. The removal of moisture brought about a significant increase in concentrations of nutrients in the products and thus higher percentages of protein, ash, Fibre and lipids. [12] These results agree with other findings reported by Ipinmoroti, (2012) on qualities of Tilapia zillii products from solar tent dryers in a humid tropical environment.

3.6 Hygiene Indicators

Table. 4 below shows the results obtained from the microbiological analysis done on the dried Kapenta samples.

TABLE 4
MICROBIOLOGICAL ANALYSIS OF KAPENTA SAMPLES

Dried Kapenta sample	Yeast &moulds		*E.coli*	
	Results (cfu/g)	Observation	Results (MPN/g)	Observation
Open sun dried	300	Satisfactory	<3	Satisfactory
Greenhouse solar dried	20	Satisfactory	<3	Satisfactory

According to the East African standards for Dry fish, the microbiological limits are as follows;

TABLE. 5.
EAST AFRICAN STANDARDS FOR DRY FISH

No.	Type of micro-organism	Maximum limits	Method of test
1	E.coli	Absent	ISO 7251
2	Yeasts and Moulds	10^2	ISO 21527-1

The counts obtained in the Dry Kapenta are within acceptable limits for the E.coli. However it can be seen that the Yeast and Moulds count was lower in the Greenhouse dried Kapenta (20) and was within acceptable limits compared to the sun dried Kapenta (300). This could be due to exposure of the Kapenta to moulds spores carried by dust in the air. These results show that exposure of Kapenta to the open sun during drying as a method of preservation results in deterioration in quality of the Kapenta due to the high amount of yeasts and moulds.

4 CONCLUSIONS

In order to investigate the performance of a Greenhouse Solar Dryer, three batches of Fresh Kapenta were dried in the greenhouse dryer at the University of Zambia. Solar drying in the Greenhouse Solar Dryer resulted in considerable reductions in drying time as compared with the natural sun drying. The quality in terms of nutritional content and hygiene of products dried; the Greenhouse Solar dried samples were better than the natural sun dried samples.

Three thin-layer drying models were investigated for their suitability to describe the drying behavior of Kapenta. The Page Model showed the best fit with high values for the coefficient of Correlation (R^2), (0.980361-0.997000) and lower values of reduced chi-square (χ^2), (0.0000619-0.001192) and the root mean square error (RMSE),(0.007235-0.034521)between temperatures of 35-55 ^{0}C.

The Greenhouse Solar Dryer gave the best final products in terms of low moisture content, highest protein, and Fibre and ash values. The lower moisture content increases the shelf life of dried products, since microbial activities and deterioration processes proceed faster with increasing moisture levels of products. It can therefore be concluded that of the two drying methods tested in this study, the better preservation method was the Greenhouse Solar Dryer due to the fact that it produced a final product that maintains its nutritional properties to a level that is valuable to consumers at the time of consumption.

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