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Mathematical Modelling and Solar Tunnel Drying Characteristics of Yellow Maize

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Abstract Solar drying experiments of maizes were conducted at Gape- Kpodzi, in southern Togo. In this purpose, new type tunnel solar dryer was used. Solar dryer consist of an air collector, drying chamber and an air circulation system. Heated air in solar air collector was forced through the maizes by a blower. Yellow dent type maize was used for drying experiments. During the drying period, drying air temperature, relative humidity, air flow rates, solar radiation, and lose of mass were measured continuously in different levels of the dryer. Maize with initial moisture content of 0.37 dry basis (kg water / kg dry matter) were dried until they reached a final moisture content of 0.13 (kg water / kg dry matter) at different temperatures with respect to solar radiation variation. Drying time was examined with moisture content ratio as exponential and polynomial correlations. The effective diffusivity varied from 1.938×10^{-10} to 1.164×10^{-10} m^2/s over the different level of temperature range. Fourteen different mathematical models available in literature were compared using their coefficient of determination to estimate solar drying curves. According to statistical analysis results, Midilli et al. drying model has shown a better fit to the experimental drying data of maize with a coefficient of determination $R^2 = 0.9975$ as compared to other models. The results of this study revealed that the developed solar tunnel dryer can used for dehydration of maize crops under the climatic conditions of southern Togo.

Keywords: *tunnel dryer, solar drying, mathematical modeling, moisture ratio, maize, effective diffusivity*

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1. Introduction

Maize (*Zea mays*) is an important food crop in Africa. It was probably introduced into West Africa by traders transporting the grain across the Sahara from the Mediterranean region [1]. Many farmers plant maize in small plots near their village (Figure 1). Farmers in southern Togo depend on maize as their main dietary staple. The average Togolese person consumes 136.9 g of maize per day, which contributes an average of 411 calories to their daily caloric intake [2]. After harvesting, Togolese dry the maize and convert it into flour, which they then use to make a thick porridge known as *"akplé"* in Ewé or "*pâte*" in French. *Akplé* is eaten with a spicy sauce.

Maize makes high demands of soil nutrients, especially nitrogen. Maize is sensitive to drought and water-logging, both of which can occur during the long and short growing seasons in southern Togo. Despite these potential obstacles, farmers continue to plant maize. Farmers believe maize is grown for eating, not for generating money, and feel they must grow it for food security. Many Togolese eat "*akplé"* two to three times a day. Across Africa, people love eating maize and do not even consider the possibility of not growing it [3]. In West Africa, maize is often grown in a mixed cropping system. A common system in southern Togo is planting cassava with maize, as cassava is a late maturing crop and maize an early maturing crop [1]. In Gape, as with the rest of southern Togo, maize is considered a "male" crop. Men are responsible for growing, harvesting and selling maize. Women and children help with the planting and harvesting but are not considered "in charge" of the crop. The maize market at local markets is one of the few venues run by men.

However, grains maize are highly perishable [4]. The novel alternative practice for preservation of grains maize is drying. Again, grains maize is a seasonal cereals and drying of the grains maize during harvesting season ensures the year-round availability and quality of maize. Furthermore, the demands for dried grains maize are increasing in the international markets because of its quality and flour. For proper understanding of transfer processes during drying and production of quality dried maize products, it is essential to know the thin-layer drying characteristics and the quality of the dried products.

Many studies have been reported on thin-layer drying of agricultural products and food materials [4,5,6]. A considerable number of studies have been reported on the drying of cereals and fruits, [7,8]. No study has been reported on the thin-layer drying of grain maize under the mixed – mode forced convection. This study aims to evaluate thin-layer drying characteristics of the grain maize and the quality of maize for good germination, which is the big problem cut out by the farmers. Because the live the grain maize long time in the drier.

The objectives of this study were to investigate the effect of the drying time of maize grain on the solar tunnel in force convection and to compare drying behaviour at the different place on the dryer. Different mathematical models have been used.

2. Materials and Methods

2.1. Materials

The grain maize (*Zea Mays*) used in this study were obtained from cooperatives farmers in the village of Gape kpodji, Togo during the harvest season of August 2013. Since they were grown in accordance with organic agriculture method, no chemical substances such as synthetics fertilizer and pesticide were used. The maize were harvested by hand in their cob and transported by the women of the cooperatives from the farm to the site for the experiments.

2.2. Experimental Apparatus

In this experimental study, solar tunnel dryer, is used for large scale drying of Yellow maize. This dryer was developed at the University of Hohenheim, Germany in the early eighties for small scale production of dried fruits, vegetables, spices, fish etc…. A low cost version of this drier has been designed for farmers of small village of Togo. This type of dryer has been widely tested and attained economic viability [9]. The pictorial view of the dryer is shown in Figure 2. The drier consists of a flat plate air heating collector, a tunnel drying unit and a small fan to provide the required air flow over the product to be dried. These are connected in series as shown in Figure 3. Both the collector and the drying unit are covered with UV stabilized plastic sheet in polyethylene. Black paint is used as an absorber in the collector. The products to be dried are placed in a thin layer in the tunnel drier. Glass wool is used as insulation material to reduce the heat loss from the drier. The whole system is placed horizontally on a raised platform. The air at required flow rate is provided by two DC fans operated by one photovoltaic module. As the air is passed over the product rather than through the product in the drier, the power requirement to drive a fan is low. To prevent the entry of water inside the drier unit during rain, the cover is fixed like a sloping roof.

Figure 1. The pictorial view of Maize Field. Gakpe, Togo. Photo by Kokou Agbossou

Figure 2. The pictorial view of new designed solar tunnel dryer

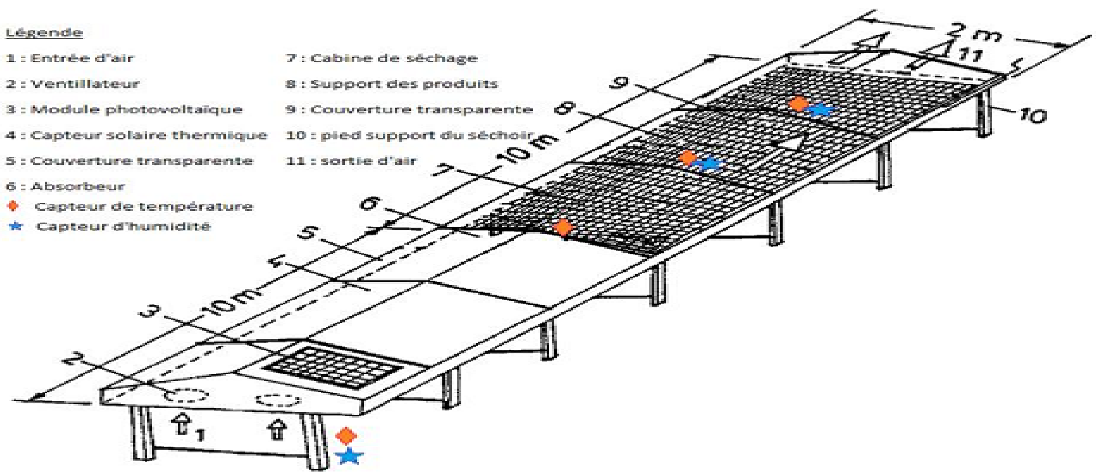

Figure 3. The structure and dimension of the dryer and the positions of the thermocouples (T), hygrometers (rh)

1. Air inlet, 2. Fan, 3. Solar module, 4. Solar collector, 5. Side metal frame, 6. Outlet of the collector, 7. Wooden support, 8. Plastic net, 9. Roof structure for supporting the plastic cover, 10. Base structure for supporting the tunnel drier, 11. Rolling bar, 12. Outlet of the drying tunnel.

2.3. Experimental Procedures

The inlet temperature, middle temperature and the outlet temperature were measured respectively by using K-type thermocouples at the load time and unload time of the drier. Hot wire anemometers (Airflow, model TA5, accuracy ± 2%) were used to monitor the air speeds at the air inlet, air outlet and middle of the dryer. Another anemometer was also used to monitor the ambient wind speed. The relative humidity of ambient air and drying air was periodically measured by hygrometers (Electronic, model EE23, accuracy ± 2%). The global solar radiation is measured on the ground with pyranometer LI 200 SA with precision of 5% connected to LI1400 central made by LICOR [10].

For each drying test, 150 kg of fresh grain maize was used. The experiments were started at 8.00 am and continued till 4.00 pm according to the weather condition in the experimental city. Grain maize flesh was kept in the dryer during night time and the drying was continued until the desired moisture content of 13% (wet basis) was reached. The final moisture content corresponds to the moisture content of high quality dried products from local markets in Togo. Product samples were placed in the dryer at various positions (Figure 3) and were periodically weighed at 1-hour intervals using a digital balance (OHAUS Pionner, accuracy ± 0.1 g). Also, samples of about 100 g of the fresh product were placed inside the dryer and the mass monitored at 1-hour intervals. The moisture contents of the products inside the dryer were compared against the control samples (open-air natural sun dried). The moisture content during drying was estimated from the weight of the product samples and the dried solid mass of the samples. At the end of the experimental drying run, the exact dry solid mass of the product samples was determined by the oven method (105°C for 24 hours, accuracy ± 0.5%).

2.4. Mathematical Modeling of Solar Drying Curves

The moisture ratio of samples during drying can be expressed by the following equation (1)

$$X_R = \frac{X_t - X_e}{X_o - X_e} \qquad (1)$$

where X_R is the dimensionless moisture content ratio; X_t, X_o and X_e are the moisture content at any given time, the initial moisture content and the equilibrium moisture content, respectively.

Drying curves were fitted to the experimental data using fourteen different mathematics models (Table 1) by using regression analysis.

The theoretical model employed in this study is based on Fick's law considering the geometric shape of a sphere, ignoring the grain volumetric variation and considering the known moisture condition at the grain surface [11]. The solution to Fick's equation, with the assumptions of moisture migration being by diffusion, negligible volume shrinkage, constant temperature and diffusion coefficients [12,13,14] is

$$X_R = \frac{X - X_e}{X_o - X_e} = \frac{6}{\pi}\sum_{n=1}^{\infty}\frac{1}{n^2}\exp\left(-\frac{D_{eff}\, n^2\pi^2 t}{r^2}\right) \qquad (2)$$

where D_{eff} is diffusion coefficient, r is the equilibrium radius of the sample product and N is the serial number.

The analytical solution of this equation is presented in the form of an infinite series, and therefore, finite terms numbers (n) in truncation are able to determinate the results with satisfactory precision.

Table 1. Mathematical models given by various authors for the solar drying curves

Model No.	Model équations	Model Name	References
1	$\frac{X_t}{X_o} = \exp(-kt)$	Newton	[27,30,36]
2	$\frac{X_t}{X_o} = \exp(-kt^n)$	Page	[35]
3	$\frac{X_t}{X_o} = a * \exp(-kt)$	Henderson and Pabis	[37,38]
4	$\frac{X_t}{X_o} = a * \exp(-kt) + c$	Logarithmic	[40],
5	$\frac{X_t}{X_o} = a * \exp(-k_1 t) + b * \exp(-k_2 t)$	Two-Term	[22,28]
6	$\frac{X_t}{X_o} = 1 + at + bt^2$	Wang and Singh	[15,39]
7	$\frac{X_t}{X_o} = a * \exp(-kt) + (1-a)\exp(-kat)$	Two-Term Exponential	[16,33]
8	$\frac{X_t}{X_o} = \exp[-(\mathrm{kt})^{\mathrm{n}}]$	Modified Page	[15,16,27,32]
9	$\frac{X_t}{X_o} = a * \exp(-kt) + (1-a)\exp(-gt)$	Verma et al.	[16,34]
10	$\frac{X_t}{X_o} = a * \exp(-kt) + (1-a)\exp(-kbt)$	Yaldiz and Ertekin	[16,30]
11	$\frac{X_t}{X_o} = \exp(-\mathrm{k}\left(\frac{\mathrm{t}}{\mathrm{l}^2}\right)^{\mathrm{n}})$	Modified Page Equation	[12]
12	$\frac{X_t}{X_o} = 1 + at + bt^2 + ct^3$	Gökhan GÜRLEK	[41]
13	$\frac{X_t}{X_o} = a * \exp(-kt^n) + bt$	Midilli et al.	[31]
14	$\frac{X_t}{X_o} = a * \exp(-kt) + b * \exp(-gt) + c * \exp(-ht)$	Modified Henderson and Pabis	[42]

The equivalent radius of a product is defined as the radius of a sphere having the equivalent volume of the product. To achieve the average volume for maize grain, a straight sphere shape was considered. In order to calculate the volume, length (*L*), width (*l*) and thickness (*E*) measurements for the maize grain were made using an electronic caliper “pied à coulisse” with 0.01 mm precision, considering the sphere diameter as the average of the width and the thickness, as shown by Equation 3.

$$V = \frac{\pi}{16} * L * (E + l)^2 \quad (3)$$

For longer drying periods, equation (2) can be simplified to only first term of the series, without much affecting the accuracy of the prediction [13].

$$Ln(X_R) = Ln\left(\frac{X - X_e}{X_o - X_e}\right) = Ln\left(\frac{6}{\pi^2}\right) - \left(\frac{D_{eff} n^2 \pi^2 t}{r^2}\right) \quad (4)$$

The diffusion coefficient are typically calculate by plotting experimental drying data in terms of ln(X_R) versus drying time. From equation (4) a plotting will give a straight line with a slope of:

$$Slope = \frac{\pi^2 D_{eff}}{r^2}. \quad (5)$$

2.5. Data Analysis

Regression analysis was done by using the Matlab statistical computer program. However, the moisture ratio (X_R) was simplified to X/X_0 instead of the $(X - Xe)/(Xo - Xe)$ [13,16].

The reduced χ -square, root mean square error (RMSE) and modeling efficiency (EF) were used as the primary criterion to select the best equation to account for variation in the drying curves of the dried samples [14,15,16]. Reduced χ -square is the mean square of the deviations between the experimental and calculated values for the models and was used to determine the goodness of the fit. The lower the values of the reduced χ-square, the better the goodness of the fit. The RMSE gives the deviation between the predicted and experimental values and it is required to reach zero. The EF also gives the ability of the model and its highest value is 1 [17]. These statistical values can be calculated as follows

$$\chi^2 = \frac{\sum_{i=1}^{N}\left(XR_{i,\exp} - XR_{i,pre}\right)^2}{N - n} \quad (6)$$

$$RMSE = \sqrt{\frac{\sum_{i=1}^{N}\left(XR_{i,pre} - XR_{i,\exp}\right)^2}{N}} \quad (7)$$

$$EF = \frac{\left[\sum_{i=1}^{N}\left(XR_{i,\exp} - XR_{i,pre}\right)^2 - \sum_{i=1}^{N}\left(XR_{i,pre} - XR_{i,\exp}\right)^2\right]}{\sum_{i=1}^{N}\left(XR_{i,\exp} - XR_{i,pre}\right)^2} \quad (8)$$

Where $XR_{i,exp}$ and $XR_{i,pre}$ are the experimental and predicted dimensionless moisture ratios, respectively and *n* is the number of observations.

3. Results and Discussion

The physical properties of the maize kernels used for this study are listed in Table 5.

During the period of experiments, the variation of the ambient air temperature, relative humidity and solar radiation are shown in Figure 4 for a typical day of August 2013 in southern Togo. During the experiments, the daily mean values of ambient air temperature, relative humidity and solar radiation ranged from 29.5to 38.6°C, 42,5-79.6%, 289.9-774.8W/m^2, respectively. The air temperature and solar radiation were reached the highest curves between 11:30 and 15:00, whereas the relative humidity was reached the lower curves during this time. The same trend of curves has reported in Turkey weather conditions [18].

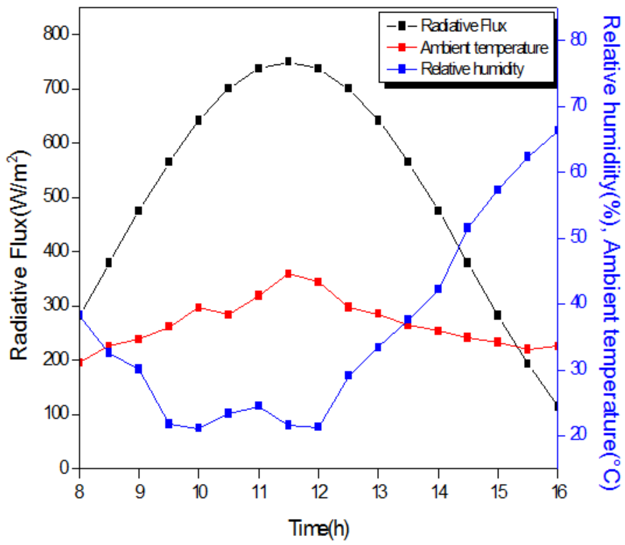

Figure 4. Variation of ambient air temperature, relative humidity and solar radiation with the drying hours for typical days of 12th August 2013

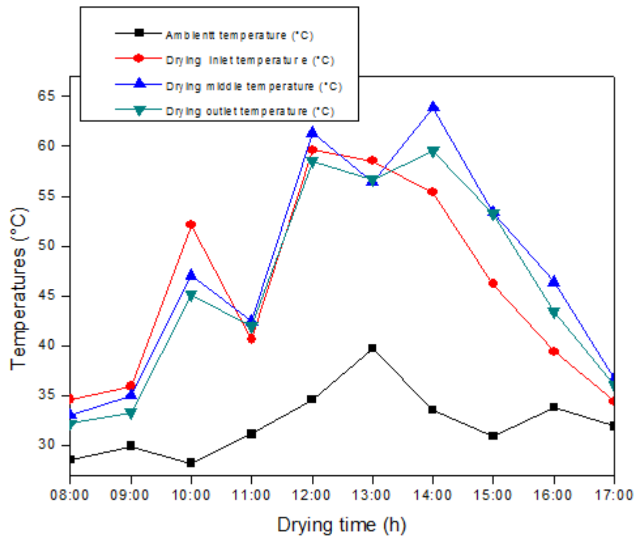

Figure 5. Variation of means of drying temperature at inlet, middle and outlet of solar tunnel drier

The Figure 5 shows the profile of variation of ambient temperature and drying temperature at inlet, middle and outlet of the Hohenheim tunnel solar dryer. The ambient temperature and drying temperature at these different levels inside the dryer change continuously from morning to evening. It is due for the variation of the solar radiation.

They reported that the dryer temperatures were higher than the ambient temperature. It observes that a maximum temperature of 62°C was recorded at 12:00hours inside de dryer which was 54 per cent higher than the maximum ambient temperature (35.5°C) at the same time.

This may be due to the absorption of more solar energy inside the solar tunnel dryer and the prevention of heat loss from the tunnel dryer. The results were in close agreement with the finding for chilly drying in farm solar dryer and for grape drying in solar tunnel [19,20,21].

Whereas the profile of relative humidity shown by the Figure 6 indicted that the relative humidity in the tunnel was lower than the ambient humidity. Also, there was a significant difference between the values of the ambient and the humidity. This difference was shows in Figure 7. It is indicated that the difference was about average 26°C and 15,3% during the experimental time respectively. That implicated that the drying rate will be higher in the dryer than the open sun drying.

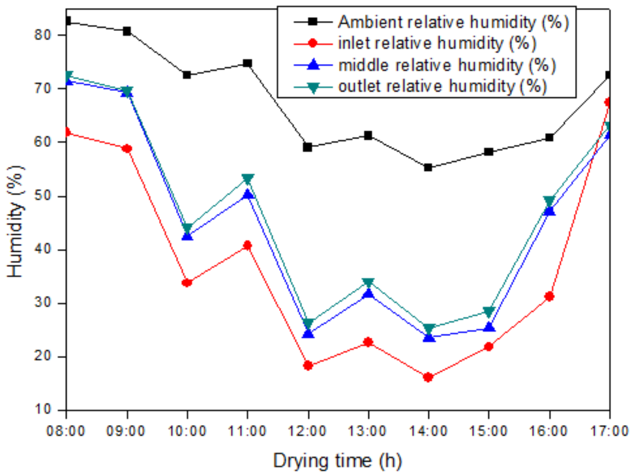

Figure 6. Variation of means of drying relative humidity at inlet, middle and outlet of solar tunnel drier

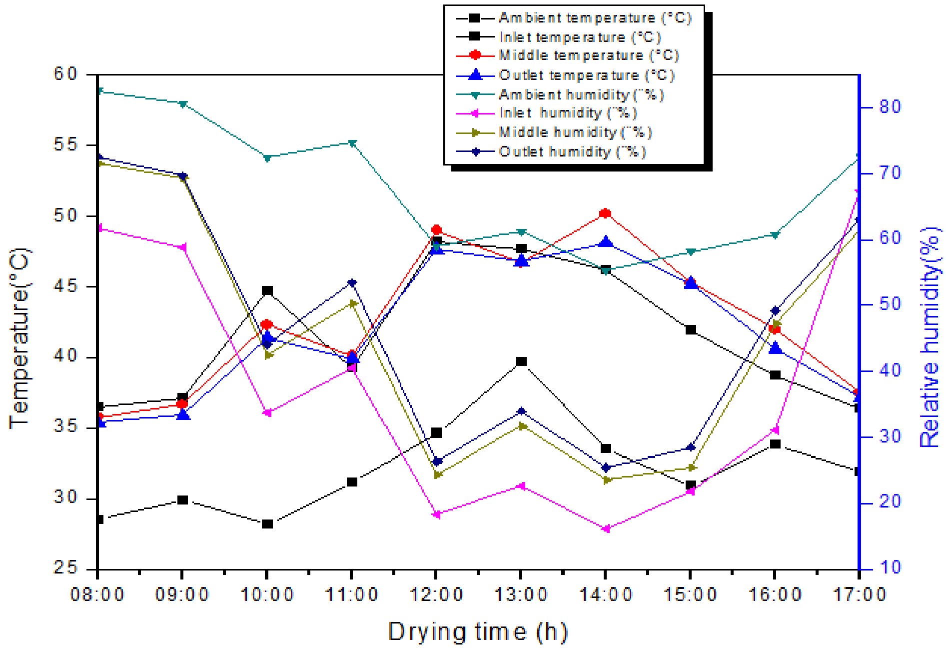

Figure 7. Variation of means of drying temperature and relative humidity at inlet, middle and outlet of solar tunnel drier

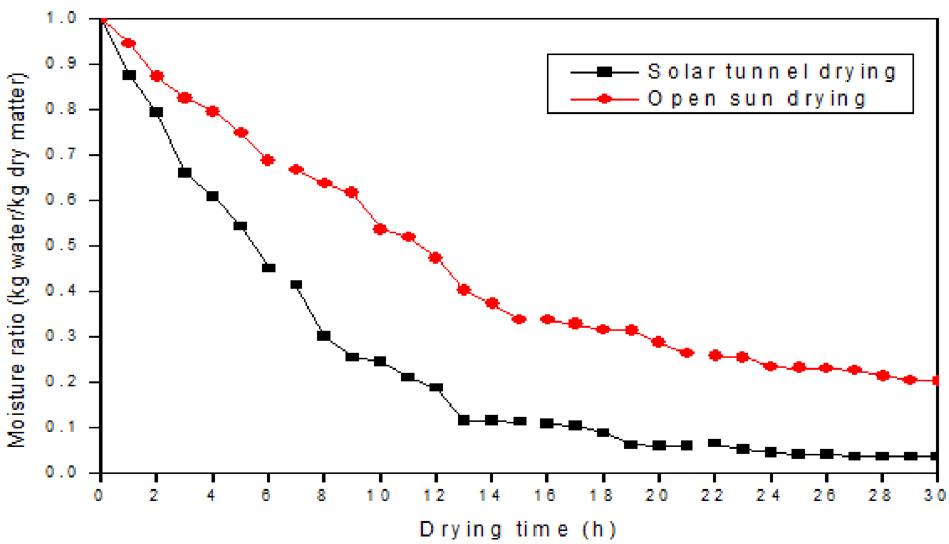

Figure 8. Variation of moisture ration with drying time for grain maize in solar tunnel and open sun drying process

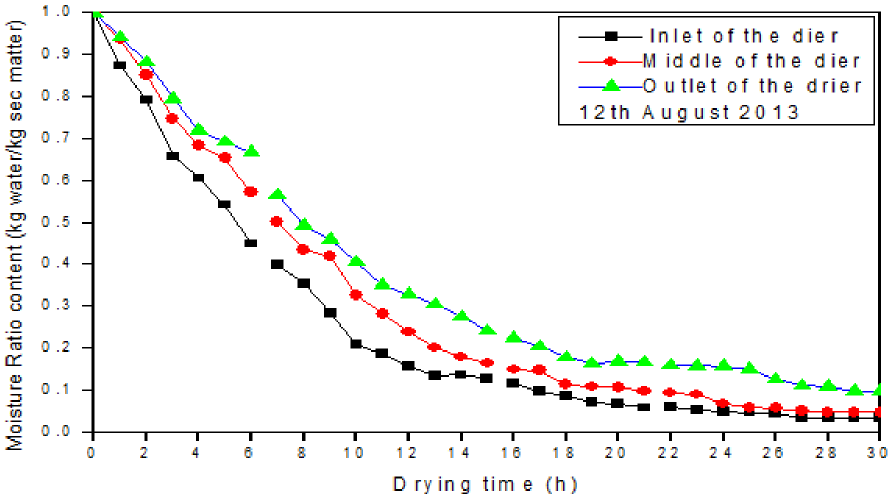

Figure 9. Variation of moisture ratio content of grain maize in inlet, middle and outlet of solar tunnel dryer

The Figure 8 shows the variation of moisture ratio of the grain maize in the dryer and the open sun drying. The average initial moisture content of around 37 Kg water per Kg dry matter was dried to the final moisture content of about 0.12 Kg water per Kg dry matter. On average, a total drying time of 20 drying hours were required for solar tunnel dryer to reduce the moisture content of maze grains from initial value of 37 per cent (w.b) to a final moisture content of 13 per cent (w.b) while the open sun drying required on an average 72 drying hours to obtain the same level of moisture content which resulted in net saving in drying time of 72.22 per cent for solar tunnel dryer over open sun dryer.

Table 2. The statistical parameters obtained in order to verify the fit of each model to the observed data during the maize drying at different ambient variation temperatures

	Mathematical model		**Statistical parameters**			
Model number	Model	Model constant	$\chi^2 * 10^{-4}$	RMSE	EF	R^2
1	$\frac{X_t}{X_o} = \exp(-kt)$	k=0.1372	3.6002	0.01952	0.9951	0.9951
2	$\frac{X_t}{X_o} = \exp(-kt^n)$	k=0.1248 n=1.0440	3.4137	0.01883	0.9954	0.9955
3	$\frac{X_t}{X_o} = a * \exp(-kt)$	a=1.017 k=0.1395	3.5172	0.01924	0.9952	0.9954
4	$\frac{X_t}{X_o} = a * \exp(-kt) + c$	a=1.013 k=0.1445 c=0.01075	3.3928	0.01889	0.9954	0.9957
5	$\frac{X_t}{X_o} = a * \exp(-k_1 t) + b * \exp(-k_2 t)$	A= - 1.989 k_1=0.1171 b=3.002 k_2=0.1239	3.8518	0.02014	0.9947	0.9953
6	$\frac{X_t}{X_o} = 1 + at + bt^2$	a=0.09199 b= 0.00210	3.1723	0.09171	0.9585	0.9603
7	$\frac{X_t}{X_o} = a * \exp(-kt) + (1-a)\exp(-kat)$	a=1.437 k=0.1574	3.5172	0.01912	0.9952	0.9954
8	$\frac{X_t}{X_o} = \exp(-(\mathrm{kt})^{\mathrm{n}})$	k=0.0515 n=1.0932	3.8344	0.0269	0.9876	0.9875
9	$\frac{X_t}{X_o} = a * \exp(-kt) + (1-a)\exp(-gt)$	a=2.089 k=0.1324 g=0.1281	5.9872	0.02018	0.9947	0.9947
10	$\frac{X_t}{X_o} = \exp\left(-\mathrm{k}\left(\frac{\mathrm{t}}{\mathrm{l}^2}\right)^{\mathrm{n}}\right)$	k=2.48 l=4.188 n=1.044	3.3432	0.01916	0.9952	0.9955
11	$\frac{X_t}{X_o} = 1 + at + bt^2 + ct^3$	a= - 0.1197 b=0.005133 c= - 0.00007	2.2511	0.01441	0.9973	0.9975
12	$\frac{X_t}{X_o} = a * \exp(-kt) + (1-a)\exp(-kbt)$	a=7.436 b=0.9879 c=0.1267	2.7343	0.2016	0.9947	0.9951
13	$\boldsymbol{\frac{X_t}{X_o} = a * \exp(-kt^n) + bt}$	a=0.988 b=0.001084 k=0.106 n=1.137	2.3331	0.01505	0.9975	0.9974
14	$\frac{X_t}{X_o} = a * \exp(-kt) + b * \exp(-gt) + c * \exp(-ht)$	a=0.1754 b= - 4.172 c=4.990 k=0.2451 g=0.270 h=0.2451	2.4762	0.03515	0.9968	0.9973

The Figure 9 shows the variation of moisture ratio of the grain maize in the different levels on inside the dryer. It was reported that the inlet level make short time of drying time than middle level and the middle level also make short drying time than outlet level. It is due of the different temperature. The during temperature decrease trough the grain surface from inlet to the outlet inside the dryer.

The statistical parameters obtained in order to verify the fit of each model to the observed data during the maize drying at different ambient variation temperatures are presented in Table 2.

The drying data as the moisture ratio (X_R) versus drying time were fitted to fourteen mathematical models. Figure 10 presents results of regression analyses done by using the Matlab computer program and the variations of moisture ratio versus drying time for twelve mathematical models. The Table 2 shows drying model coefficients and the comparison criteria used to evaluate goodness of fit, namely the coefficient of determination (R^2), the reduced Chi-square (χ^2), mean bias error (MBE), the root mean square error (RMSE) and the modeling efficiency (EF) for solar tunnel drying. According to Table 2, the Midilli model showed good agreement with the experimental data and gave the best result for maize grains samples.

The constants and coefficients of the accepted model for the solar tunnel drying of maize grain were shown in Table 3.

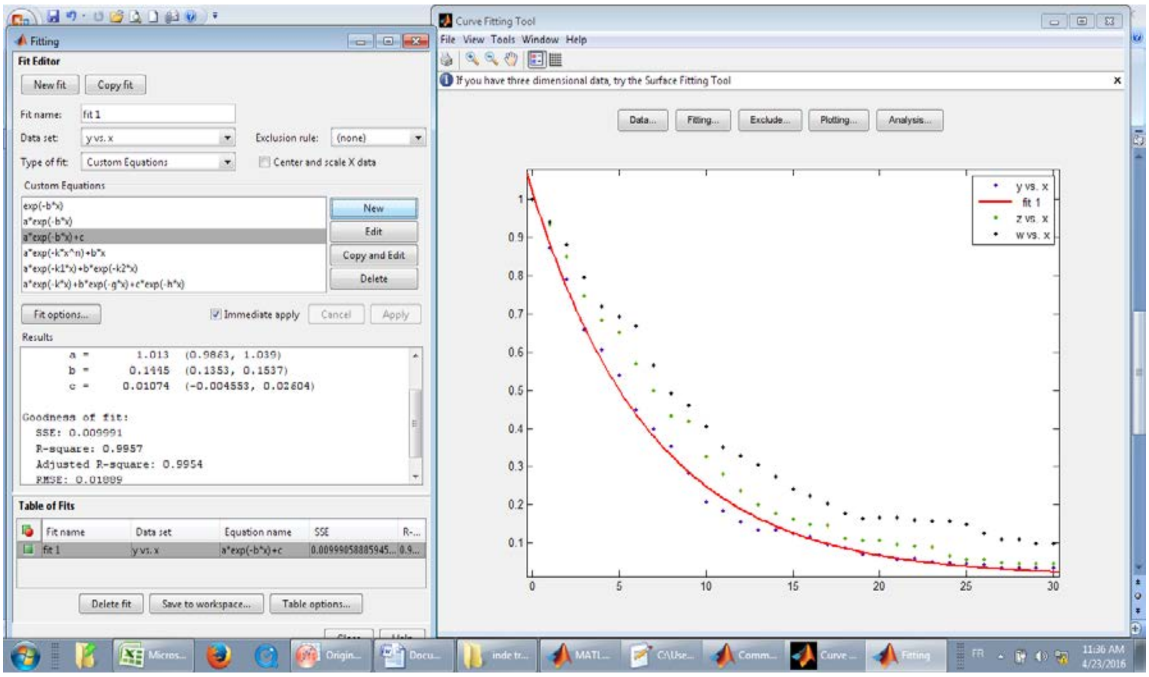

Figure 10. Result of regression analyses for midilli mathematical model

Table 3. The constants and coefficients of the accepted model

Drying air temperature	Model contents				R^2	χ^2
	a	b	k	n		
Inlet mean temperature (60°C)	0.9909	0.001324	1.1061	1.137	0.9974	2.2592×10^{-4}
Middle mean temperature (50°C)	0.9909	0.001324	0.06272	1.2525	0.9972	2.4074×10^{-4}
Outlet mean temperature (40°C)	0.9939	0.003467	0.05401	1.2525	0.9959	2.5481×10^{-4}

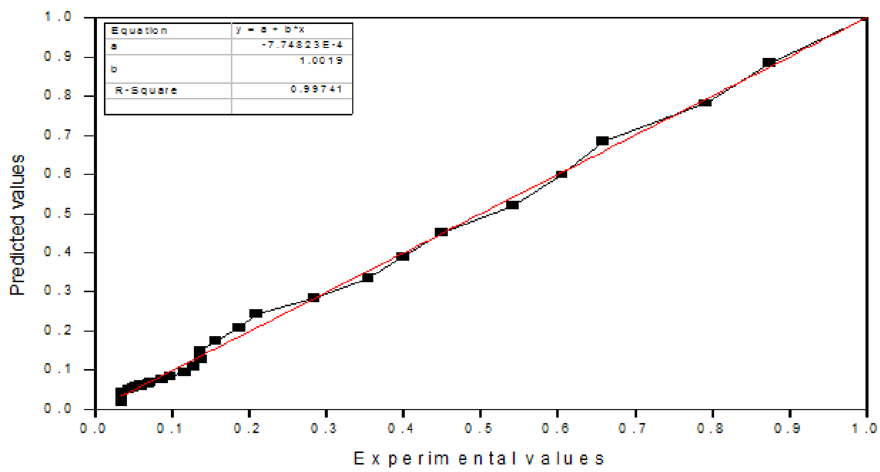

Figure 11. Experimental and Midilli model predicted moisture ratio at different drying conditions

By comparing the experimental and predicted moisture ratio values at any particular drying condition for validation of the established model, these values laid around the straight line (Figure 11). The Midilli model provided satisfactorily a good conformity between experimental and predicted moisture ratios, and predicted data generally banded around the straight line, which showed the suitability of this model in describing solar drying behaviour of Maize grains.

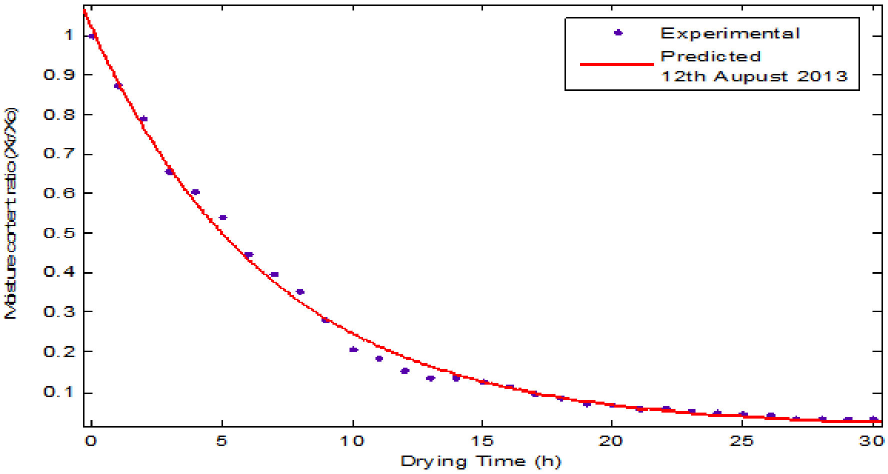

Figure 12. Comparison between the curves predicted by Midilli drying model and the experiment data at for solar tunnel drying mixed mode force convection in inlet (means temperature 60°C)

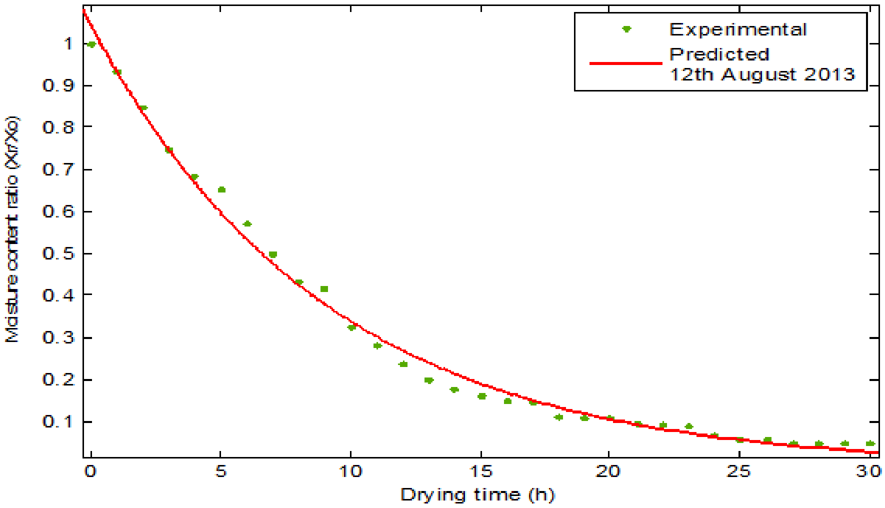

Figure 13. Comparison between the curves predicted by Midilli drying model and the experiment data at for solar tunnel drying mixed mode force convection in middle (means temperature 50°C)

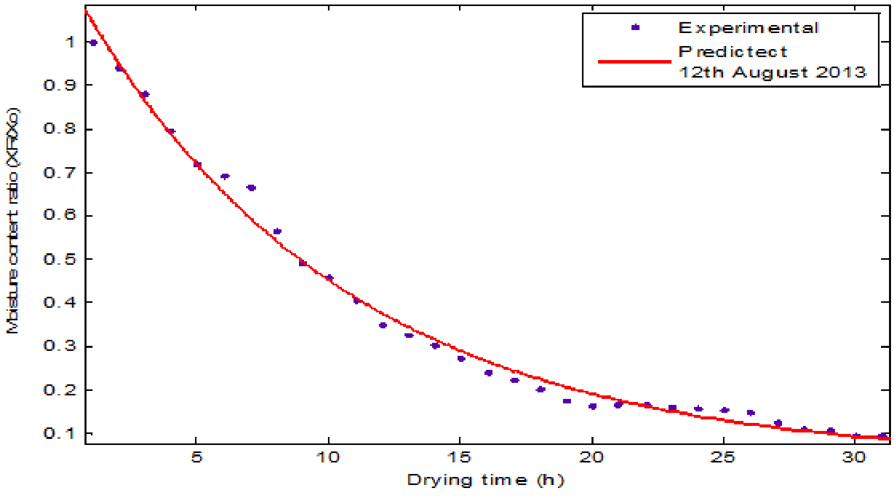

Figure 14. Comparison between the curves predicted by Midilli drying model time and the experiment data at for solar tunnel drying mixed mode force convection in outlet (means temperature 40°C)

Moisture contents ratio, simulated by Midilli equation with a, b, k, and n determined by regression, were compared with measured moisture contents ration in Figure 12 to Figure 14. The measured and predicted values were in good agreement. Similar agreements were also observed in other drying conditions.

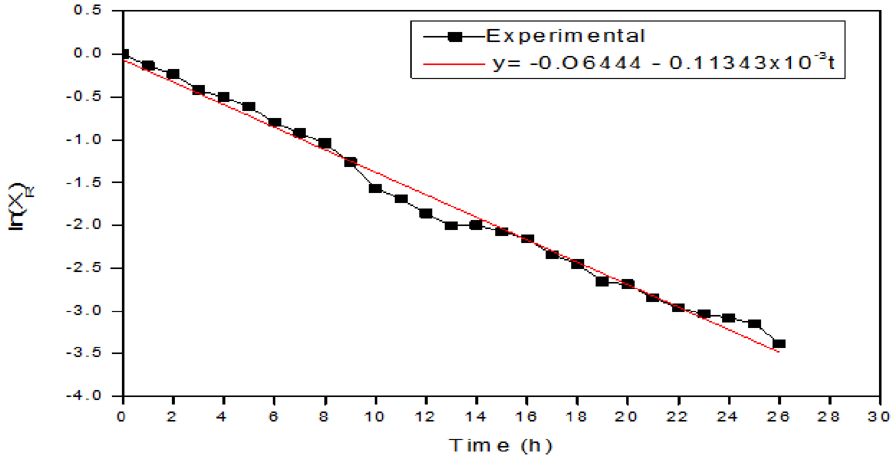

Figure 15. Experimental ln(X_R) versus time

The effective diffusivity (m^2/s) is calculated by equation 4 for solar tunnel dryer is ranging from 1.938x10^{-10} to 1.164x10^{-10}. According to this result, using slope derived from the linear regression of Ln (MR) versus time data shown in Figure 15. Yellow maize grain diffusion coefficient values at the various temperatures are shown in Table 4. According to Table 4, the Yellow maize grain diffusion coefficients increased with increasing temperature, and they were consistent with the results of the drying processes of other agricultural products cited in the literature, which, according to [22], presented values with magnitudes ranging from 10^{-11} to 10^{-9} $m^2.s^{-1}$. [23], observed that corn diffusion coefficients ranging from 9.488 x 10^{-11} to 1.768 x $10^{-10}m^2.s^{-1}$ at temperatures of 55 and 75°C, and [24] obtained diffusion coefficients for wheat grains ranging from 1.2181 x 10^{-10} to 2.8611 x 10^{-10} for temperatures ranging from 40 to 60°C. Diffusion coefficients can vary depending on air drying temperatures and soybean varieties, as reported by [25] for soybeans, or they can vary inside the product, according to [26] who studied different parts of the apple.

Table 4. Yellow maize grain diffusion coefficient values at the various temperatures

Differents levels and means temperature corresponding	Effective Diffusion coefficients (m^2s^{-1})
Inlet temperature (60°C)	1.938x10^{-10}
Middle temperature (50°C)	1.759 x10^{-10}
Outlet temperature (40°C)	1.164 x10^{-10}

Table 5. Physical properties of Yellow Maize Corn types

Parameter	Yellow Dent Maize
Moisture Content (%db)	36.92 ± 0.1
Length (mm)	8.75 ± 0.1
Width (mm)	8.75 ± 0.1
Thickness (mm)	4.55 ± 0.1
Radius (mm)	4.17

4. Conclusions

In this study, the new designed solar Hohenheim tunnel dryer can be used for drying of cereal agricultural products as well as Yellow dent maize grain under the climatic conditions of Southern Togo. Maize with initial moisture content of 0.37 dry basis (kg web / kg dry matter) were dried until they reached a final moisture content of 0.13 (kg web / kg dry matter) in 20 hours. All drying processes occurred in the falling rate period. In addition, the maize samples of solar tunnel dryer were completely protected from birds, insects, rain and dusts.

In order to explain the drying behavior of maize grains, fourteen different models were fitted to thin layer experimental data and compared according to their R^2, *RMSE* and χ^2. According to the results of thin layer drying of maize grains, the Midilli et al model was found as the best model which could be used to predict the moisture content of the product during drying process with high ability in different temperature in different levels drying of hohenheim tunnel dryer.

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Nomenclature

a, b, c, n	Empirical coefficients in drying models
Def	Effective diffusion coefficient (m^2 s^{-1})
EF	Modeling efficiency
E	Thickness maize (m)
L	Length (m)
l	Width (m)
Int	Inlet
a, b, c, d, h, g, k,	Empirical constants in drying models
X_t	Sample mass in time (kg moisture / kg dry matter)
MBE	Mean bias error
X_R	Moisture ratio
X_{Rexp}	Experimental moisture ratio
n	Number of constants in the model

N	Number of observations
Exp	Experimental result
RMSE	Root mean square error
R^2	Coefficient of determination t drying time
X^2	Reduced chi-square
r	Equivalent radius (m).
X_{Rpre}	Theoretical moisture ratio
Out	Outlet
Mid	Middle temperature
V	volume.

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