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INVESTIGATING THE PERFORMANCE EFFICIENCY OF A PV POWERED SOLAR DRYER (A CASE STUDY OF DAMATURU, YOBE STATE – NIGERIA.)

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ABSTRACT

In this paper, samples of chili and tomato were used to focus on performance comparison between open air drying and inside a PV powered solar dryer. The hourly system performance of the PV powered solar dryer has been measured for several days in Damaturu (Latitude: 11.7470^0 N, Longitude: 11.9662^0 E), Yobe state – Nigeria and the drying efficiency was calculated on the basis of weight change, drying time, heat gain and moisture removal. The results obtained showed that the dryer efficiency are 15% and 16% for tomato and chili respectively, while for open air drying the efficiency was found to be 10% and 13% for tomato and chili respectively. These results showed vast difference between open drying and drying inside a PV powered solar dryer. Thus, base on these results it can be concluded that the dryer is more efficient way of preserving vegetables food than the open air drying.

Keywords: Solar Energy, Drying Process, Moisture Removal, Temperature, Efficiency

INTRODUCTION

The solar food drying is one of the oldest Agricultural techniques related to preservation, but every year millions of naira worth of gross national product is lost through spoilage that is attacks from fungal and microbial organism [1,2]. These wastages could be easily prevented by proper drying, which enhance storage of crops over long period of time [3]. Solar drying system is developed by utilizing solar energy source to improve food preservation. The solar energy can easily have harnessed by a proper design of solar dryers for crops preservation. This method of drying requires transfer of both heat and water vapor consequently reducing moisture content of the crops. This is the appropriate food preservation technology for a sustainable world [4]. Since energy from the sun is free, the Solar Dryers are readily available, affordable and easy to maintain. They can also be carried from one place to another. In recent times more sophisticated dryers have been constructed to meets its growing demand. This device could be comfortable used by all since it requires no special skills before usage [5]. The main items dried using solar energy in Damaturu are okra, onion, spring, fish, red chili, carrot, pepper, green pepper, rice, meat etc. In this paper, we evaluate the performance efficiency of a PV powered solar dryer using two different samples (tomato and chilli) and compared the results with open air drying.

The average daily incident shortwave solar energy experiences some seasonal variation over the course of the year. The brighter period of the year lasts for 2.3 months, from February 18 to April 27, with an average daily incident shortwave energy per square meter above 6.4 *kWh*. The brightest day of the year is April 2, with an average of 6.7 *kWh*. The darker period of the year lasts for 2.5 months, from July 8 to September

23, with an average daily incident shortwave energy per square meter below 5.5 *kWh*. The darkest day of the year is August 10, with an average of 5.2 *kWh*. In Damaturu, the wet season is hot, oppressive, and mostly cloudy and the dry season is sweltering, windy, and partly cloudy. Over the course of the year, the temperature typically varies from 15 ℃ to 42 ℃ and is rarely below 12 ℃ or above 43℃. Damaturu experiences extreme seasonal variation in the perceived humidity. The muggier period of the year lasts for 6.2 months, from April 20 to October 27, during which time the comfort level is muggy, oppressive, or miserable at least 25% of the time. The muggiest day of the year is August25, with muggy conditions 100% of the time. The least muggy day of the year is December 27, when muggy conditions are essentially unheard of. Hence drying vegetative products and fisheries is a great challenge in summer. In a day of bright and intense sunlight, it is easier to dry those materials, but during cloud covered condition or rainy day, it becomes hard and fungus formation is enhanced due to moist weather [6-8].

MATERIALS AND METHODS

Solar Energy

The enormous amount of energy continuously emitted by the sun is dispersed into outer space in all direction only a small fraction of these is intercepted by the earth and other solar planets. The solar energy reaching the peripheral of the earth's atmosphere is considered to be constant for all practical purposes and is known as solar constant. Because of difficulties in achieving accurate measurements the exact value of solar constant is not known with certainty. The value of solar constant is believed to be approximately between 1,353 W/m^2 and 1,395 W/m^2 (approximately 1.4 km/m^2 or 2.0 $Cal/cm^2|min$.).

Table 1: Average hourly solar insulation for a typical day in March, 2018 (rounded value) [9].

Time (*hour*)	Solar insulation *W/m*
09:00	606.78
10:00	704.07
11:00	829.64
12:00	987.44
13:00	829.64
14:00	704.07
15:00	606.78
16:00	501.89
17:00	312.01

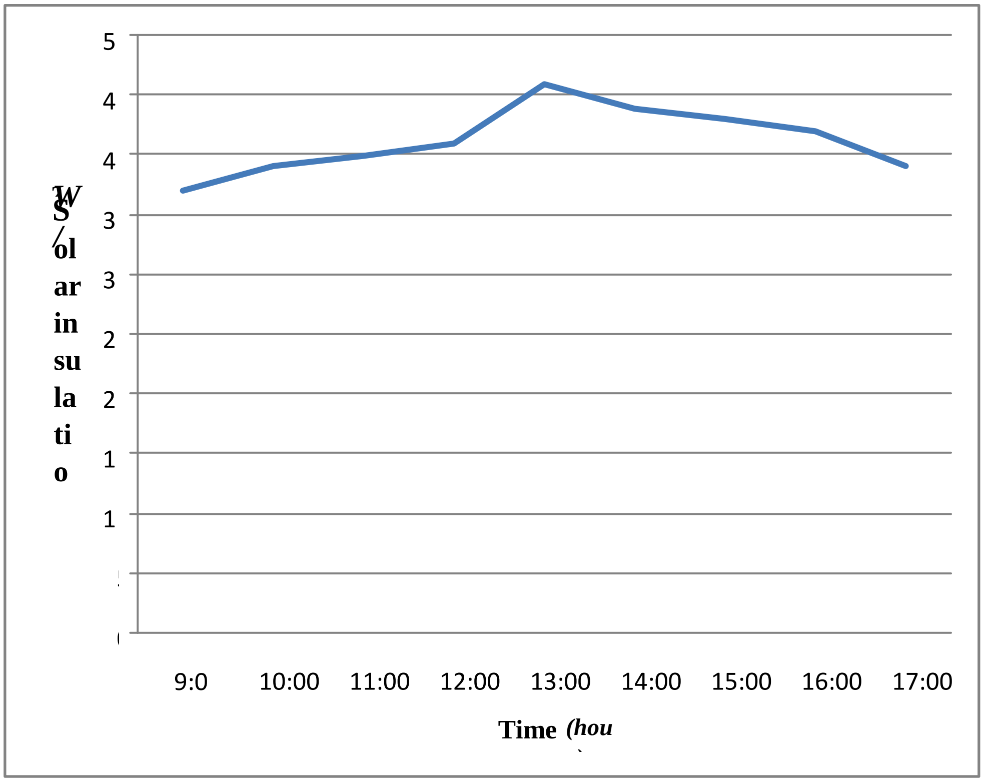

Figure 1: Solar insulation (W/m^2) verses time (*hour*) curve

Figure 1 represents the average variations of the hourly solar insulation for a typical day in March, 2018 which is obtained from the Metrological Department Maiduguri, Borno state. It can be observed from the above figure there is an average maximum value of the solar insulation of (987.44 W/m^2) at 13:00. This is due to high intensity of the radiation received when the solar inclination angle is about 90^0 this value gradually decreased and reached minimum value of (312.01 W/m^2) at 17:00 due to low intensity of the radiation received thereafter.

The PV Solar Drying

Each of the samples of 1 *kg* was taken inside the dryer separately. Dryer temperature and sample weight were measured with thermometer and spring scale balance respectively. Then after each hour, sample weight and dryer temperature were measured and recorded. These parameters were taken from 09:00 to 17:00, i.e. for 8 hours and measurement time interval was taken 1 hour.

(*a*) (*b*)

Figure 3: (***a***) Experimental set up of PV powered solar dryer with tomato and chili inside (***b***) Openair drying of tomato and chili

Figure 4: A dried samples of tomato and chili from a PV powered solar dryer

The Open Solar Drying

When placed in a current of heated air, food initially loses moisture from the surface. This is the constant rate period. As drying proceeds moisture then removes from inside the food material starting near the outside. Moisture removal becomes more and more difficult as moisture has to move deep inside the food to the surface. This is the falling rate period. Eventually no more moisture can be removing and the food is in equilibrium with drying air. The greatest potential for drying crops in a short time is when the ambient air is arid and warm then less air is needed. This temperature will itself depend mainly on the air temperature but also on the amount of the solar radiation received directly by the food being dried [10].

For an open solar drying, each samples of 1 *kg* each were taken in an open place maintaining the same area as dryer collector. Just like in dryer, this process also started from 09:00 and parameters like temperature and weight loss i.e. moisture removal were taken up to 17:00 maintaining one-hour interval.

Figure 5: A dried sample of tomato and chili from an Openair drying

Moisture Content (MC)

The moisture removal was calculated by subtracting the instantaneous weight from the weight measured an hour before that time. For each two samples chili and tomato, for the PV powered solar dryer the process was repeated for three individual days and averaged. The change of temperature inside dryer was assumed to be the temperature change of the subject. The change of ambient temperature was assumed to be the temperature change of samples subjected to open drying. This process was repeated for five days. The percentage moisture content was determined by using equation (1) below

$$MC(\%) = \frac{W_1 - W_2}{W_1} \times 100\% \quad (1)$$

Where, W_1 = Weight of the sample before drying (*gram*) and W_2 = Weight of total or partially dried sample (*gram*)

The Dryer Moisture Content (MC) for tomato is given by

$$MC(\%) = \frac{1000 - 223}{1000} \times 100\% = 77.7\%$$

The Dryer Moisture Content (MC) for chili is given by

$$MC(\%) = \frac{1000 - 398}{1000} \times 100\% = 60.2\%$$

The open air drying Moisture Content (MC) for tomato is given by

$$\text{MC } (\%) = \frac{1000 - 220}{1000} \times 100\% = 78.0\%$$

The open air drying Moisture Content (MC) for chili is given by

$$\text{MC } (\%) = \frac{1000 - 396}{1000} \times 100\% = 60.4\%$$

Drying Rate (DR)

The drying rate samples during drying period was determined using equation (2) below and recorded in Tables 2 for the two samples

$$DR = \frac{\Delta w}{\Delta t} \qquad (2)$$

Where, Δw = change in weight loss in one-hour interval (gram) and Δt = difference in time reading (hour).

Table 2: shows the drying rate (*gm/hour*) verses time (*hour*) inside PV solar dryer and at open air drying condition

Time (*Hour*)	Drying Rate (*gm/Hour*)			
	Inside PV Solar Dryer		An Open Air Drying	
	Tomato	Chili	Tomato	Chili
09:00 – 10:00	71	56	42	34
10:00 – 11:00	97	99	51	61
11:00 – 12:00	102	110	76	98
12:00 – 13:00	117	130	81	101
13:00 – 14:00	79	90	58	86
14:00 – 15:00	54	51	60	63
15:00 – 16:00	37	44	40	37
16:00 – 17:00	16	20	5	12

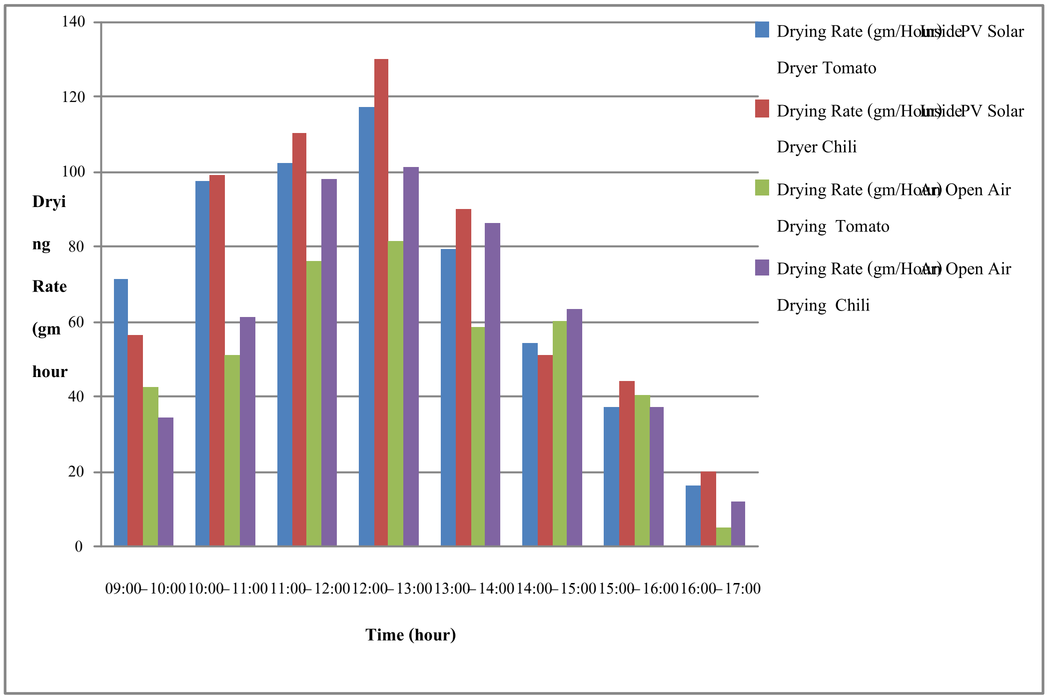

Figure 6: Drying rate (*gm/hour*) verses time (*hour*) for both inside PV dryer and open air drying

The Figure 6 above showed that the drying rate of tomato and chili increase due to increased in the dryer and ambient temperature and (from 12:00 to 13:00) the increased of the dryer temperature and ambient temperature is due to high intensity of the solar radiation received at that hour. The dryer and ambient temperature was up to 71^0C and 46^0C respectively at 13:00 and decreases gradually due to low intensity of radiation received at the noon. The PV dryer average maximum drying rate at 12:00 to 13:00, for tomato and chili are 0.117 *gm/hour* and 0.130 *gm/hour* respectively while for the open drying for tomato and chili are 0.081 *gm/hour* and 0.101 *gm/hour* respectively as shown in tables 4 and 5 below.

Table 3: The Table below shows the average ambient temperature and the dryer temperature over the month of March, 2018 (rounded value).

Time (*hour*)	Ambient temperature °C	Dryer temperature °C
09:00	37	49
10:00	39	54
11:00	40	57
12:00	41	60
13:00	46	71
14:00	44	67
15:00	43	62
16:00	42	58
17:00	39	53

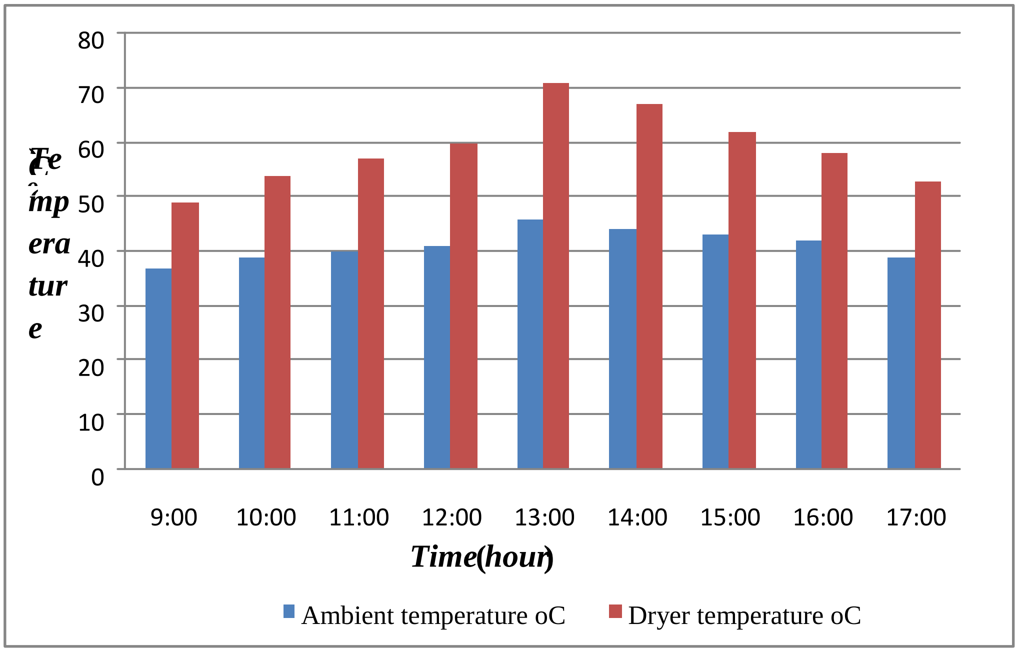

Figure 7: The variation of the average ambient temperature ^{O}C and dryer temperature ^{O}C.

In the figure 7 above the variation of the ambient and dryer temperature were measured and recorded with the help of thermometer for every one hour interval in the month of March 2018 in Damaturu Yobe state. The figure showed that the hourly variation of the temperature inside the dryer (represented by red bars) is higher than the ambient temperature (represented by blue bars) during the observation period (09:00 to 17:00).

RESULTS AND DISCUSSIONS

To facilitate the calculation for efficiency of a PV powered solar dryer, only the hour from 12.00 to 13.00 was taken as a standard drying time. Since, at that time the insulation is maximum in general. The weight measured at 12.00 was subtracted from the weight measured at 13.00 in order to gain moisture removal.

Table 4: Samples initial weight and moisture removal inside PV powered solar dryer.

Sample	Weight (at 12.00) *kg*	Drying time (from 12.00 – 13.00) *Hour*	weight (at 13.00) *kg*	Moisture removal (*kg*)
Tomato	0.625	1	0.508	0.117
Chili	0.437		0.307	0.130

Table 5: samples initial weight (*kg*) and moisture removal (*kg*) at open air drying condition

Sample	Weight (at 12.00) *kg*	Drying time (from 12.00 – 13.00) *Hour*	Weight (at 13.00) *kg*	Moisture removal (*kg*)
Tomato	0.737	1	0.656	0.081
Chili	0.648		0.547	0.101

Drying efficiency of both solar dryer and open air drying can be calculated using the formula below [11].

$$E = \frac{\Delta W \times \Delta H_L + W_i \times C_p \times \Delta T_d}{A_c \times I_d \times t_d} \quad (3.3)$$

Where, ΔW = Moisture evaporated (*kg*), ΔH_L= Latent heat of vaporization of water, 2260 ($kJkg^{-1}$), W_i= Instantaneous sample weight at 12.00 (*kg*), C_p= Specific heat capacity of the subject (= 3.98 $kJkg^{-1}K^{-1}$ for tomato and 3.81 $kJkg^{-1}K^{-1}$ for chili), ΔT_d= Monthly averaged change of dryer temperature from 12.00 *am* to 13.00 = (71 – 60) °C = 11°C= 11 *Kelvin*, A_c= Area of collector (in case of dryer) or bed area (in case of open dry) =

0.58063 m^2, I_d= Monthly average hourly insulation upon collector between 12.00 and 13.00 = (987.44 + 829.64)/2=908.54 W/m^2 and t_d= Drying time =1 *hour* = 3600 *seconds*.

The Efficiency of a Solar Dryer (E_d) for tomato is given by

$$E_d = \frac{\Delta W \times \Delta H_L + W_i \times C_p \times \Delta T_d}{A_c \times I_d \times t_d} = 15\%$$

The Efficiency of a PV powered Solar Dryer (E_d) for chili is given by

$$E_d = \frac{\Delta W \times \Delta H_L + W_i \times C_p \times \Delta T_d}{A_c \times I_d \times t_d} = 16\%$$

The Efficiency of Open Air Drying (E_o) for tomato is given by

$$E_o = \frac{\Delta W \times \Delta H_L + W_i \times C_p \times \Delta T_a}{A_c \times I_d \times t_d} = 10\%$$

The Efficiency of Open Air Drying (E_o) for chili is given by

$$E_o = \frac{\Delta W \times \Delta H_L + W_i \times C_p \times \Delta T_a}{A_c \times I_d \times t_d} = 13\%$$

Where, ΔT_a = monthly averaged change of ambient temperature from 12.00 to 13.00 = (46 – 41) = 5 °C = 5 *Kelvin.*

Table 6: The efficiency of a solar dryer and open air drying condition

Sample	Dryer efficiency (%)	Open dry efficiency (%)
Tomato	15	10
Chili	16	13

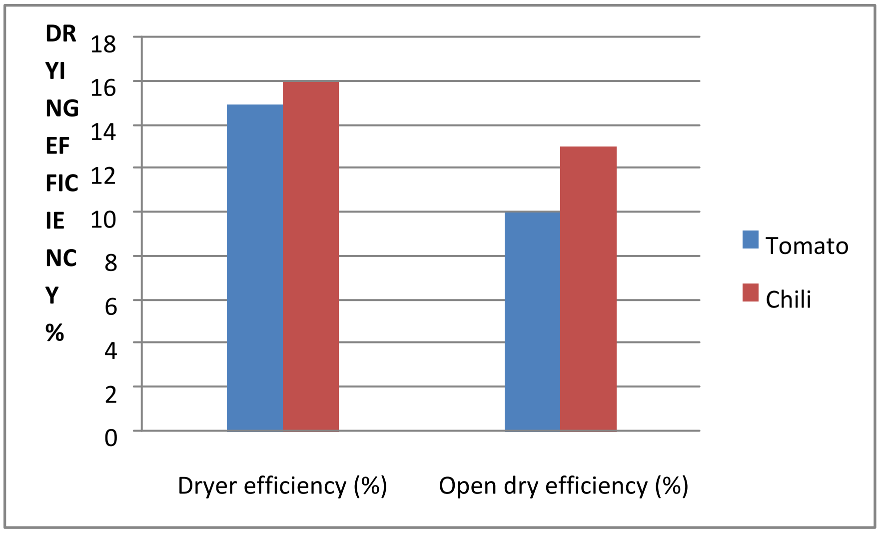

Figure 8: pictorial representation of the efficiency of PV powered solar dryer and open air drying. The advantages of this solar dryer are numerous. Dried foods are tasty, nutritious, light weight, easy to prepare, easy to store and use. Nutritional dried food is ranked by United States food and drugs agency as better than canning and freezing the tastes are related to the food, but there is some uniqueness in their flavor and texture. If drying of food were widely implemented, significant savings to farmers would be achieved. These saving could help strengthen the economic situation of government, consequently, resulting to wealth creation and as well, change the nutritional condition of our country this would be a very big relief to industrialist since it does not involve heavy complicated machine [1].

Most of our crops are harvested during the peak period of rainy season and so preservation proves difficult and most of these crops perish. Vegetable and other perishable agricultural crops are routinely seen dumped in villages and major cities. This of course, constitutes environmental hazards. These crops can be preserved and stored so that they can be of great economic importance both to the farmer and the societies at large. Seasonal foods are not presently dried for export or local consumption during period of scarcity. Rural farmers do this by open -air drying. This practice in rural areas has some obvious disadvantages [3]. This method is unhygienic since the crops are easily contaminated by animals, dropping and consequent infestation by fungi and bacteria. Human health is thus endangered as a result of food poisoning. This method also prolongs drying and may result in deterioration of the quality of crops. It also makes it more difficult for moisture to escape and food does not dry properly. Although, it is a laborious method of food preservation and the procedure is not exact [5]. They are also watched in order to prevent physical attacks from birds and other animals.

CONCLUSION

Focusing on the experimental results above, the PV powered solar dryer efficiency at that specific hour (12:00 – 13:00) ranged from 15% to 16% for the samples taken and efficiency ranges from 10% to 13% at open dry condition for the same samples so we are able to utilize the solar thermal power much better in dryer than open air condition. Additional things can be added to enhance the performance of that dryer are, we could attach a sand bed at the bottom of the dryer. Also a DC heater can be attached, which will get electricity from the solar panel. The main problem with that dryer was heat leakage due to its old infrastructure; it also affects the proper temperature gain and moisture removal.

Nevertheless, the dryer performed much better than open air drying system. It also provides security and sustainable drying environment.

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BIOGRAPHICAL NOTE

Fatima M. Mustapha's first degree was in Physics in 2018 from University of Maiduguri, Borno State. In addition, she had a Nigeria Certificate in Education (NCE) in Mathematics and Physics at Sir Kashim Ibrahim College of Education, Maiduguri in 2014. She holds Diploma in Computer from Federation of Muslim Women Association in Nigeria (FOMWAN), Damaturu, Yobe State in 2013. However, the author has experiences in the field of teaching, trainings and workshops.

Aliyu Adamu had obtained his B. Sc. Degree in Physics in 2009 and M.Sc. Degree in Nuclear Physics in 2015 both from University of Maiduguri, Borno State. He also holds Diploma in Database Management and programming from YAYSIB Computer Institute, Maiduguri in 2014. However, Aliyu has experiences in the field of teaching, publications and trainings. He was employed as an Assistant Lecturer in the year 2015. He has now risen to the rank of Lecture II. Presently he has registered for his PhD in Theoretical Nuclear Physics at the University of Maiduguri.

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