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Environment, Agriculture and Health Oral Presentation Papers

The Diversity Field Forum (DFF) participatory approach and its impacts in West Africa

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Abstract

Farmers' capacity to select and maintain crop varieties that meet their production, market and environmental challenges, underpins smallholders' food security. Extension programmes are in place to provide technologies developed by research to support farmers to overcome these challenges. However, these technologies are often developed centrally without farmers' participation and without building on their knowledge, therefore adoption rates by farmer communities are very often low. Failure rates of adoption of technologies from agricultural extension frameworks in the 1970s to 1990s resulted in the suggestion of a paradigm shift to employ farmer knowledge and participation to co-develop adapted solutions. Diversity Field Forum (DFF) is among the approaches that has proven efficient in strengthening smallholders' ability to use their local plant genetic resources to manage risks, and increase agroecosystems resilience, and food security in marginal zones, with a strong gender component. The DFF is a participatory and community-based educational approach that aims to strengthen the skills of rural male and female farmers to assess, manage, use, and benefit from their plant genetic resources. The approach has been tested repeatedly in West Africa and shows to be efficient in supporting farmers to increase productivity, to reduce risks of crop failure, and to strengthen seed systems through management of crop intraspecific diversity. The approach is now being scaled up in several countries in West Africa. This paper presents the approach, its objectives, principles, and steps for implementation. Implications of the DFF approach and empowerment of marginalized smallholder groups to increase their social and natural capitals are discussed. The impacts of the DFF participatory approach on farming systems resilience and food security in West Africa are presented, together with the way forward for institutionalization.

Keywords: Diversity Field Forum, Participatory Plant Breeding, Agricultural Biodiversity, Plant Genetic Resources, Traditional Varieties, Farmer Management, West Africa

Paper category: Environment and Agriculture

INTRODUCTION

Several agricultural extension programmes were implemented in the developing world in the second half of the 20th century. The first extension programmes consisted in the transfer of external inputs such as chemical pesticides, inorganic fertilizers, hybrid varieties, animal feedstuffs, tractors and other machinery to farmers (Pretty 1995). This was favored by agricultural policies and practices that successfully promoted these external inputs. However, after an initial improvement this rendered most agricultural systems more vulnerable, for instance inadvertent consequences in water use, soil degradation, and chemical runoff have had negative environmental impacts beyond the sites cultivated (Pingali 2012). The late 1970s saw many failures of these top-down programmes and projects because they did not fit or meet local needs (Chambers 1994). This called for a paradigm shift in the 1990s to increase farmers' participation in constraints analysis and to co-develop solutions. Several participatory approaches were then developed and tested, among which the Diversity Field Forum (DFF).

The Diversity Field Forum (DFF) or "*Champ de Diversité* (CD) in French" is a well-tested farmer participatory approach that builds on the concept of Farmer Field School (FFS), which is a group-based learning process developed at the end of the 80s, that brings together concepts and methods from agroecology, experiential education and community development, as an alternative to the prevailing top-down extension method of the Green Revolution. The DFF approach was developed in early 2000s, in low-heritability environments in West Africa to strengthen the capacity of farmers to analyze and manage their own crops' plant genetic resources. Low-heritability environments are those in which seedling establishment and breeding of locally adapted varieties are difficult due to extreme spatial and temporal heterogeneity in crop environment conditions, including the unpredictability of seasonal distribution of rain. As in other subject domains, this community participatory approach generates skills, leading to better and more locally adapted outcomes for farmers with regard to their crop-plant genetics, when compared to a strict "technology transfer" approach that has historically been applied uniformly across large geographic areas.

OBJECTIVES AND PRINCIPLES OF THE DFF APPROACH

DFF experimental plots at the village level aim to strengthen the capacity of farmers to examine and set priorities to overcome barriers in order to better manage their own plant genetic resources in a manner that maximizes adaptive potential. The DFF is based on the non-formal education principle of learning-by-doing. It creates a social "safe space" (low risk to participants) that facilitates the exchange of ideas and knowledge among farmers, extension agents and researchers. It therefore offers a space where scientific / modern and local knowledge and practices meet to co-innovate. This approach puts emphasis on the role plant genetic resources, more specifically intraspecific diversity, can play in improving production systems. The farmers' group work on the adaptive traits of crop portfolios to local environments while ensuring farmer preferences are fully taken into account for a greater technology uptake. In the DFF, farmers experiment with different varieties – both landraces and improved varieties – and evaluate different management practices. The DFF is an adaptation of the joint learning process developed under the FFS approach and was first established in Mali and extended in Burkina Faso and Niger at three sites per country, representing different environmental conditions with average annual rainfall ranging between 200 – 800 mm.

STAGES IN THE DFF APPROACH

A group of 25-30 male and female farmers meet from a cluster of neighboring villages. The group examines major constraints to the production of their food crops, prioritizes those problems that can be resolved through participatory research, and performs an assessment of the crop genetic resources existing in the site. The group decides on a number of priority crop species to be tested and agrees on a suitable plot where the experiment will be set up. With facilitated guidance from research and the extension service personnel, the farmers select both landraces and publicly released varieties of the species to be tested at the chosen site. The choice of crops and varieties is based on the constraints identified, for instance drought or pests and diseases or striga. The group agrees on criteria for testing and selection of the best performing cultivars and on conservation practices. Both traditional and modern crop selection criteria are used.

Weekly meetings at the experimental site allow DFF participants to closely monitor the crop cycle and performance of varieties through to harvest. As in the Farmer Field Schools, participants are divided into smaller groups to observe and collect data on the various crop varieties. This information is then presented and discussed in the local language in the larger group plenary. The facilitator then synthesizes and records the information.

The most important constraint identified at each stage of the crop development cycle becomes the focus of discussion and experiments aimed at finding solutions. At the end of the cycle, varieties with desired traits (e.g. plant vigor, resistance/tolerance to pests and disease, tolerance to water stress and with good taste and yield potential) are selected, multiplied and disseminated within the DFF group and beyond. The different steps described above are grouped into four major stages (Figure 1):

a) ***Stage 1: Participatory appraisal of the initial state of plant genetic resources (PGR)***. At this stage farmers, extension agents and researchers conduct an initial situation analysis where major constraints to agricultural development are identified, and local PGR characterized. A set of activities are prepared and executed to this end.
b) ***Stage 2: Negotiating activities for PGR characterization***. In this stage the problems to be solved using local PGR are analyzed and prioritized. The local knowledge and skills on PGR management are assessed, crops to be studied identified and a Multi-Stakeholder Learning Group (25-30 men and women farmers, plus district extension agents, plus researchers) is established. Then activities to be conducted during the crop cycle are negotiated.
c) ***Stage 3: Implementation of the DFF (experimentation)***. Here the group conducts experiments on the selected crop varieties. Each group monitors crop development, collects, analyzes and presents data.
d) ***Stage 4: Evaluation of the DFF***. In this final stage, the DFF group evaluates the outputs, analyses impacts on their welfare, identifies new constraints and plans for future activities.

In Figure 1, the dashed arrows indicate that after stage 4 the group can start again with another DFF cycle, from stage 1. The appendices contain several tools and materials that have been developed by Bioversity International (2008) and freely available for use to conduct activities of a DFF session. Appropriate tools are designed for each stage of the learning process. For instance, there are tools to create group dynamics and social cohesion, but also other guidelines to conduct the different group exercises.

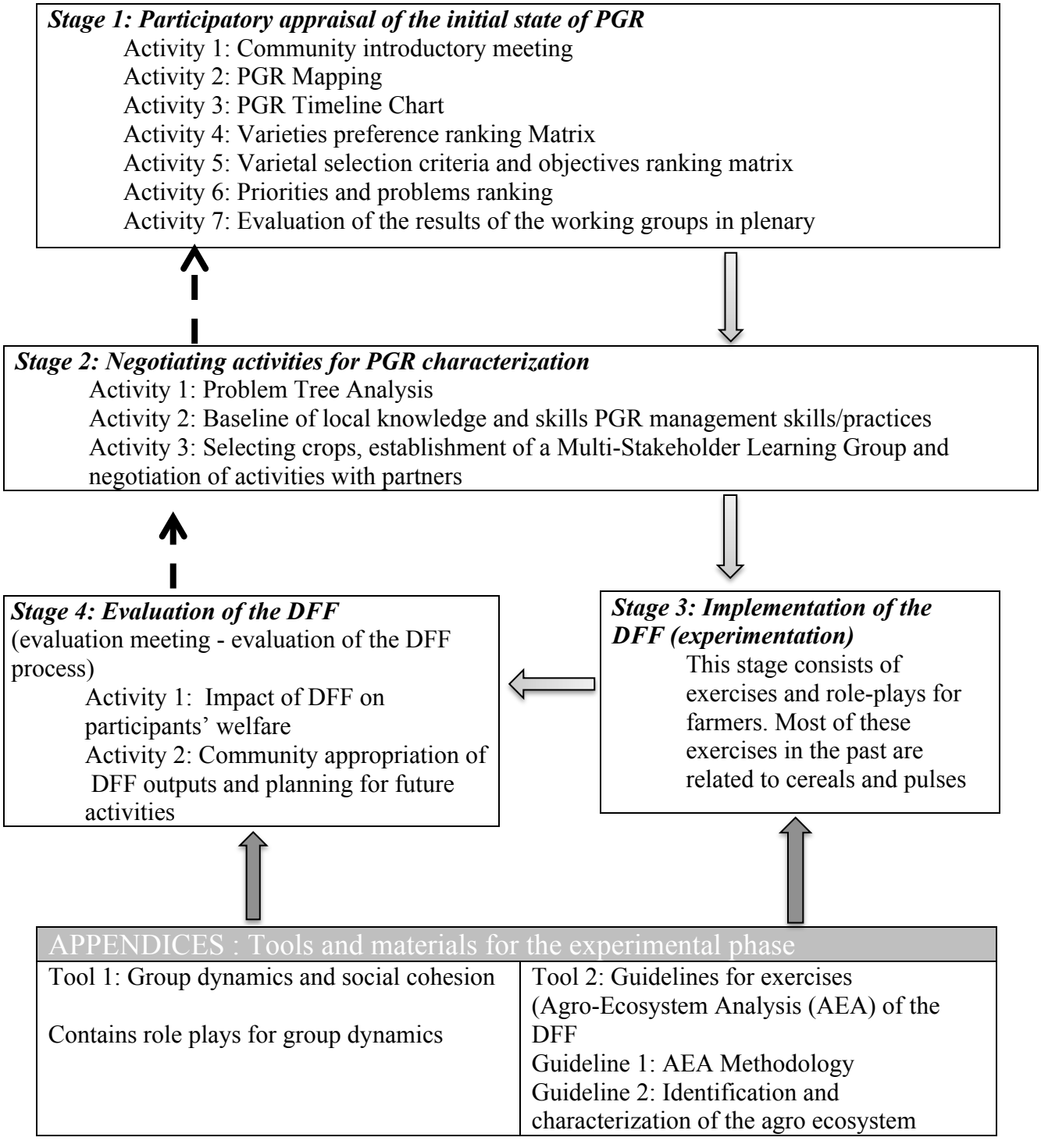

Figure 1. The different steps of the DFF process and tools. Source: (Bioversity International 2008)

GENDER IMPLICATIONS IN THE DFF

Male and female farmers should be equally represented in the DFF group but to date, the farmer groups have managed to include about two-thirds male and one-third female participants. The age of participating farmers varied from one site to another with an average of about 30 years. Depending on religious or cultural constraints, the groups sometimes have been subdivided into separate groups of men and women. Previous experience shows that female farmers tend to assign higher value to criteria related to cooking quality and post-harvest characteristics, while male farmers give more importance to productivity and market value.

In Dan Saga at Aguié in Niger, the women's sub-group successfully worked on the newly domesticated leafy vegetable *Senna tora* (L.) Roxb. and produced seeds that were sold to farmers from other villages. A study conducted in the same area in Niger revealed the fundamental role played by women in increasing genetic diversity through the production and dissemination of seeds of various crops, including newly domesticated ones. Indeed, in parts of the project area, tradition requires brides to bring varieties from their villages of origin to their new homes, as gifts and as agricultural 'working capital'. If a woman should later lose her introduced variety, it is reintroduced from her village of origin. Women are often the first to domesticate and conserve seeds of wild food species, e.g. *S. tora* and *Ceratotheca sesamoïdes* Endl. In Thiougou located in South-West of Burkina Faso, the women's sub-groups successfully worked on okra (*Abelmoschus esculentus* (L.) Moench.) and produced leaves, fruits and seeds that were sold to farmers from neighboring villages and from the capital Ouagadougou.

EXPERIMENTAL DESIGN

As indicated above, the species and cultivars to be tested in the DFF are selected by farmers based on their preferences for crops and the constraints they have identified in their production systems. A simple randomized complete-block experimental design is used in the DFF and generally, an equal number of landraces and improved varieties of the same crop are grown and compared. It is recommended to not involve more than 12 varieties, i.e. 6 landraces and 6 improved varieties. The size of the experimental plots varies with the number of varieties to be tested and with land availability. However, 50 m^2 plot per crop variety is recommended. The experiment is also repeated in different local soil conditions (e.g. sandy, clayey or intermediate soil types) to take into consideration the variability of environments.

IMPACTS OF THE DFF PARTICIPATORY APPROACH ON FARMING SYSTEMS RESILIENCE AND FOOD SECURITY IN WEST AFRICA

Positive impacts of the DFF participatory approach have been reported at two different levels; i.e. at farm and seed systems levels. Experiences in Mali indicated a general tendency of increased varietal diversity in smallholders' farms in the communities were the approach was promoted (Figure 2). The overall richness of landraces doubled in the project sites from 2005 to 2012 (Figure 2B). This is the result of the reintroduction of some landraces, which had disappeared from the communities. For instance, with the climate variability in the areas, farmers generally favor testing of drought resistant varieties. Relatively well-performing cultivars from dryer zones are reintroduced into relatively more favorable (wetter) zones, in order to benefit from their evolved traits for drought tolerance. Ancient cultivars, known for specific traits, which have disappeared from a village, are recovered from wherever possible (neighbor villages, regions, national or international genebanks) with the help of extension agents and scientists, and are tested for possible reintroduction.

The diversity field fora established in a given community are usually connected to a community seed bank (CSB) and seed fairs should be periodically organized to disseminate the selected varieties and technologies developed through the DFF. The network of DFF together with the CSB and seed fairs form a model for resilient production systems (Figure 3). With this model, farmers' capacities to co-develop technologies (adapted crop varieties and quality seed production) are enhanced, their skills in plant genetic diversity management improved, the availability of quality planting materials of both publicly released and farmer varieties increased.

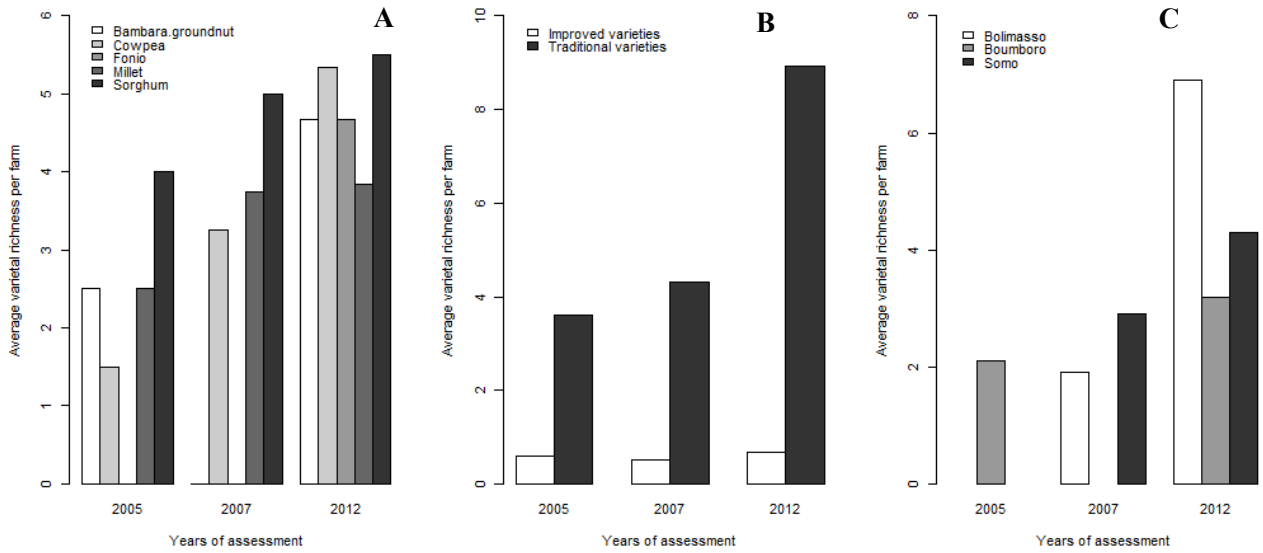

Figure 2. Trends in the varietal diversity of five crop species in project sites in Mali, from 2005 to 2012

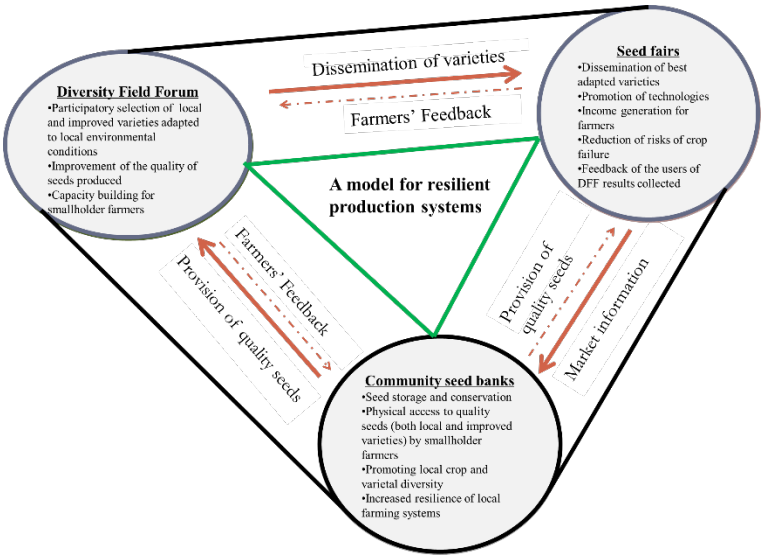

Figure 3. Model for resilient production systems

An impact evaluation in Mali reported that the DFF and the diversity seed fairs have had positive impact in increasing farm productivity, introducing new varieties (both landraces and publicly released varieties) and increasing information and experience exchange between farmers (Gotor and Cherfas 2011; Smale et al. 2010). Thanks to the trainings on participatory

crop breeding in the DFF, a sorghum landrace '*Kénikénidjèma*' was successfully registered on the Malian National Catalogue of Varieties. In addition, about 2 tons of seeds produced by trained farmers of the informal seed system were certified by the Seed Laboratory, and were legally sold.

Another good case of success is the DFF and CSB of Dan-Saga established in 2005 in Maradi region in Niger. A recent report indicated the DFF and CSB are all still running well and represent an important source of livelihood for the group members and for the community. This DFF established 13 years ago is now the main diversity quality seed source for the community. It also arbores samples (seeds) of several threatened crop landraces and fodder species. In Mali, three community gene and seed banks established in 2014 in Somo (Cercle of San), Bolimasso and Boumboro (Cercle of Tominian), and renovated in 2018, are responsible for the production and conservation of both improved and local varieties, and representing the main source of seed for community farmers and neighboring villages. A total of 466 kg, 2508 kg, and 4841 kg of seeds of six crops (fonio, pearl millet, sorghum, rice, cowpea, and Bambara groundnut) were produced in the DFF respectively in 2015, 2016, and 2017, and conserved in the three CSB (Figure 4). These cases represent striking examples of the power of this farmer participatory approach to unlock farmer groups' capacity to innovate in the sector of plant genetic diversity management and conservation, when they are given the adequate technical support (Smale et al. 2010).

Lastly, the DFF approach has also inspired several agricultural development projects and international agencies working in West Africa. Another variant of the concept, the Famer Field Fora (FFF) has been described and used to strengthen farmers' capacities in Benin, Burkina Faso, Cameroon, Ghana, Mali, Niger, Nigeria, Senegal, and Togo (Gbadugui and Coulibaly 2013; Opare-Atakora et al. 2014). The approach is getting momentum because is able to increase farmers' social and natural capital (Bioversity International 2008).

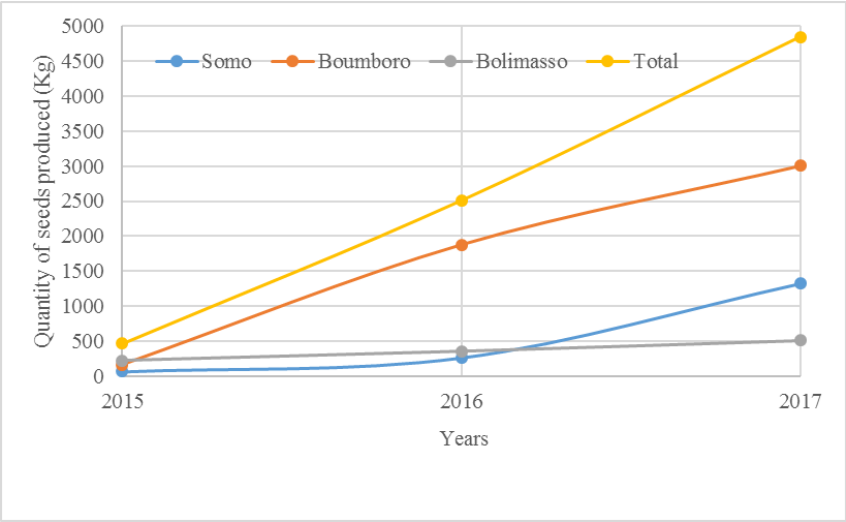

Figure 4. Quantity of quality seeds produced and conserved in the community seed banks of Somo, Bolimasso and Boumboro, Mali

PATHWAY FOR INSTITUTIONALIZATION

It was found by Smale et al. (2010) in their impact assessment that long-term commitment to foster local leadership and capacity is necessary to achieving impacts with this type of extension approach. Fortunately, the approach received significant support from donors and national governments in Mali, Burkina Faso and Niger where it was developed

and tested. The approach is now being scaled up in West and Central Africa. In the last five years, there have been initiatives to mainstream the approach into the national agricultural extension programmes in the above-mentioned countries. For instance, extension officers and technicians at all levels were trained in 2017 and 2018 in Mali and Niger in the framework of country agricultural development programmes supported by the International Fund for Agricultural Development (IFAD), and the Food and Agriculture Organization of the United Nations (FAO) through the Global Environment Facility (GEF) funding.

ACKNOWLEDGEMENTS

Authors acknowledge the financial support from IFAD, FAO and GEF for the various projects implemented in Burkina Faso, Mali and Niger, to promote the DFF approach in West Africa. Our gratitude also goes to the farmers' groups and the communities that participated and shared their knowledge in the different projects sites, in the different countries. We extend the same to extension technicians, researchers, NGOs staff who contributed their time and knowledge.

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Development of a Smart Diabetes Monitoring Device

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Abstract
The prevalence of diabetes has been steadily increasing in the past few decades, particularly in low- and middle-income countries. This work develops a non-invasive diabetes monitoring device that is cost effective, cheap, stress and pain free which can measure glucose level on the spot. This work is based on the fact that on the spot blood glucose monitoring device can reduce or replace the invasive method of monitoring diabetics, reduce pains from pricking the finger, reduce the length and expensive cycle of visiting doctors and pharmacies and eradicate other diseases that are associated to diabetes. The developed glucose monitoring device consists of three parts; the transmitter section (light source), the receiver section (photodiode) and the data display section. Near Infrared (NIR) light is applied onto one side of the ear lobe, while a receiver on the other side receives the attenuated light and then converts the signal into a voltage signal. All these variables are then amplified, sampled, and processed inside the PIC16F877A microcontroller after which the glucose reading is displayed on the LCD or communicated via bluetooth on android application. From the results obtained, the device has successfully shown that the relationship between the output voltages from photodiode is directly proportional to the concentration of glucose. When the concentration of glucose increases, the output voltage from photodiode also increases. This proved that the concentration of glucose could be predicted using near-infrared light at wavelength 1550 nm.

Keywords: diabetes, glucose, microcontroller, near infrared, photodiode

Paper category: Health

1. INTRODUCTION

Diabetes mellitus is defined as a metabolic disorder of multiple aetiology characterized by chronic hyperglycemias with disturbances of carbohydrate, fat and protein metabolism resulting from defects in insulin secretion, insulin action, or both (Burmeister and Arnold, 1999). In a simple term, diabetes is a condition where the body does not produce enough

insulin (WHO, 2017). Insulin is a hormone produced by the pancreas that helps glucose (the main source of fuel for the body) move from the blood into the cells. In a diabetic condition, the cells cannot use the glucose and this causes the blood glucose level to rise. The factors driving the dramatic rise include overweight and obesity (WHO, 2016). There are three main types of diabetes; Type 1 diabetes (known also as insulin-dependent diabetes mellitus); type 2 diabetes (known also as non-insulin dependent diabetes mellitus); and gestational diabetes mellitus (GDM). Increasing number of diabetic patients however has been on an alarming increase due to lack of on the spot facility to monitor the glucose blood level of diabetic patient. WHO (2015) reported that the number of people living with diabetes has risen from 108 million in 1980 to 422 million in 2014. Diabetes can be treated and its consequences avoided or delayed with diet, physical activity, medication and regular screening as well as treatment for complications (WHO, 2017). The available solution for the treatment of diabetics are painful, inconvenient, very costly and requires regular visits to doctor hence home testing kits must be in place to record glucose levels. Availability of a portable diabetics monitoring device will enable diabetics patient have good information about their health status and reduce periodic patients' visit to the hospital for check-up. This study will provide a preferable solution to the problem so as to reduce death rate caused by diabetes mellitus. The aim of this work is to develop a diabetics monitoring device for on the spot monitoring of blood glucose. The spot blood glucose monitoring device can replace the invasive method of monitoring diabetics, reduce pains from pricking the finger, reduce the length and expensive cycles of visiting doctors and pharmacies and prevent other diseases that are associated with diabetes. Several methods have been identified for glucose measurement. These include; Near Infrared Spectroscopy (NIR) (Haaland and Thomas, 1988; Heise *et al.,* 1989; Jeon *et al.,* 2006; Burmeister and Arnold, 1999); Near Infrared Diffuse-Reflectance Spectroscopy (NIDRS) (Jagemann, 1997); Thermal Emission Spectroscopy (TES) (Held, 2008); Raman Spectroscopy (Berger *et al.,* 1999; Berger *et al.,* 1996); photoacoustic and optoacoustic techniques (Qi Li; 2005); Infrared Emission Spectroscopy (IES) (Klonoff, 1998), Continuous Glucose Monitoring (CGM) (Nguyen *et al.*, 2013; Thorlabs, 2007), Fluorescence Spectroscopy (FS) (Geddes and Lakowicz, 2006), glucose meter based on PIC microcomputer (Wang and Yuan, 2006) . Optical Coherence Tomography and fluid glucose biochemical measurement strategies are; photonic crystal glucose-sensing material; reverse iontophoresis followed by glucose oxidase enzyme treatment used in glucowatch; implantation of catheters in the area of subcutaneous layer of skin and reaction with glucose oxidase enzyme used in glucometer and measurement of glucose by metabolic heat Conformation method (Thorlabs, 2010; Tamada, 1995). The Near Infrared Spectroscopy (NIR) is employed in this study for glucose measurement because of its high sensitivity to glucose. This work is in line with WHO 2030 Agenda for Sustainable Development, Member States have set an ambitious target to reduce premature mortality from NCDs – including diabetes – by one third; achieve universal health coverage; and provide access to affordable essential medicines (WHO, 2015).

2. MATERIALS AND METHOD

The following materials shown in Table 1 were employed for the development of the diabetes monitoring device.

Table 1: Materials Employed and their Functions

S/N	Material	Function
1.	LED1550E	The light source
2.	FGA04	The light sensor
3.	AD620	Amplifier
4.	MCP3424	Analog to Digital Converter
5.	PIC16F877A	The controller
6.	LCD	Result display
7.	Ear Clip	Holds the sensor and light source
8.	Red Led	High glucose indicator
9.	Green Led	Normal glucose indicator
10.	White Led	Low glucose indicator
11.	555 Timmer	Pulse generation to drive LCD
12.	Voltage Regulator	Separate the voltage in the circuit
13.	Resistors	Control the flow of current
14.	Capacitors	To store energy
15.	Sallen Key Filter	To remove noise

2.1 Method

The work is divided into three major parts namely; circuit for glucose detection using infrared LED, the microcontroller and data analysis using android phone application. In designing the non-invasive system, near-infrared spectroscopy method was used. The wavelengths of infrared that is suitable for glucose level measuring are between 1100 nm to 1850 nm and 2050 nm to 2392 nm. Therefore, the source of light must have the wavelength of the range mentioned. The glucose concentrations were divided into three classes, namely; hypoglycemia, hyperglycemia and normal blood glucose level.

2.1.1 Determination of Glucose Concentration

As an absorbance measurement, a photodiode was chosen to receive the light. Photodiodes are photo-detector that converts the light into voltage signals. The properties of photodiodes were determined by the constituent material. Table 2 shows the comparison of four different photodiode materials and their respective electromagnetic spectrum wavelength sensitivity. Based on Table 2, the possible options of photodiode are either indium gallium arsenide or lead (II) sulfide.

Table 2: Photodiode Material and Respective Electromagnetic Spectrum Wavelength

Material	**Electromagnetic Spectrum wavelength range (nm)**
Silicon	190 - 1100
Germanium	400 – 1700
Indium gallium arsenide	800 – 2600
Lead (II) sulfide	<1000 - 3500

The output of the photodiode was used as input for microcontroller. The microcontroller was set with a condition that was needed. The microcontroller used in this study is PIC (peripheral interphase controller). It can be powered via universal serial bus (USB) or a voltage supply between 7 to 12 V. For testing and programming purpose, the microcontroller is connected through USB. The supply voltages from microcontroller were used to bias both LED and photodiode. Near Infrared Transmittance Spectroscopy (NITS) is used across the ear lobe to measure glucose. Transmittance spectroscopy involves a light source and a light detector positioned on either side of the ear lobe. The amount of near infrared light passing through the ear lobe depends on the amount of blood glucose in that region. The ear lobe was chosen due to the absence of bone tissues and also because of its relatively small thickness. Near Infrared (NIR) light is applied onto one side of the ear lobe, while a receiver on the other side receives the attenuated light. This attenuated signal is then sampled and processed. Two LEDs from Thor Labs (LED 1550E) were used as the light source. An Indium Gallium Arsenide (InGaAs) photodiode from Thor Labs (FGA04) with a high response around a wavelength of 1700 nm was also used. An RC low pass filter was also connected to the output of the photodiode to reduce high frequency noise. The light transmitters and receptors around a wavelength of 1550 nm are relatively cost effective as compared to other wavelengths with equal or higher response to glucose. There are three other LEDs used in the system to indicate when it is low, normal and high. In the design circuit, white led indicate low glucose level, green led indicates normal glucose level and red led indicate high glucose level as per the programming. The same InGaAs photodiode used to sense the NIR signals was also used to sense the other wavelengths (green, red, and white), as its spectral response also contains these wavelengths. All these variables are then amplified, sampled, and processed inside the PIC16F877A, after which they are communicated via the Bluetooth to an Android application.

Figure 1 shows a step by step glucose level measurement system.

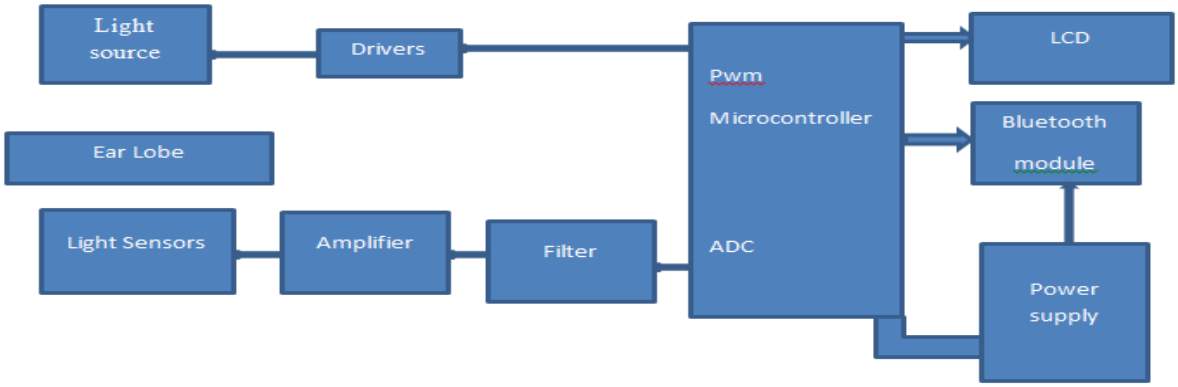

Figure 1: Glucose Level System Diagram

2.1.2 Sensing and Circuit operations

The InGaAs photodiode signals were fed into an amplifier to amplify the weak NIR signals and a ADS20 amplifier was used for this purpose. Amplification was not required for the red, white, and green light signals, as their attenuation did not give a problem. Voltage variations on the order of a few millivolts were recorded from glucose variations. These were amplified using the PGA with a gain of 50. A single MCP3424 Analog-to-Digital Converter in

conjunction with an analog multiplexer was used for sampling the sensed signals. A resolution of 18 bits was also used to sample the NIR and green signals, while a resolution of 16 bits was used for the red and white signals so as to increase the sampling rate in order to avoid aliasing due to heart rate variation.

2.1.3 Theoretical and Design Consideration

Figure 2 shows the schematic diagram for the biasing LED circuit of LED1550E LED. From the specification sheet of the LED1550E, it has a current rating of 20 mA and voltage drop of 1.2 V. The operation is a 100% duty cycle with a 5 V source from the microcontroller. From the calculation, the value of resistance is 190 Ω but in this circuit, a 1% 200 Ω was chosen so that it will not surpass the LED current rating.

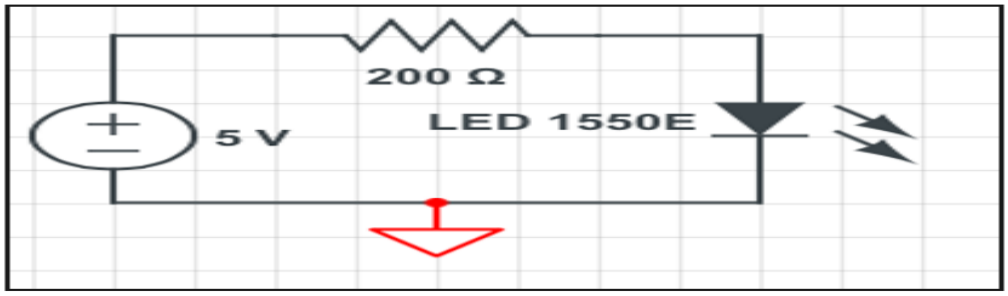

Figure 2 Circuit for biasing LED1550E

The resistance for biasing the voltage is calculated using Equation 1.

$$\text{Resistance} = \frac{\text{power supply voltage } V_s\text{-LED voltage drop } V_f}{\text{LED current rating (I)}} \qquad (1)$$

The specifications sheet of the ThorLabs FGA04 states the Equations 2 and 3. Equation 2 is used to calculate the output voltage of photodiode whereas Equation 3 is for the responsivity of photodiode.

$$V_o = P \times R(\lambda) \times RL \qquad (2)$$

Where; P is the incident light power at a given wavelength λ (watt); R(λ) is the responsivity (v/watt); and RL is the load resistor (Ohms)

$$R(\lambda) = \frac{IP}{P} \qquad (3)$$

Where:

IP is the photocurrent at a given wavelength (Ampere); P is the light power at a given wavelength (watt).

Figure 3 shows the responsivity of InGaAs photodiode from ThorLabs whil both of Figures 3 and 4 show the responsivity of FGA04.

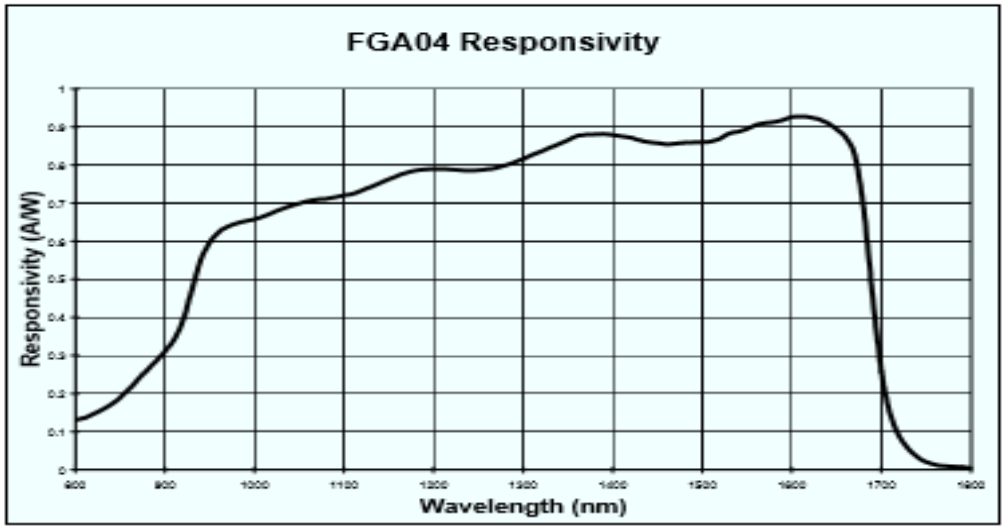

Figure 3: InGaAs Photodiode Responsivity

Figure 4 shows the responsivity of FGA series photodiode and the different wavelengths of the photodiode. Physical observation shows that FGA04 has a range wavelength of 800 nm-1800 nm suitable for detection of glucose concentration.

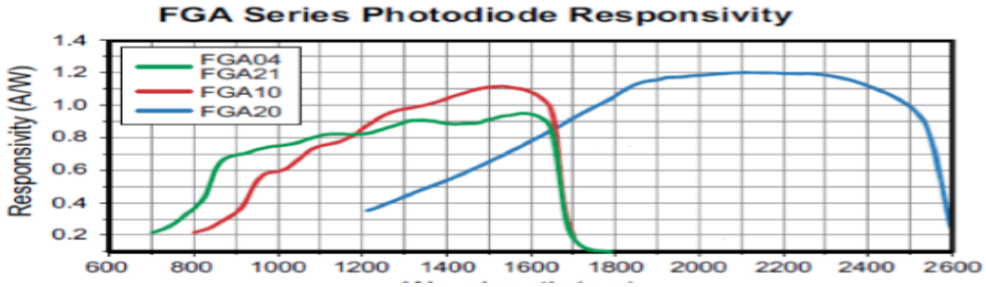

Figure 4: FGA Series Photodiode Responsivity

The operational circuit diagram for the near infrared which shows the glucose indication is shown in Figure 5.

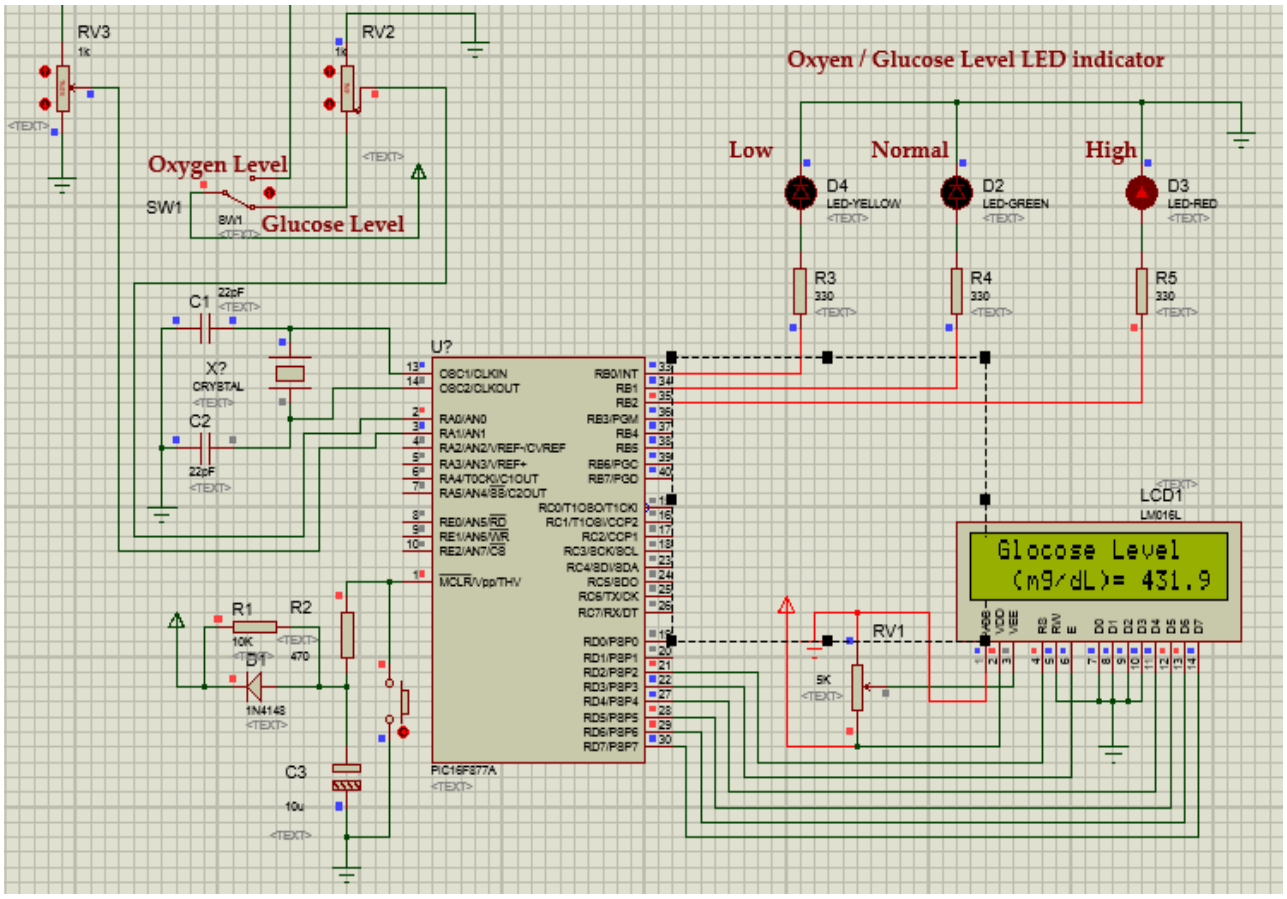

Figure 5: Operational Circuit Diagram

The transmitted power of LEDs was controlled with the use of pulse width modulation (PWM). As five LEDs were being used (2 NIR, 1 white, 1 red, and 1 green), five 8-bit PWM modules were implemented. In the case of the NIR LEDs, the transmitted wavelength also changes based on the average DC voltage across it. The NIR LEDs were run at 3 different duty cycles to vary the optical wavelength around 1550 nm. This was used to reduce noise between raw glucose values. The heart beat- and heart rate-based blood variations in the ear-lobe can become a major noise source if not accounted for correctly. To remove heart rate variations, the red, white, and NIR LEDs were turned ON, and their attenuated signals were sampled within 100 ms.

3.14 Signal Processing

Once all the variables have been stored, the processing begins. The algorithm flow is shown in Figure 6.

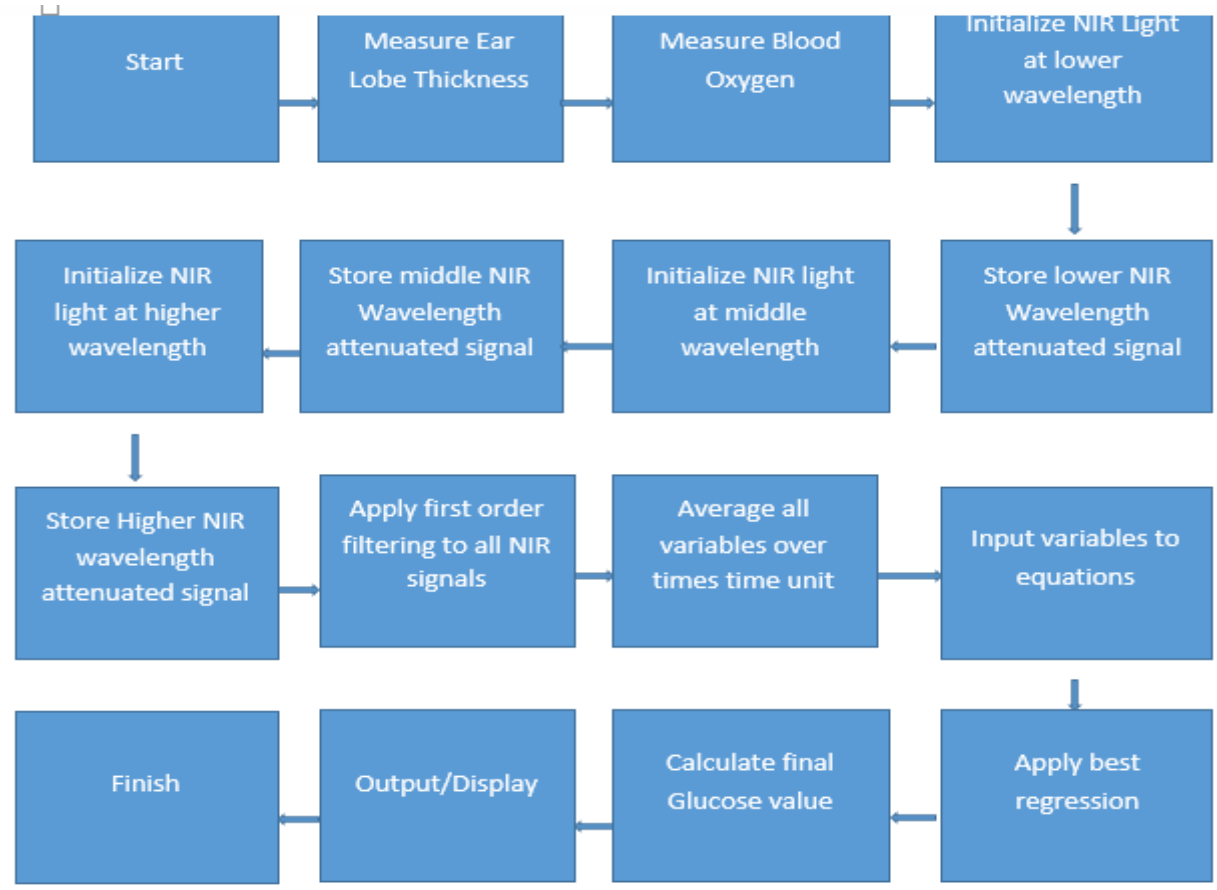

Figure 6: Non-Invasive Glucometer Algorithm Flow

The developmental stage of the diabetes monitoring device is shown in Figure 7 while Figure 8 shows the device

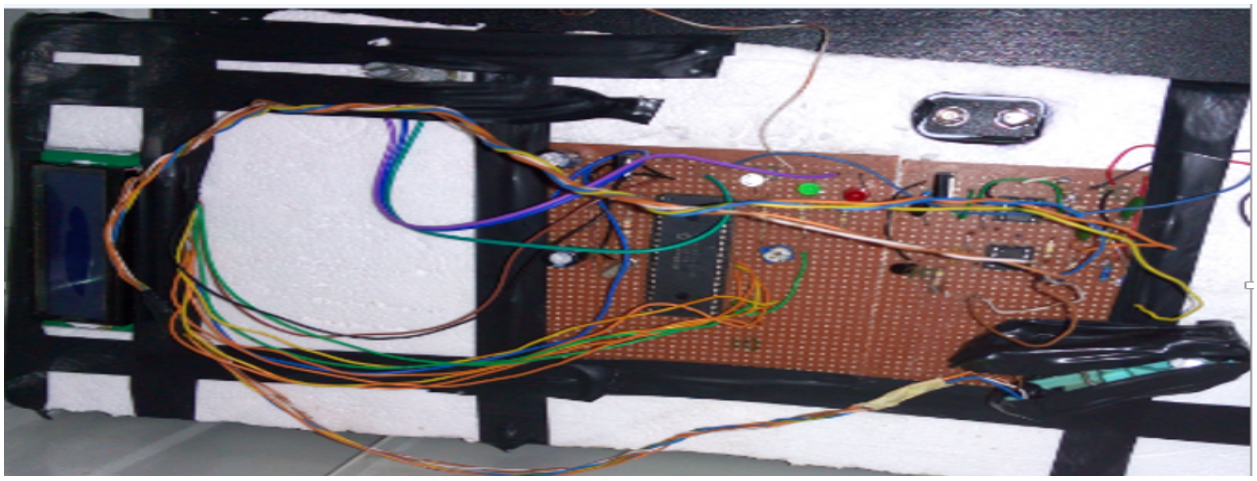

Figure 7: Diabetes Monitoring Device under Development

Figure 8: Diabetes Monitoring Device

The Bill of Engineering Materials and Measurement (BEME) is presented in Table 3

Table 3: The Bill of Engineering Materials and Measurement

S/N	List of Materials	Numbers of Materials	Unit Price (USD)	(USD)
1	LED1550E	2	1	2
2	FGA04	1	3	3
3	ADS20	1	1	1
4	MCP3424	1	3	3
5	555 Timer	1	1.5	1.5
6	Resistor	10	1	10
7	Capacitor	2	2	4
8	Voltage Regulator	1	100	100
10	LCD	1	5	5
11	Red Led	1	1	1
12	Green Led	1	1	1
13	White Led	1	1	1
14	Battery	1	1	1
15	Ear Clip	1	1	1
			Sub Total	144.5
			VAT	14.45
			Total	158.95

3. RESULTS AND DISCUSSION

The following results were obtained after the successful development of the diabetes monitoring devices.

3.1 Glucose Concentration

The device was tested on different people, the concentration of glucose in the ear lobe varies with the voltage. This has to do with the amount blood present in the ear lobe as at the time of measurement. The angle of the LED was adjusted to the highest output voltage displayed on the computer screen. Voltages reading from the photodiode were observed. The voltage

reading from each person ear lobe and their respective glucose concentration is presented in the Table 4.

Table 4: Photodiode Voltages for Various Glucose Concentrations

Concentration of glucose (mg/dL)	Minimum Voltage (mV)	Maximum Voltage (mV)
50	1727	1765
100	1727	1785
150	1760	1801
200	1795	1839
250	1830	1860
300	1875	1891

The output voltage of the photodiode changes with the change in the LED angle. However, the reading of the maximum voltages remained unchanged even though it was tested many times. This showed that the results are repeatable. From Table 4, it can be observed that there are overlapping values with different concentrations. When the maximum voltages were compared, each value corresponds to only one concentration. Figure 9 shows the graph of glucose concentration against maximum voltage while Figure 10 shows the mesh root mean square for glucose concentrations and voltages.

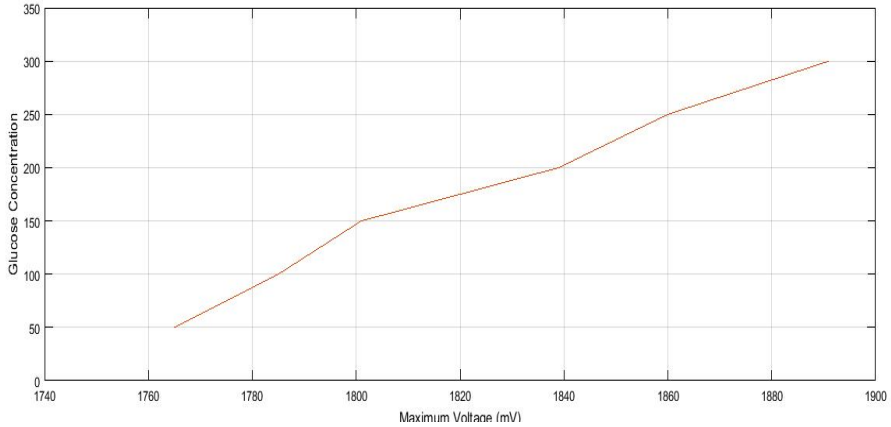

Figure 9: Glucose Concentrations against Maximum Voltage from Photodiode

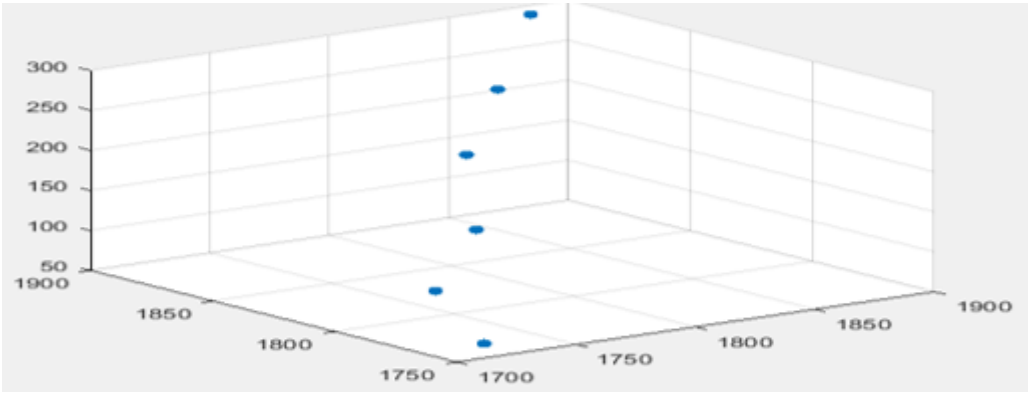

Figure 10: Mesh root mean square for glucose concentration and voltage

3.2 Discussion of Results

MATLAB software was used for result analysis. A command of function 'regress' was used for the regression analysis with the help of statistical toolbox, a command of 'robust' was used to develop a best fit model. Figure 11 shows a 3-dimentional plot of glucose concentration versus minimum and maximum values of voltage as well as a mesh which represents multiple linear regression analysis.

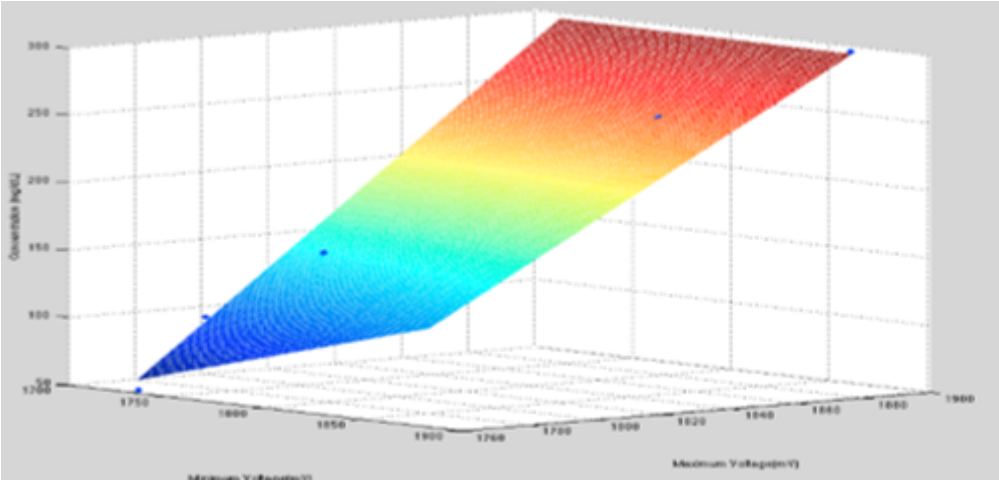

Figure 11: Glucose Concentration versus Minimum and Maximum Voltages Regression Model

Also from Figure 11, it can be seen that the concentration of glucose increases with the increase values of minimum and maximum voltages. The relationship is linear. Furthermore, Figure 12 shows the result of the 'robust' command with the data point.

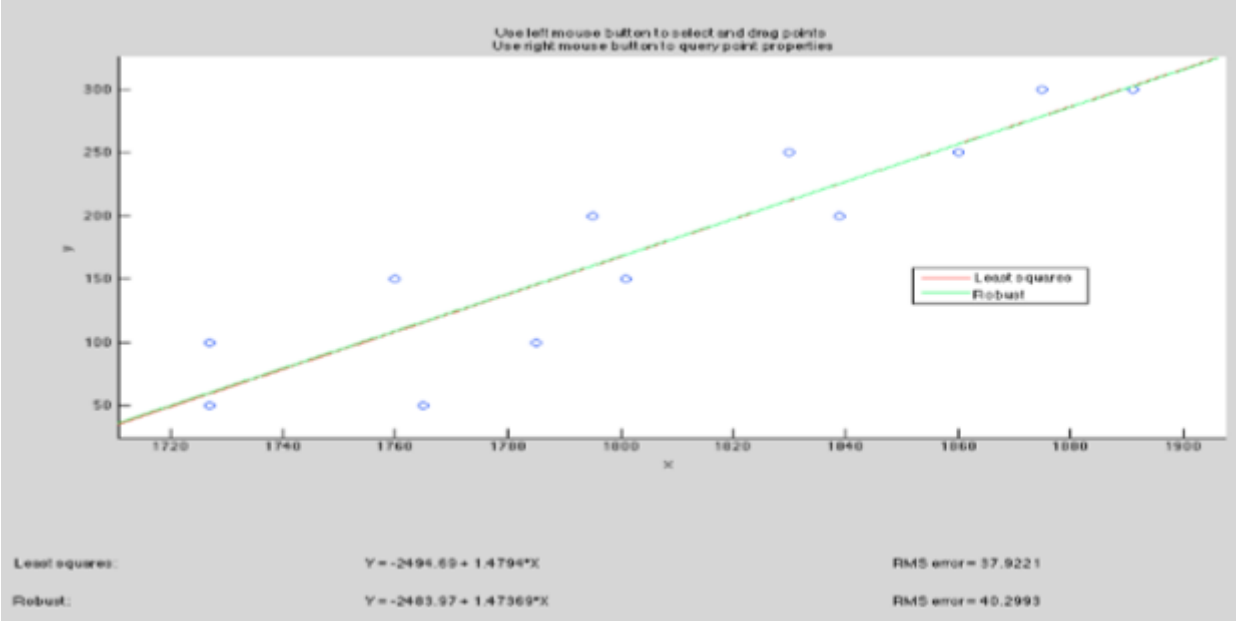

Figure 12: Robust and Least Square Model

From Figure 12, it can be seen that the relationship between the output voltage and the glucose concentration is linear. It means that when the voltage measurement increases, the glucose concentration also increases. However, the Root mean Square (RMS) error of the least square model is high (37.9221). This RMS error shows whether or not the measurement

is accurate to be used clinically. In order to be used clinically, the error must be 0.779 or less. It can be seen that the error is so high, which means the data collected are not enough. If readings from higher wavelength are collected, the error may reduce. Nevertheless, the data obtained formed a linear fit model, which means a near-infrared at wavelength of 1550 nm is possible to be used to predict the concentration of glucose.

4. CONCLUSIONS

This study provides a non-invasive, pain and stress free monitoring device for glucose level monitoring. It has proven that a non-invasive blood glucose meter can provide glucose measurements without stress, pain, blood sample or finger pricks, within a few seconds. The device can be easily adapted to provide continuous blood glucose and blood oxygen level monitoring. The device algorithm can also be modified to provide other capabilities like heart beat rate measurement using the same devices and sensors. It can be seen that the relationship between the output voltages from photodiode is directly proportional to the concentration of glucose. When the concentration of glucose increases, the output voltage from photodiode also increases. This proved that the concentration of glucose could be predicted using near-infrared light at wavelength 1550 nm.

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Development of Energy Efficient Multi-Crop Tray Dryer

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Abstract

A drying system utilizes heat energy to raise the temperature of air in order to dry any food substance, which is beneficial in reducing wastage of agricultural product and helps in preservation of agricultural produce. Based on the limitations of other systems of drying crops which include; exposure to direct sunlight, liability to pests and rodents, lack of proper monitoring and inability to provide real time monitoring of drying process parameters, the multi crop dryer is therefore developed to address this limitation. This work develops a multi crop dryer for food preservation. The multi crop dryer consists of a drying chamber measuring 400 x 790 mm, drying trays each having an area of 122,500 mm^2, a thermostatically controlled heating element and temperature regulating system. Performance test of the dryer was carried out with apple, plantain and potato samples using the multi-crop dryer under 60 ^oC and drying interval of one hour. The percentage moisture loss and drying rates were determined for the various samples. The average drying rates were 8.505 g/hr, 16.14 g/hr and 5.56 g/hr for the apple, potato and plantain respectively. The results obtained during the test period show that the drying rate increases after the first three hours and declined afterwards. The dryer exhibited adequate ability to dry food items rapidly to a safe moisture level and simultaneously it ensures a superior quality of the dried product. This will also help in the availability of agricultural produce in a relatively affordable prices during off season and also avert micronutrient deficiencies in diet especially among the low-income groups.

Keywords: agricultural produce, dryer, moisture, micronutrient, multi crop

Paper category: Energy

1. INTRODUCTION

According to Dincer (2016) and Essiet (2017), the disturbing level of wastage of agriculture produce is due to poor processing and this is occurring at a time when an estimated population of people over the world is increasing. Nigeria yearly merchandise export

commodities were from the agriculture sector (Ekpo and Egwaikhide 1994; Oyejide 1998; Oni, 2007). Despite being one of the world's largest producers of agricultural products, Nigeria has failed to derive maximum benefit from the industry (CBN, 2016). Experts blame this on logistics and storage issues, which, according to them, have led to waste over the years (USDS, 2014; Ufiobor, 2017). Drying was probably the first ever food preserving method used by man, even before cooking. It involves the removal of moisture from agricultural produce so as to provide a product that can be safely stored for longer period of time (Scalin, 1997; Bialobrzewski and Markowski, 2004). Fruits and vegetables are dried to enhance storage stability, minimize packaging requirement and reduce transport weight. Drying is a suitable alternative for post-harvest management especially in developing countries where poorly established low temperature distribution and handling facilities exist (Karapinar and Gonul, 1992; Jasim, 2011). It is noted that over 20% of the world perishable crops are dried to increase shelf-life and promote food security (Grabowski *et al.,* 2003; Joset, 2006). Several drying systems have been reported by researchers, but they are mostly solar dryers depending on the climatic conditions (Alonge and Hammed, 2007; Folaranmi, 2009; Amer *et al.,* 2009; Gatea, 2010). Also some of the dryers constructed were electric dryers mostly for tubers and grains crops and not for general purpose. Most of the electric dryers constructed were faced with the problem of inaccurate temperature measurements within the drying unit but Opiriairi, (2008) suggested the use of thermocouples instead of thermometers for temperature measurement within the drying unit. Ndukwu (2009) in a study of batch drying methods for cocoa beans provided useful hints on how fermented locust beans can be processed through drying. Ogunleye and Awogbemi (2009) reported that, the two methods of preserving and improving the quality of fermented locust beans are drying and salting. When the locust beans seed are boiled and soaked for 12 hours respectively, the fermented seeds were subjected to direct sun drying for 5 days, the result showed that dried salted seeds contain 67.65 % of protein and dried unsalted sample contains 66.82 % of protein. Hany *et al.* (2012) conducted an experiment using two convective hot air dryers namely; gas fired hot air dryer and electrically heated hot air dryer. The research was done in terms of drying process, energy consumption and quality of dried onion slices. The choice of energy source was based on the initial moisture content of the crop, the type of crop and rate of drying. They explained that air temperatures and air flow velocities affect drying of any product and recommended 50 ^{o}C to 70 ^{o}C of air temperature and air velocities of 0.5 m/s to 2.0 m/s for drying effectiveness. Muazu *et al.* (2012) also developed a forced air convection dryer with capacity of 20 kg to dry vegetables. They recommended an average rate of drying to be 7.23 x 104 kg/s, critical moisture content of 72 %, wet base and temperature range of 35 ^{o}C to 63 ^{o}C for drying fruits and vegetables. Compared to related researches, the multi-crop dryer is highly versatile and not limited to specific agricultural products. Another advantage of this dryer is the inclusion of a self-regulating temperature control system which serves as a means for the dryer to regulate its operations with minimal human reliance irrespective of the product being dried. Hence, the dryer can dry large quantity of any kind of crop including fruits and vegetables with better quality and relatively better efficiency than the traditional method. In addition, the heating element is controlled thermostatically controlled. The essence is to save energy which in turns reduces the green house emission.

2. MATERIALS AND METHOD

The following materials used for construction of the crop dryer are shown in the Table 1.

Table 1: List of Materials Involved in the Construction of the Dryer

S/N	Material	Description	Function
1	Mild Steel	2 square metre	Used for housing the drying chamber.
2	Fiber Glass	1 square metre	Used as lagging material
3	Stainless Steel	1 square metre	Used for making drying tray
4	Hinges	2 pieces	Used to facilitate access to the drying chamber.
5	Thermocouple	1 piece	Used measure heating element temperature.
6	Temperature Control	1 piece	Used for regulating temperature
7	Contact	1 piece	For distributing electricity to other components
8	Wire mesh	4 yards	To connecting electric temperature
9	Fan	1 piece	For regulating temperature
10	Heating element	1 piece	For increasing temperature of the drying chamber
11	Thermostat	1 piece	Generates voltage that corresponds to the pre-set temperature

2.1 Fabrication Process

The mild steel and fiber glass was cut into various sizes for the exterior of the drying chamber (front, sides, back, top and bottom panel). With the cut fiber glass placed in between two layers of mild steel, the panel was joined by welding operation. The temperature control and the switch box were mounted on the top surface of the drying chamber. The wires from the plug were connected to the contact (contact was also placed in the switch box). A 10 mm diameter hole was drilled at the base of the dryer to run the thermocouple in order to make sure it's in contact with heating element. A 800 mm hole was also made at the rear of the chamber where the electric fan was fixed and fastened in position by four screws. The heating element was installed at the base of the chamber to provide heat for drying.

The two 400 x 380 mm drying trays were cut and holes were drilled into it. Placeholders were fixed to the walls of the right and left panel to hold the trays. The completed dryer had a dimension of 455 x 455 x 890 mm.

2.2 Design Considerations

The crop dryer was designed for drying agricultural produce that requires low temperature rise above the ambient. The produce used for the study is banana, plantain and apple. The fruits were chosen for the study because of their perishable nature and their availability locally. Therefore, proper preservation of the produce through drying will enhance the storability and transportability, hence will further increase the economic gains from the crops. The design incorporates a fan which aids temperature regulation in the drying chamber. The materials of construction are locally available and friendly to end-users with low maintenance cost.

2.3 Description of Dryer

The design of the drying chamber depends on many factors such as the product to be dried, the required temperature, velocity of the air to dry food material, the quantity of the dried product and the relative humidity of the air passing over the food material. Its main features include: the heating element, a drying chamber, fan and heating trays. The isometric view of the dryer is shown in the Figure 1 and the orthographic projection of the dryer chamber door, drying tray and dryer chamber are shown in the Figures 2, 3 and 4 respectively.

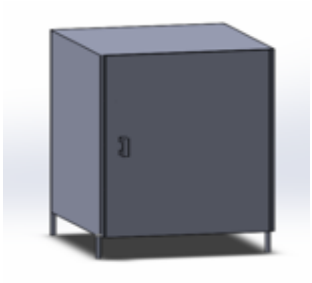

Figure 1: Isometric View of the Multi-Crop Tray Dryer

Figure 2: Orthographic Projection of Chamber Door

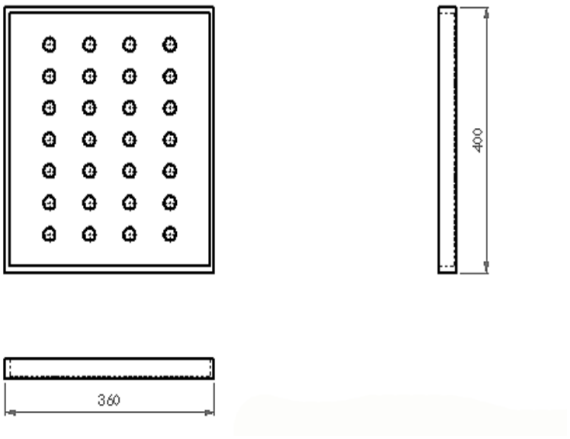

Figure 3: Orthographic Projection of Dryer Tray

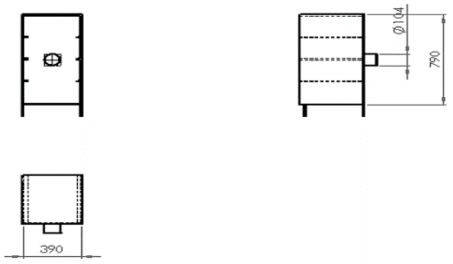

Figure 4: Orthographic Projection of Drying Chamber

2.3.1 Material for drying chamber

The material for the drying chamber together with the structural frame of the dryer was a 1 mm mild steel and the dryer has a dimension of 455 x 790 mm. Access door to the drying chamber was also provided at the front of the cabinet. The drying chamber was also lined with lagging material which is 20 mm thick to prevent loss of heat. The material for the dryer was selected to meet the following requirements; ability to withstand the relatively high operational temperature within the drying chamber; ease of machining and fabrication; low cost as compared to stainless steel and high tensile strength to withstand the load.

2.3.2 Material for heating tray

Two drying trays (350 x 350 mm) are contained inside the drying chamber and were constructed from stainless steel with holes drilled into the structure to allow drying air to pass through the food items. Metal handles were attached on each tray for ease of handling and sliding the trays inside the chamber through the produce to be dried.

2.3.3 Material for fan

The material used for the air blower is aluminum. It was chosen based on its ability to be cast into different shapes and the low cost of aluminum scrap.

2.3.4 Material used for lagging

Fiber glass was used as lagging material in order to minimize heat loss from the system.

2.3.5 Thermostat

The thermostat generates voltage that corresponds to the preset temperature. The heating element is operated by a 220 V power supply. A type K thermocouple is connected to the heating element to measure the temperature. A thermocouple amplifier AD595 is also connected to the output of the thermocouple to amplify the voltage coming out of the thermocouple. Therefore, the amplified voltage from the amplifier is then passed through a micro controller and the value is converted to digital using Analogue to Digital Converter (ADC) on a micro controller (PIC18F452). On the controller, the threshold temperature is set to the desired operating temperature of the dryer and the measured voltage is compared to the acceptable voltage range. If the measured temperature of the heating element is lower than the threshold, the micro controller turns ON the contactor which in turn activate the heater. On the other hand, if the measured temperature is greater than or equal to the desired threshold, the micro controller turns OFF the contactor which in turns puts OFF the heating element. This saves energy considerably which in turns reduces greenhouse emissions as the thermostat only supply voltage corresponding to the pre-set temperature.

2.4 Mathematical Equations

In the design of the dryer, various criteria which are used for heat applications are as follows.

2.4.1 Determination of drying capacity of chamber dryer

The drying capacity of chamber is calculated using Equation 1.

$$M_1 = \frac{A_{chamber}}{t_{drying}} * M_B \qquad (1)$$

where,

M_1 is the drying capacity (g/hr); $A_{chamber}$ is the drying area of the chamber taken as 0.4 x 0.79 = 0.316 m^2

t_{drying} is the drying time which is taken as 8 hours

M_B (mass of apple on 1 m^2 of drying area) is calculated from Equation 2.

$$M_B = \frac{M_{1piece}}{A_{1piece}} \qquad (2)$$

A_{1piece} is the area of one of an apple sample (m^2); and M_{1piece} is the mass of apple sample (g)

With the area of one apple sample as 6.1 m^2 and the mass of one wet apple piece as 0.0006 g.

$$M_B = \frac{6.1}{0.0006} = 10.17\ kg/m^2$$

The drying capacity can now be determined from Equation 1 as follow

$$M_1 = \frac{0.316}{8} \times 10.17 = 0.402\ kg/hr$$

2.4.2 Mass balance calculation

The amount of dry matter when the drying process does not change, is described by Equation 3.

$$M_1 * \xi_1 = M_2 * \xi_2 \qquad (3)$$

Where

M_1 is the amount of dried material entering the dryer (kg/hr); M_2 is amount of dried material from the dryer (kg/hour); and ξ_1 and ξ_2 are the proportions by weight of dry mater including input and output quantity of the material respectively, which is calculated from Equation 4.

$$\xi_1 = 1 - w_1 \ and \ \xi_2 = 1 - w_2 \quad (4)$$

w_1 and w_2 are the initial moisture content and required moisture after drying respectively.

Therefore,

w_1 = 77.5% = 0.775 kg; w_2 = 15% = 0.15 kg

Hence, ξ_1 and ξ_2 can be calculated using Equation 4

$$\xi_1 = 1 - w_1 = 1 - 0.775 = 0.225\ kg \quad ; \xi_2 = 1 - w_2 = 1 - 0.15 = 0.85 \text{ kg}$$

Hence, the dried material leaving the dryer M_2 can be calculated using Equation 5.

$$M_2 = M_1 * \frac{\xi_1}{\xi_2} \quad (5)$$

$$M_2 = 200 * \frac{0.225}{0.85} = 52.94\ kg/h$$

The amount of moisture loss is calculated using Equation 6.

$$W = M_1 - M_2 \quad (6)$$

$$W = 200 - 52.94 = 147.06\ kg/hr$$

To calculate the necessary amount of drying air, the specific humidities (X_{A1} and X_{A2}) need to be determined from the Mollier diagram according to the known temperatures.

From the diagram, inlet air temperature before heating, t_{A0} = 25 ℃ gives humidity X_{A1} = 0.01 kg/kg of dry air; and at temperature after heating at entry into the dryer, t_{A1} = 80 ℃ has humidity X_{A2} = 0.01 kg/kg of dry air.

Thus the necessary amount of drying air can be calculated using Equation 7.

$$M_A = \frac{W}{X_{A2} - X_{A1}} \quad (7)$$

$$M_A = \frac{147.06}{0.023 - 0.01} = 11.312\ kg\ of\ air/hour$$

2.4.3 Energy balance calculation

Drying is accomplished by vaporizing the water that is contained in the matter, and to do this the latent heat of vaporization must be supplied. There are thus, two important process-controlling factors as input for the unit operation of drying (Earle, 2004).

i. Transfer of heat to provide the necessary latent heat of vaporization
ii. Movement of water or water vapor through the material and then away from it to effect separation of water from material.

The heat or energy consumption for heating during the drying process is determined using Equation 8.

$$Q_A = M_A \times (h_{A1} - h_{Ao}) \quad (8)$$

Where,

h_{A1} and h_{Ao} are the specific enthalpies gotten from Mollier diagram according to the inlet air temperature before heating t_{A0}, temperature after heating t_{A1}.

h_{Ao} = 50 kJ/kg dry air; $h_{A1} = h_{A2} = 110$ kJ/kg dry air; $M_A = 11{,}312\ kg\ of\ air/hour$

Putting the parameters into Equation 8, the heat or energy consumption for heating during the drying process is calculated thus

$$Q_A = 11{,}312 \times (110 - 50) = 678{,}720 J/hr = 188.53\ J/sec = 188.53\ W$$

From the result, a supply 188.53 W of energy for the given amount of targeted dried food samples in kg/hour is required in order to heat up the air during the drying process.

2.4.4 Determination of the air blower power for dryer

The power of air blower is a function of volume of air entering the blower and the air inlet temperature. The power of the blower P (Joules) is expressed as Equation 9.

$$P = 2.72\ X\ 10^{-5} \times Q \times P \qquad (9)$$

where;

Q is the fan volume (m^3/hr); P is the blower operating pressure (cm) water column

The volume of fan volume is from Equation 10.

$$Q = \frac{G_{max} \times 22.4 \times t_{A1}}{29 \times t_{atm}} \qquad (10)$$

where;

t_{A1} is the inlet air temperature (K); G_{max} is the maximum mass flow of air required for drying (kg/hr)

t_{atm} is the atmospheric temperature air (K)

2.4.5 Determination of the percentage moisture loss

The overall percentage moisture loss from the food sample as well as the moisture content of the food sample for various drying times is obtained using Equation 11.

$$PM = \frac{m_i - m_f}{m_i} \times 100\ (\%) \qquad (11)$$

where,

m_i is the initial mass of the apple samples (g); m_f is the final mass of the apple samples (g),

2.4.6 Determination of drying rate

The knowledge of the length of time needed to dry a product from initial moisture content m_i , final moisture content m_f is the rate at which drying is taking place. The drying rate is calculated using Equation 12.

$$R = \left(\frac{dM}{dt}\right) = \frac{m_i - m_f}{t} \qquad (12)$$

where, R is the drying rate (g/hr); dM is the change in mass (g); dt is the change in time (hr); t is the total time (hr); m_i is the initial mass of the apple samples (g); m_f is the final mass of the apple samples (g)

3. RESULTS AND DISCUSSION

The sample of food items namely; apple, potato and plantain before and after drying as well as the drying system is shown in Figures 5, 6 and 7 respectively.

Figure 5: Samples before Drying

Figure 6: Samples after Sixth Hour of Drying

Figure 7: Multi-Crop Tray Dryer

The dryer was pre-heated for 30 minutes in order to establish steady state conditions to the desired temperature of 60 ^{o}C using the temperature controller. The freshly sliced apple, plantain and potato samples were spread on the trays and placed in the dryer. The weight of the samples were checked after every one hour using an electronic weighing balance throughout the drying period.

Tables 2, 3 and 4 show the results obtained from the performance evaluation of the fabricated multi-crop tray dryer.

Table 2: Hourly Moisture Loss, Drying Rate and Mass of Apple Sample

Drying Time (hrs)	Mass of apple (g)	Drying Rate (g/hr)	% Moisture Loss

0	92.22	-	-
1	82.00	10.22	11.08
2	74.00	8.00	9.78
3	62.69	11.31	15.28
4	53.00	9.69	15.45
5	46.23	6.77	12.77
6	41.19	5.04	10.90

Table 3: Hourly Moisture Loss, Drying Rate and Mass of Potato Sample

Drying Time (hrs)	Mass of Potato (g)	Drying Rate (g/hr)	% Moisture Loss
0	219.18	-	-
1	199.00	20.18	9.21
2	183.00	16.00	8.04
3	159.96	23.04	12.59
4	143.00	16.96	10.60
5	130.51	12.49	8.73
6	122.37	8.14	6.23

Table 4: Hourly Moisture Loss, Drying Rate and Mass of Plantain Sample

Drying Time (hrs)	Mass of Plantain (g)	Drying Rate (g/hr)	% Moisture Loss
0	74.89	-	-
1	67.00	7.89	10.53
2	59.00	8.00	11.94
3	52.39	6.61	11.20
4	48.00	4.39	8.38
5	44.18	3.82	7.96
6	41.55	2.63	5.95

The initial mass of apple, potato and plantain samples were 92.22 g, 218.19 g and 74.89 g respectively. At the end of drying, 51.03 g, 96.81 g and 33.44 g of water evaporated from the apple, potato and plantain samples. The time spent on samples drying for temperature 60 °C was 6 hours and it can be easily seen on the Figure 8 which shows the graph of mass of samples against drying time.

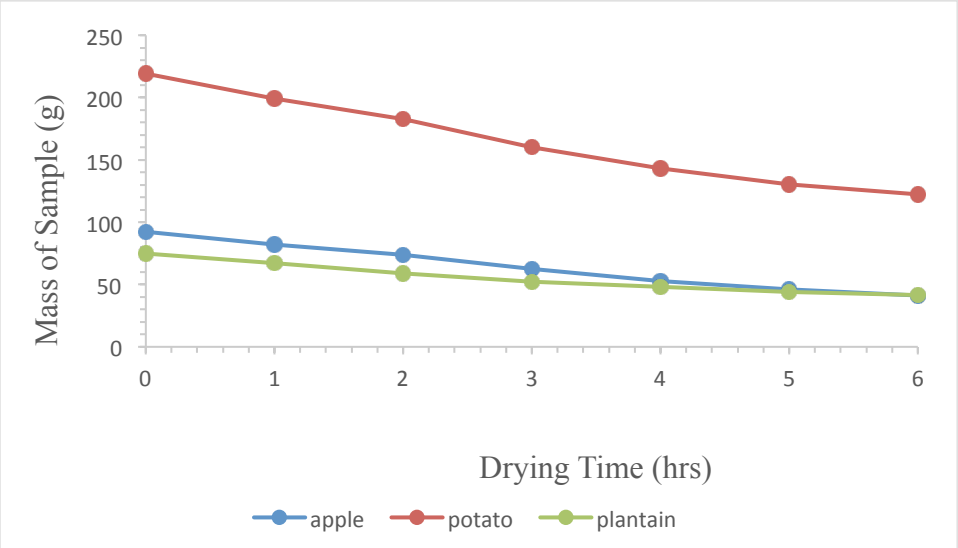

Figure 8: Graph of Mass of Samples against drying time

Figures 9 shows the drying rate and drying time of the various samples. After the first hour, the drying rate of plantain sample dried was 7.89 g/hr. After the third hour, the apple and potato sample attained the highest drying rate of 11.31 g/hr and 23.04 g/hr respectively. After 2 hours for the plantain samples, the drying rates increases from 7.89 g/hr to 8.00 g/hr. It was observed that for apple and potato samples, the drying rate after 3 hours of drying later reduced. The drying rate of the apple samples had increased initially and later reduced for all the levels of quantity dried. The drying rates of the two other samples was observed to follow the same trend.

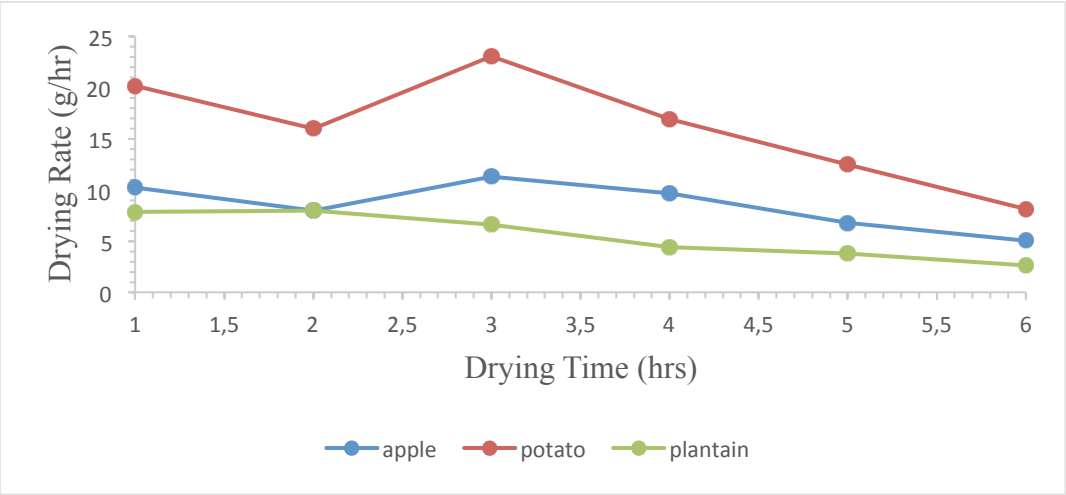

Figure 9: Graph of Drying Rate against Drying Time

From Figures 8 and 9, the first drying stage is a function of the heat transfer between the heating element and water if the moisture of the product is present as surface water. In this case, the drying rate is constant up to the point when a dry layer develops in the product. The dry layer poses an additional resistance to the heat and mass transfer and results in a reduced drying rate.

It can be deduced that as drying time increases, the rate of drying and moisture loss decreases. There are two types of water in a food namely; free or bulk water and bound

water. Free water can easily be extracted from food by the application of pressure to the food. Bound water cannot be easily removed from food and even upon drying, the food samples still contains some amount of bound water. During the initial 3 hours of drying, the free water was easily removed from the samples.

4. CONCLUSIONS

The product samples dried with the developed dryer are hygienically fit for consumption because the drying operation requires less human handling. They are also kept free from the invasion rain or pest (both human and animals), compared with those in the open sun drying. Although the dryer was used to dry potatoes, plantain and apple, it can also be used to dry other crops like yams, potato, cassava, maize etc. The dryer exhibited sufficient ability to dry food items rapidly to a safe moisture level and simultaneously it ensures a good quality of the dried product. This study contributes to the existing concept of food processing and preservation methods following the successful development of the multi-crop dryer that is not limited to a specific agricultural produce. Therefore, the dryer can dry a large quantity of crops of any kind including fruits and vegetables with better quality and relatively better efficiency than the traditional method. In addition, the incorporation of the thermostatically controlled heating element was able to save energy considerably when compared to the conventional dryer. This in turns reduces the effect of green-house emissions.

5. RECOMMENDATIONS

The performance of the dryers can still be improved especially in the aspect of reducing the drying time. Also, more process data should be readily available to users of multi crop dryer to ensure maximum drying efficiency and improved system performance. Such information will guide a local farmer on systems' monitoring in order to optimize the process. Also, a smart system should be incorporated into the system to facilitate the selection process of the various crop drying time.

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