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Original Research Article

Characterizing the Performance of *Keke* Emitter in Drip Irrigation System

Sani Isa Abubakar *, Abubakar Sadiq Abdullahi

Department of Agricultural and Bio-Resources Engineering, Abubakar Tafawa Balewa University Bauchi Nigeria

*Corresponding author: S. I. Abubakar; Department of Agricultural and Bio-Resources Engineering, Abubakar Tafawa Balewa University Bauchi Nigeria; sanisatak@gmail.com

Abstract: Rural farmers in Nigeria barely meet the cost of drip irrigation equipment because it is expensive. They resort to acquiring polyvinyl chloride (PVC) pipes, medi – emitters, syringes needles, etc., as improvised emitters and install them in irrigation farms. This study uses a bicycle (*Keke*) air pressure valve as an emitter on the drip irrigation system. Rural farmers use air pressure valves to inflate their bicycle tubes, which is affordable and generally acceptable. The calibration and performance evaluation of the *Keke* emitter was done on sandy loam soil. The experiment involved using the *Keke* emitter to discharge water at 5, 10 and 20 minutes. Discharges were selected randomly and calculated using the volumetric method. It was observed that variations in flow volumes along the laterals are minor. For the 5, 10 and 20 minutes of applications, the average discharge was calculated to be 5.67, 10.48 and 20.3 Lh$^{-1,}$ respectively. Correspondingly, the uniformity coefficient was found to be 96.8%, 97.0% and 98.4%, and distribution uniformity was 97.4%, 98.1% and 98.9%, respectively. The uniformity coefficient was high, which describes the emitter as proper for discharging water into the field. This is a new dimension in economic drip irrigation technology and exploiting cheap materials in drip irrigation systems, especially for rural farmers in Nigeria and beyond.

Keywords: Drip irrigation; *Keke* emitter; Discharge; Valve; Maize crop.

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1. Introduction

World water resources are fast diminishing, and drip irrigation (DI) is today's need because water nature's gift to humankind is limited (Shi *et al.*, 2022). DI is one of the most appropriate technologies in modern irrigated agriculture and has excellent potential (Sokol, 2020). DI is a method that releases water slowly and directly to a plant's root system and involves dripping water onto the different soil at meagre rates (2–20 Lh^{-1}) from a system of plastic pipes fitted with outlets named emitters (Jayat *et al.*, 2022). DI systems have become increasingly popular in recent decades. With suitable design and precise management, drip irrigation can provide more irrigation efficiency than surface irrigation (Pawar *et al.*, 2013; Hezarjaribi *et al.*, 2008; Khan *et al.*, 2014). However, the water use efficiency can be much lower than possible with poor design and/or incorrect management (Evans & Sadler, 2008; Hossain & Siddique, 2015).

Clay soils absorb water slowly; runoff can occur if water is applied too quickly. Clay soils will hold water well and stay wet for several days. Drip emitters of 2 Lh^{-1} are selected when planting in clay soils, and spacing tends to be further apart. Sandy soils absorb water very quickly, and runoff usually does not occur. Sandy soils do not hold water well and can dry out quickly. Drip emitters of 4 to 8 Lh^{-1} discharge are chosen for planting in sandy soils. The emitter spacing tends to be closer together. Loam soils are an ideal in-between mix of clay and sandy soils. Its absorption rate is greater than that of clay soil but not as fast as that of sandy soil. When wet, water will move outward and down more evenly. Loam soils will hold water well and dry out at a medium rate. Drip emitters of 2 to 4 Lh^{-1} are selected for planting in loamy soils (Figure 1) (Sharma, 2013; Jayant *et al.*, 2022).

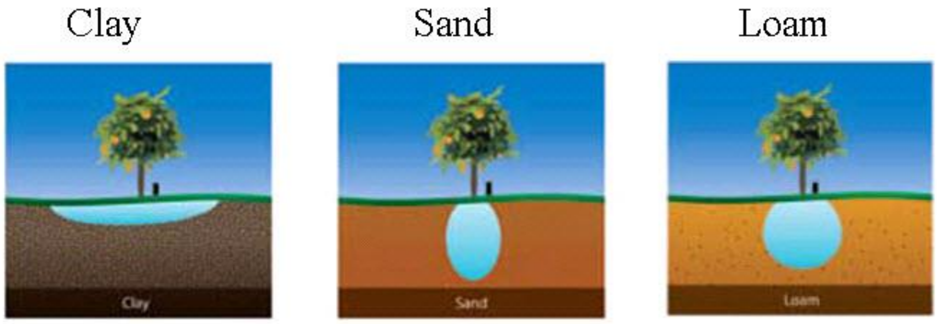

Figure 1. Water pattern in different soil (Source: Jayant *et al.*, 2022)

Previously, surface irrigation (SI) methods such as basins, borders and furrows have been used to irrigate crops in many counties. Under the SI methods, water flows over the entire field or along furrows by gravity (Sokol, 2020). Ponding of water on the surface, deep percolation, and evaporation losses are standard features of these traditional methods. Field application efficiency can reach 90% with drip irrigation compared to 60–80% for sprinklers and 50 – 60% for surface irrigation (Chen *et al*., 2022). However, DI systems have often been associated with high capital costs and a lack of training on proper system operation and maintenance (Mostafa & Thormann, 2013). An emitter is a device that precisely delivers a small amount of water. The emitters' capacity in the market varies from 2 to 16 Lh^{-1} (Sharma, 2013). An emitter could be formed by drilling a tiny hole in a pipe. Conventional emitters include points and line source emitters that operate above or below the ground surface. These emitters are very efficient but are being imported beyond the reach of rural farmers who produce more than 90% of total agricultural commodities in Nigeria (Nanyang *et al.*, 2005). Thus, the search for and use of substitute materials has become necessary. Researchers resort to testing bamboo pipes to enable rural communities to carry out inexpensive and less complex construction of water conveyance schemes for irrigation, medical infusion sets, syringe needles, etc., as improvised emitters and install them in irrigation farms.

This study tested using a bicycle *(Keke*) air pressure valve as an emitter on the drip irrigation system. Rural farmers use air pressure valves to inflate their bicycle tubes, which is affordable and generally acceptable. However, its potential as a substitute emitter for irrigation is yet to be established. The acceptance of drip technologies involves three essential aspects: the technology must be economically and technically feasible, farmers must be aware of the technology, and farmers must be able to access it. With the works mentioned earlier, we can see the limits and reasons why rural farmers in different parts of the world are not using drip irrigation (Jayant *et al.*, 2022). In a DI system, the emitter is the critical part, consisting of a water inlet, a flow path, and an outlet. It can make the pressurized water flow through its internal flow channel to meet energy dissipation requirements and then drip into the soil with a uniform and stable water flow for crop absorption and utilization (Shi *et al*, 2022). The main objective of this work is to measure the efficiency of the *Keke* emitter drip irrigation system (KEDIS) by determining discharge variation, coefficient of variation, and emission uniformity, as well as the effect on the growth and yield of maize crops.

2. Materials and Methods

The study was conducted on the Department of Agricultural and Bioenvironmental Engineering teaching farm, Federal Polytechnic Bali Taraba State, Nigeria. The area lies within the latitude of 10^{0} $02^{|}$ $00^{||}$ N, longitude 70 02| 14|| E, and altitude of 450 m above mean sea level. Temperature ranges from 23 - 300C characterize the climate of the study area. The area has a well–defined wet season with an average annual rainfall of 1110 mm beginning around March and ending in October (IWMI, 2009).

The water supply was from a 500-litre plastic tank with a gate valve to control flow and a filter to reduce clogging (Figure 2).

Figure 2. 500 litres plastic tank

The irrigation system was assessed in a subunit comprising five (5) lateral lines, 3m long and 0.75m apart, with a spacing of 0.3m set in a flat area, selected based on recommended agronomic practices for maize. On each lateral, ten drip points were made using a drill bit to ensure the fixing of the *Keke* emitter (Figure 3).

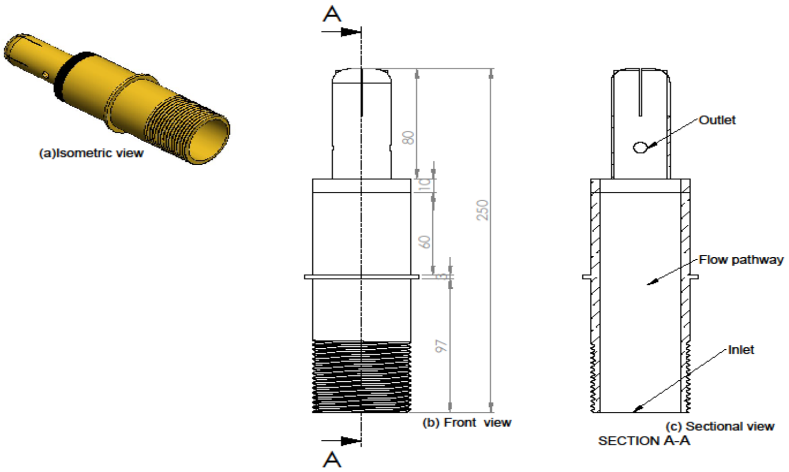

Figure 3. *Keke* emitter (All dimensions in mm) (Hezarjaribi *et al.*, 2008)

The main line and the laterals were joined with a 25mm PVC tee joint. End caps were used to cover the ends of the pipeline to prevent water from flowing out. PVC elbows, T-connectors, hacksaw, PVC–gum, mallet and measuring tape were used for the study. Fifty (50) emitters were fixed into the drip points drilled on the PVC laterals (Figure 4).

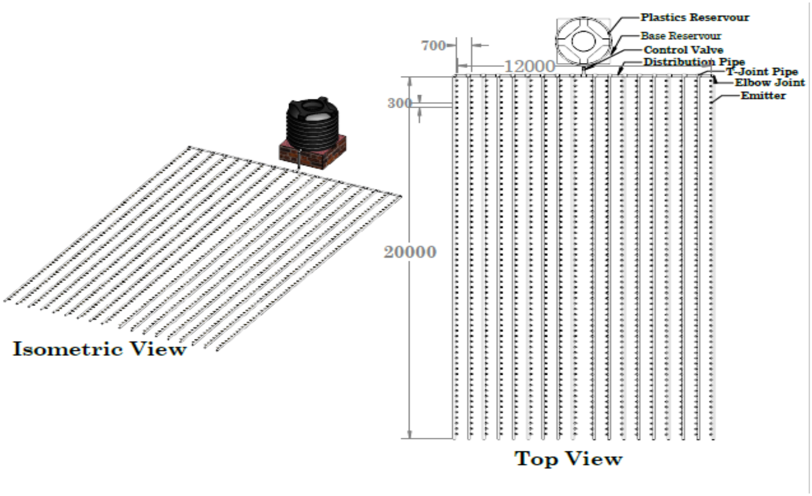

Figure 4. Distribution line and the laterals (Source: ASAE (1999))

The tank supplies water to the field at a constant head, 1m high (enough to supply water to every part of the subunit). After the installation, a test run was conducted by fully opening the gate valve. Leakages along the mainline and joints were corrected. After the test, the emitters were calibrated to obtain the discharge rates at 5, 10, and 20 minutes, respectively. Three (3) emitters on each lateral were randomly selected for discharge measurement. Fifteen (15) emitters were randomly selected for the experiment. Along each lateral, flow volumes were collected. Containers were placed under each selected emitter in such a way that the water drops from emitters could be collected inside the containers simultaneously at the set time using a stopwatch. The control regulator controls the water flow to turn the system on/off; it is between the plastic tank and the primary line water source. The pressure regulator is also installed to maintain consistent pressure in the system, and the filter is used to remove debris from the flowing water. The flow rates were determined by directly collecting the volume in the container and measuring it in a graduated measuring cylinder. The experiment was replicated three times in order to minimize human error. The results were compared with ASAE EP 405 (1996 and 1999) standards.

Discharge through selected emitters was calculated by volumetric method; the collected volume of water was divided by the time as described by (Shi *et al.*, 2022; Jayant *et al.*, 2022)

2.1 Discharge

$$Discharge\ Rate = \frac{Volume\ Collected\ (L)}{Collecting\ Time\ (H)} \quad (1)$$

The Keke emitter was calibrated to obtain the discharge at the rate of 5, 10, and 20 minutes, respectively. The hydraulic parameters measured include:

2.2 Flow Variation

Emitter flow variation, $Q_{var,}$ was calculated using the equation:

$$Q_{var} = \frac{(Qmax - Qmin)}{Qmax} x\ 100 \tag{2}$$

Where: Q_{var} = Emitter flow variation (%);
Qmax = Maximum emitter flow rate, Lh^{-1};
Qmin = Minimum emitter flow rate, Lh^{-1}

2.3 Distribution Uniformity

Distribution uniformity, DU, was calculated using Kruse (1978) as:

$$DU = \frac{Q25\%}{Qav} x\ 100 \tag{3}$$

Where: DU = distribution uniformity (%);
$Q_{25\%}$ = average of the 25% lowest value of flow rate (Lh^{-1});
Qav = average flow rate, Lh^{-1}.

2.4 Coefficient of Variation

The CV was expressed by the following relationship (Keller & Karmeli, 1974).

$$CV = \frac{Sq}{Qav} x\ 100 \tag{4}$$

Where: CV = coefficient of variation
Sq = standard deviation of the emitters flow rate, (Lh^{-1})
Qav = mean of flow rates, (Lh^{-1})

2.5 Uniformity Coefficient

The uniformity coefficient was tested using Christiansen's formula (1942). It gives information on how efficiently water is distributed in the field.

$$CU = 100\ (1 - \sum X/mn) \tag{5}$$

Where: CU = Coefficient of uniformity
m = Average value of all observations
n = Total number of observation points
X = Numerical deviation of all observation points from the average application rate.

The parameters used to determine the effect of KEDIS on the growth and yield of maize crops were crop yield, plant height, number of leaves, and leaf width. Plant height measurements were carried out using a measuring tape. Plants were measured from the base of the stem to the highest leaf at 15, 30 and 45 days after planting (DAP). Calculating the number of leaves was only carried out on leaves that had fully opened at 15, 30 and 45 DAP. Leaf width was also measured the same way as the plant height. The irrigation field was divided into three plots: T1, T2, and T3, with control of C1, C2, and C3. KEDIS were watered automatically as designed, while the controls were watered manually.

3. Results and Discussion

The result for emitter discharges at different application times (Lh^{-1}) is presented in Table 1; for the 5, 10 and 20 minutes of applications, the average discharge obtained were 5.67, 10.48 and 20.3 $Lh^{-1,}$ respectively. Hence, it was observed that variations in flow volumes along the laterals are small. Similarly, table 2 evaluates the performance of flow for the *Keke* emitter. The results show that the uniformity coefficients obtained during the experiments were 96.8%, 97.0% and 98.4%, and distribution uniformity was 97.4%, 98.1% and 98.9%, respectively. The uniformity coefficient was high, which describes the emitter as proper for discharging water into the field. The uniformity of application describes how evenly an irrigation system distributes water over a field. Based on this study, the water application rate was not significantly affected. The performance evaluation of the system revealed an excellent achievement of the adopted materials. The variation in discharge is relatively low. These findings indicate the efficacy of KEDIS in determining discharge variation, coefficient of variation emission uniformity and the effect on the growth and yield of maize crops (Figure 5).

Figure 5. An experimental setup for KEDIS shows the growth and yield of maize crops.

A similar finding was obtained by Mofoke *et al.* (2004) on adopting the media emitters as drippers for the design, construction and evaluation of an affordable continuous-flow drip irrigation system. Moreover, Awe and Ogedengbe (2011) on the adoption of medical infusion sets, or media-emitters, coupled with a mechanism to control flow rate and bamboo in place of PVC pipes to convey water, and can be employed as a substitute for the conventional drippers for the drip irrigation system.

Table 1. Emitter Discharges at Different Application Time (Lh^{-1})

Time (m)	Laterals					Mean
	1	2	3	4	5	
5	5.43	5.41	5.33	5.30	5.27	5.67
15	10.54	10.54	10.53	10.53	10.52	10.48
20	20.55	20.52	20.50	20.49	20.49	20.31
Mean	12.17	12.15	12.12	12.13	12.13	12.15

Table 2. Performance Evaluation of Flow for the *Keke* Valve Emitter

Application Time (m)	DU (%)	CV (%)	CU (%)	S	Q_{var} (%)
5	97.40	0.018	96.80	0.011	0.096
15	98.10	0.020	97.00	0.031	0.089
20	98.90	0.025	98.40	0.036	0.077

DU = Distribution uniformity, CV = Coefficient of variation, CU = Coefficient of uniformity, S = Standard deviation, Q_{var} = Flow rate variation.

3.1 Effect of KEDIS on the Growth and Yield of Maize Crop

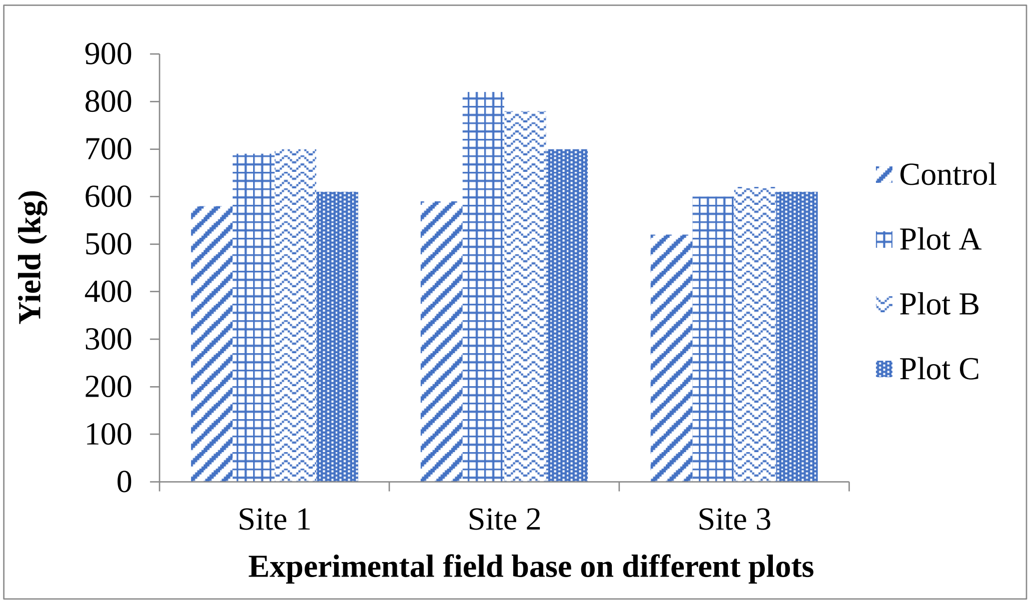

Figure 6. Effect of KEDIS on the yield of maize crop

Figure 6 presents the crop yield histogram for three experimental fields with different planting sites and plots (P) and control. It can be seen from the figure that the control experiment has the lowest yield across all three planting sites. The yield obtained is 580, 590 and 520 kg for site 1, site two and site three, respectively. Besides the control, a marginal low yield was observed in site one from plots (C = 610 kg) and in site three from the three plots as (A = 600, B = 620 & C = 610 kg). Also, an average yield with a minimal difference was observed in site 1 form plots (A = 690 & B = 710 kg) and site two from plot (C = 700 kg).

Similarly the highest yield of the maize crop with insignificant differences was observed in site two from plots (A = 820 & B = 780 kg). Hence, the experimental result for KEDIS on the effects of maize yield revealed that the maize crop's growth and yield parameters differed significantly at various research fields and plots (Figure 6). The crop yield from site two across all plots was significantly higher than that of site 1. In contrast, the low crop yield was recorded from site 3, on par growth parameters like plant height, number/area of leaf, stem girth, number of grains, cob diameters, cob weight, grain weight and grain yield. Higher growth parameters were mainly due to better availability of soil moisture and improved nutrient uptake, which might have favoured cell elongation and division, leading to higher crop growth.

Furthermore, yield is eventually a result of crop growth. Higher growth attributes might have resulted in higher photosynthesis, carbon assimilation and carbohydrate reserves in the plant, which helped develop a higher number of reproductive parts and a more oversized-sized sink, i.e., the size of the cob (Awe & Ogedengbe, 2011). Contrarily, the lowest growth parameters, yield parameters and grain yield were recorded in the control sample. This is mainly because insufficient soil moisture leading to root stress might have led to shorter plants, a lower number of leaves and leaf area and hence lower reproductive parts and yield (Sharma *et al.*, 2013). Thus, the parameters studied showed a significant increase in the growth and yield of maize crops. This optimum yield indicates that the crop water requirement for Zea mays is met. Therefore, The design presents an attractive prospect for the propagation of Keke emitter and the advancement of affordable drip irrigation technology.

Table 3. Effect of KEDIS on average plant height and planting days

S/N	Planting Days	Plant height (cm)	
		T_0 (control)	T_1 (KEDIS)
1	15 DAP	14.26 ± 0.21^a	15.07 ± 0.20^a
2	30 DAP	31.97 ± 0.24^c	33.04 ± 0.28^c
3	45 DAP	51.80 ± 0.18^b	61.06 ± 0.17^b

Values = Mean ± Standard deviation: mean in different columns with the same superscripts are not significantly different at ($P \leq 0.05$); DAP = Days after planting.

From Table 3, the highest plant height at the ages of 15, 30, and 45 DAP was found at T1, although statistically, no significant difference exists between T_0 and T_1. This condition shows that, statistically, using KEDIS does not affect the height growth of corn plants. There is no effect of drip irrigation on plant height parameters, presumably because the water content obtained by corn plants is sufficient for plant height growth. This follows (Nanyang *et al.*, 2022), who stated that water with different volumes does not significantly affect plant height. The difference in plant height depends on the type of planted plants. However, overall, at the ages of 15, 30, and 45 DAP, the height of corn plants at T_1 was greater because water availability at the root zone helped increase the number of cells faster than corn plants at T_0, following the statement of (Pawar *et al.*, 2013) who explained that the process of increasing plant height was due to an increase in the number of cells and an increase in cell size.

Table 4. Effect of KEDIS on an average number of leaves and planting days

S/N	Planting days	Number of leaves (sheet)	
		T_0 (control)	T_1 (KEDIS)
1	15 DAP	3.62 ± 0.12^b	3.79 ± 0.11^b
2	30 DAP	6.74 ± 0.51^a	6.55 ± 0.62^a
3	45 DAP	9.64 ± 0.15^c	9.86 ± 0.21^c

Values = Mean ± Standard deviation: mean in different columns with the same superscripts are not significantly different at ($P \leq 0.05$); DAP = Days after planting;

Table 4 shows that the parameters of the number of leaves at 15, 30 and 45 DAP were not statistically significantly different between T_0 and T_1. This was presumably because the availability and absorption of water were sufficient so that the number of leaves in both treatments was not affected by the presence or absence of drip irrigation. The formation of leaf organs is influenced by water, which helps dissolve nutrients in the soil. In addition, water is one of the factors of photosynthesis. If sufficient water is sufficient, the leaves will carry out photosynthesis (Mostafa *et al.*, 2013). Sharma *et al.* (2013) stated that the need for sufficient water causes stomata opening and increases the absorption of CO_2 for photosynthesis. In addition, Sokol (2020) also said that if water availability is sufficient, it will accelerate the rate of cell division, cell elongation, and the formation of tissues such as stems, leaves, and roots.

4. Conclusions

The assessment of the system discovered an excellent performance of the adopted materials. The variation in discharge is relatively low. The high discharge values indicated that higher variation is expected if the flow rate is low. However, higher flow rates that gave low variations imply more undesirable water losses. It is evident from the study that the *Keke* emitter fits into the recommended standard as stipulated by the American Society of Agricultural Engineering (ASAE) in terms of coefficient of global variation (coefficient of manufacturer's variation). The values obtained were less than 10% margin for excellent emitters. The adoption of the substitute materials performed very well, yielding high uniformity and indicating low coefficients of manufacturer variation. The plant (*Zea mays*) growth parameters studied showed increased plant height and number of leaves. However, the low heights and number of leaves were recorded under the control treatments. This optimum yield indicates that the crop water requirement for Zea mays is met. Therefore, The design presents an attractive prospect for the propagation of Keke emitter and the advancement of affordable drip irrigation technology.

Author Contributions: Abubakar, S. I., and Abdullahi, A. S. were responsible for conceptualization; Abubakar, S. I., and Abdullahi, A. S. handled the methodology and experimental design; Abdullahi, A. S. provided important guidance and supervision throughout the study; Abubakar, S. I. conducted the formal analysis and experiments; data collection, interpretation, and result presentation were carried out by Abubakar, S. I.; Abubakar, S. I. also provided resources; the original draft was written by Abubakar, S. I.; proofreading and editing were done by Abdullahi, A. S. Both authors have read and approved the final manuscript.

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