Influence of Rainfall Magnitude on Maize, Beans and African Nightshade Production in Nyando Sub-County of Kisumu County, Kenya

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DOI: https://dx.doi.org/10.47772/IJRISS.2025.905000503

Received: 18 May 2025; Accepted: 22 May 2025; Published: 25 June 2025

ABSTRACT

Sustainable Development Goal (SDG) number 2 appreciates that sustainable agriculture is significant in empowering small-scale farmers, promoting gender equality, ending rural poverty, ensuring healthy lifestyles, and tackling climate change. Regrettably, the global issue of hunger and food insecurity has increased since the inception of the SDGs, not sparing Nyando sub-County. This study employed a quasi-longitudinal research design to investigate the influence of rainfall magnitude on maize, beans and African Nightshade production in Nyando sub-County of Kisumu County, Kenya. Primary data was collected using questionnaire, key informant interview, focus group discussion, and observation and photography. Secondary data was obtained from Kenya Meteorological Department and sub-County and County Agricultural Offices. Qualitative data was analyzed using themes. Quantitative data was analyzed using descriptive statistics and linear regression analysis. Findings of the study showed a significant effect between rainfall magnitude and maize, beans, and African Nightshade yields, overall, and during both long and short rain seasons. About 44 percent, 38 percent, and 34 percent of the variation in maize, beans, and African Nightshade yields, respectively, could be explained by change in rainfall magnitude. This implied that rainfall magnitude affected the production of the three crops: maize, beans, and African Nightshade. There is need to engage precision agriculture, adopt climate-smart farming, minimize absolute reliance on rain-fed farming, and use hybrid seeds for early crop maturity.

Keywords: Rainfall magnitude; Maize; Beans; African Nightshade; Nyando

INTRODUCTION

Climate variability and change is here to stay. Its impacts, among them, influence on agricultural production and hence food (in)security, cannot be overlooked. In 2015, at the elapse of the Millennium Development Goals, the United Nations came up with seventeen sustainable development goals. Among the goals was the appreciation that sustainable agriculture was significant in empowering small-scale farmers, promoting gender equality, ending rural poverty, ensuring healthy lifestyles, and tackling climate change (UNDP, 2015). Rainfall variability, measured in terms of timing, duration and magnitude, is a major element of climate that affects crop production leading to food insecurity (Odundo, 2023). Shackleton et al. (2009) defined rainfall magnitude as the amount of rainfall received in millimeters per hour whenever it rains. Such rainfall magnitude can be low, moderate, or high leading to varied crop production.

Maize grain is the most predominant cereal for over 300 million people in sub-Saharan Africa (Yacoubou et al., 2021) forming beyond 30 percent of the peoples' calories intake (Ekpa et al., 2019). Additionally, maize and maize products are essential components of livestock and poultry feeds, and raw materials for alcoholic beverages (Amponsah et al., 2021). Food and Agricultural Organization (FAO) (2020) appreciated that maize yields in Africa are low due to limited modern farming techniques, poor infrastructure and unpredictable weather conditions. In their study in Ghana, Baffour-Ata et al. (2023) pointed out that maize was extremely dependent on climatic factors of rainfall and temperature. Results of regression analysis showed that, combined with rising temperatures, increasing annual rainfall positively affected maize yields by contributing about 70 percent of the yield variation ($r^2 = 0.7030$) (Baffour-Atta et al., 2023). Locally, Muriithi et al. (2023) found about 47 percent of fluctuation in maize yield to be explained by variation in rainfall amount.

Studies have shown varied patterns in maize yields based on varied rainfall amounts and magnitudes. Regionally, Baffour-Ata et al. (2021; 2023) found maize yields to increase with increase in rainfall amount. On their side, Li et al. (2019) found excessive rainfall to be a significant contributor to reduced maize yields. Kiprono et al. (2024) explained that above-optimal rainfall results to waterlogging that negatively affects maize yields. Locally, Omoyo et al. (2015) found reduced rainfall and rain shortage to lead to maize crop mortality and hence reduced maize yields. Below-average rainfall leads to reduced soil moisture that affects maize crop germination and plant growth, ultimately leading to reduced crop yields (Kiprono et al., 2024). These studies clearly fail to agree on the pathway through which rainfall magnitude affects maize yields with some indicating a positive relationship (Baffour-Ata et al., 2021; 2023; Omoyo et al., 2015) while others indicating negative relationship (Li et al., 2019). Other studies have given mixed results on the influence of rainfall magnitude on maize production (Kiprono et al., 2024; Adamgbe & Ujoh, 2013).

Beans production is also rain-determined. A study by Edmonds and Chweya (2018) revealed that reduced rainfall by 8 inches in northern Nigeria in 2017 affected growing of beans since most soils became moisture-deficient. In Hai District of Tanzania, the production of the common beans was affected due to a limited supply of moisture as a result of the decline in the duration and amount of rainfall (Maundu, 2007). In northern Uganda, where drought was more severe, there were 61 percent lesser bean yields than the yields in central Uganda (Onzima et al., 2019). Earlier on, Thornton et al. (2009) predicted that there would be a reduction in beans production in the mixed rain-fed humid and sub-humid zones of Uganda come the year 2050, under no adaptations. A study by Omondi (2018) showed that there was an increase in amount of rainfall in western Kenya by 2 percent between the period 2012 and 2020 which increased the production of bean crop. In Kajiado County of Kenya, farmers feared that the prolonged rains were destroying the bean crop that they were eager to harvest (Meneto, 2024) thus leading to reduced production. This literature therefore presents a mixed relationship between rainfall magnitude and bean production. The current study set out to investigate whether there exists any clear relationship between rainfall magnitude and bean production in Nyando sub-County.

African Nightshade is one of the traditional vegetables grown regionally for its nutritional value, food security and income generation (Noella et al., 2018). Its production fluctuates based on rainfall variability (Abukutsa, 2010). Regionally, a study by Guntu et al. (2020) revealed that long rains in southern Cameroon between the months of July and November affected the production of African Nightshade vegetable. For the three months, there was between 60mm/hour and 80mm/hour of rainfall received leading to flooding of the farms. This led to the rotting of most roots and falling off most leaves of the African Nightshade and thus reduced production. Other researchers indicate that rainfall of high magnitude cause flashfloods that wash away vegetable crops and lead to waterlogging (Chepkoech et al., 2018; Barasa et al., 2015).

Nyando sub-County in Kenya is not spared of the pangs of climate variability and change, with their related impacts on food crop production. Existing literature fails to provide a clear pathway through which rainfall magnitude affects maize, beans and African Nightshade production (Kiprono et al., 2024; Baffour-Ata et al., 2021; 2023; Li et al., 2019; Omoyo et al., 2015; Adamgbe & Ujoh, 2013). This study sought to investigate the influence of rainfall magnitude on maize, beans and African Nightshade production in Nyando sub-County of Kisumu County, Kenya. This was guided by the pressing need to ensure food security for the resident population. Maize *(Zea mays)* is the leading staple food in Kenya, followed by beans (*Phaseolus vulgaris*). African Nightshade *(Solanum nigrum)* is one of the preferred vegetables in the country. The study findings are important in guiding adaptation of climate-smart farming, minimizing absolute reliance on rain-fed farming, and use of hybrid seeds for early crop maturity in Nyando and Kenya, by and large.

METHODOLOGY

Location, climate and soils of the study area

Geographically, Nyando sub-County is positioned between longitude 33° 20’ East to 35° 20' East of the Prime Meridian and latitude 0° 20' South to 0° 50' South of the Equator. Sandwiched between the Nandi Hills of Rift Valley and the Nyabondo Plateau of Upper Nyakach, the sub-County is approximately 163 square kilometers with a population of 122,376 persons (KNBS, 2019). The sub-County falls within the Modified Equatorial Climate of the Lake Victoria Basin region. Black cotton soil that stays sticky and difficult to work on during wet seasons, and dry to crack during dry seasons, is dominant.

Research design and data sources

This research used a quasi-longitudinal research design to get the qualitative and quantitative data on rainfall from the meteorological department and data on food crop production from household heads. Primary data on food crop production and yields was obtained from household heads' questionnaires, interview schedules for key informants, photography, and observation checklist. Secondary data was obtained from publications, Kisumu County Meteorological Department and Ministry of Agriculture. The unit of data analysis was the household.

Study population and sampling

A sample size of 384 was used in observance with Yamane (1967) formula. Systematic random sampling was used in selecting the 384 respondents from the farming households in the study area. Purposive sampling was used to reach key informants. These included: (1) officers from the Ministry of Agriculture (MOA) who provided data on crops grown in the area for the 10 last years, and (2) officers from the Kenya Meteorological Department (KMD), Kisumu County chapter, who provided significant data on the rainfall amounts for the last ten years.

Data analysis

Quantitative data on food crop yields was analyzed using descriptive statistics of frequencies. Documented data on rainfall duration from the KMD was analyzed by regression analysis. These data were processed using Statistical Package for Social Science (SPSS Version 22). Qualitative data on types of food crops was analyzed by creating categories, themes, and patterns in order to help in evaluating the usefulness of the information in answering research questions.

Ethical considerations

Prior to questionnaire administration, written informed consent was obtained from each respondent after a brief introduction of the study. Participation in the study was on a voluntary basis. Confidentiality, privacy, and anonymity of the participants was maintained to ensure that they were protected.

RESULTS AND DISCUSSION

Influence of rainfall magnitude on maize, beans and African Nightshade production

Analysis was conducted to show hourly variation of rainfall on crop production trends during the low and high rainfall concentrations and expected yields during the low and high rainfall magnitude. The result further established the perception of respondents on fluctuation effect of rainfall on maize, beans and African nightshade production, the crop production trend and expected yields during short and long rains. The results were presented in Table 1.

Table 1: Variation in rainfall magnitude on production trends of Maize, Beans, and African Nightshade

Fluctuation effect of rainfall/hour on maize, beans and African Nightshade	Crop production trends (2019-2022)	Expected crop yield (90 kg bags) with high rainfall magnitude	Expected crop yield (90 kg bags) with low rainfall magnitude
No – 38.02% Yes – 59.38% Undecided – 2.60%	**Maize** Increasing – 26.04% Decreasing – 62.50% Constant – 10.42% Undecided – 1.04% **Beans** Increasing – 46.88% Decreasing – 42.71% Constant – 9.90% Undecided – 0.52% **African Nightshade** Increasing – 58.59% Decreasing – 17.19% Constant – 8.85% Undecided – 15.36%	(1-10) - 22.14% (1-5) - 24.48% (5-15) - 52.34% (Others) – 1.04%	(1-10) - 18.75% (1-5) - 49.74% (5-15) - 2.86% (Others) - 28.65%

Source: Field data, 2022

The results from Table 1 showed that most respondents observed that maize production was on the decline between 2019 and 2022. The hourly rainfall received was insufficient for growing of maize as most farms dried because of minimal soil moisture. Moreover, respondents recognized the great decline in the amount of rainfall witnessed in the area that almost made them abandon maize production. Conversely, 46.88 percent respondents agreed that beans production was on the rise during the same time period. This was because beans required low amount of rainfall and reduced millimeters per hour of rainfall was enough for positive fluctuation in its production. Majority of the respondents agreed that rainfall fluctuations affected the yield of African Nightshade. When asked whether the vegetable required a lot of rainfall, most respondents agreed that African Nightshade never required high rainfall intensity. This confirmed the positive rise in African Nightshade production despite the reduction in rainfall intensity. The modal crop yield expected by most of the households was 5-15 bags. This amount of yield of African Nightshade was reasonable to the households as it met their home consumption as well as selling the surplus to obtain income for other necessities.

Further analysis was done to determine the number of hours of long and short rains, the respondents' perception on whether there were long hours of rainfall or not. The views of the respondents were also established to establish the hourly decline in rainfall as well as the effect of such decline on the selected crop yields. The results were presented in Table 2.

Table 2: Data on magnitude of rainfall on Maize, Beans and African Nightshade production

Long rain hours	Short rain hours	Long rainfall hours and surface runoff	Surface runoff effect	Hourly rainfall declines and crop yield	Effect of increase in hours of rainfall on crop yield
0.75	0.54	Yes -79.69% No -16.41% Undecided -	Maize - 29.69% Beans -	Yes -46.61% No -40.63% Undecided -	Yes -53.39% No -44.79%

ISSN No. 2454-6186 | DOI: 10.47772/IJRISS | Volume IX Issue V May 2025

		3.90%	65.36% Nightshade-2.60% Undecided -0.26%	12.76%	Undecided -1.82%

Source: Field data, 2022

The data provided from the meteorological department showed that millimeter per hour of rainfall had drastically reduced. For instance, the seasonal average long rain hours were 0.75 while the short rains reported 0.54. When probed on their perception about the rainfall concentration, majority of the respondents said that there was significant reduction of rainfall concentration in the study area. Majority of the respondents (79.69%) further agreed that longer rainfall hours contributed massively to surface runoff (higher rainfall concentration), 16.41 percent of the respondents were in disagreement while 3.90 percent remained undecided. By perception, bean and African Nightshade crops were greatly affected by surface runoff unlike maize crop. The respondents generally felt that more rainfall magnitude was the reason for positive increase in maize production. However, leguminous crops like beans were affected by more rainfall which led to stagnation of water on the farms thus withering of bean crop.

Respondents perceived hourly rainfall to be reducing with time, an observation that affected the production of the three crops. Most household heads who had practiced food crop farming for a long time had a better idea on the change in rainfall magnitude in the area. They generally perceived the millimeter per hour of rainfall to be decreasing thus affecting food crop production. Further, the respondents agreed that the decline in maize production was attributed to the change in millimeter per hour of rainfall. The respondents' perception on hourly rainfall amount was confirmed by the data provided by the meteorological department. Information provided by the Meteorological Department of Kisumu showed that, in 2022 the hourly rainfall reduced from 70mm/hour to 35mm/hour. This confirmed that there was a significant reduction on millimeter per hour of rainfall within the study area. As a crop that require high rainfall concentration, maize declined due to insufficient rainfall for optimal yield. Despite the negative influence on maize production, the reduced rainfall magnitude led to positive fluctuations in beans production since the farms had sufficient moisture for bean growing. The African Nightshade was the greatest beneficiary of reduced rainfall magnitude as it required least rainfall magnitude among the three crops.

Rainfall magnitude and Maize, Beans and African Nightshade production during long rain seasons

Simple linear regression analysis was used to establish the extent of relationship between rainfall magnitude and the production of the selected crops during the long rains. The results were as shown in Table 3.

Table 3: Relationship between rainfall magnitude and Maize, Beans and African Nightshade production during long rains

Model	r^2	df_1	df_2	F statistics	T	ρ -value	N
Maize Yield (bags/acre/annum)	0.378	1	383	22.31	13.641	0.000	384
Bean Yield (bags/acre/annum)	0.286	1	383	18.34	-3.325	0.000	384
Nightshade (kg/acre/annum)	0.244	1	383	16.41	-2.347	0.000	384

Source: Field data, 2022

Results in Table 3 indicated that there was significant effect between rainfall magnitude during long rains and Maize yield ($F = 22.31$, $\rho < 0.001$, $r^2 = 0.38$), Beans yield ($F = 18.34$, $\rho < 0.001$, $r^2 = 0.29$), and African

Nightshade Yield (F = 16.41, $\rho < 0.001$, $r^2 = 0.24$). Maize had a significant positive linear association (t = 13.6, $\rho < 0.001$), whereas Beans and African Nightshade revealed significant negative linear relationships: (t = -3.33, $p < 0.001$), and (t = -2.35, $\rho < 0.001$), respectively. About 38 percent, 29 percent, and 24 percent of the variation in Maize, Beans, and African Nightshade yields could be explained by change in rainfall magnitude during long rains season.

An increase in the hours of rainfall during the long rain season was good for maize production. This was because the soils had enough moisture that was sufficient for maize maturity. Beans and African Nightshade were negatively affected by the increase in millimeter per hour rainfall. The 29 percent variation of Beans yield during the long rains was due to oversaturation of water in the soil that introduced beans' pests and diseases. Moreover, during the long rains, most farmers engaged in production of numerous crops thus giving little attention to bean crop. This was confirmed from an interview with a key informant who revealed that:

"The increase in the number of hours of rainfall attract growing of very many crops. Personally, I grow maize, beans, water melon, kales, onions and spinach during the long rains. Watermelon, spinach and kales are on higher demand and fetch higher prices that is why I concentrate more on them than beans. Secondly, the more hours of rainfall attract certain disease that causes several holes on bean crop. This has made me not concentrate on beans production during the long rain cycle".

From the excerpt, it is evident that increase in hours of rainfall affected Bean production negatively. The high rainfall concentration led to diseases thus lowering the yield. Secondly, the high demand for other crops made farmers to grow other crops in large scale and giving little concentration on beans growing. This therefore confirmed the decline in beans production during the long rains.

Just like beans, the increase in hours of rainfall led to more stagnation of water that forced the African Nightshade crop to wither. Secondly, the surface run off also carried away the soil nutrients thus lowering the quality of the crop. This therefore explained the reason for decline in production of African nightshade during the long rains. With such variations in beans and African Nightshade production, farmers opted to capitalize on maize production during the long rains.

The result on maize production agreed with findings of other studies (Baffour-Ata et al., 2021; 2023; Omoyo et al., 2015). It however differed with the findings of other studies (Kiprono et al., 2024; Li et al., 2019) which reported a reduction on maize yield as a result of significantly higher rainfall. Beyond-optimal rainfall leads to excess soil moisture that hampers normal maize crop growth. Notably, other than rainfall magnitude, maize production is influenced by other factors such as temperature, altitude, soil type, farming techniques and infrastructure (Baffour-Ata et al., 2023; FAO, 2020; Edmonds & Chweya, 2018).

The study findings on beans and African Nightshade production during high rainfall magnitude are consistent with findings of other studies (Meneto, 2024; Guntu et al., 2020; Chepkoech et al., 2018; Barasa et al., 2015). High rainfall magnitude and long rains creates waterlogged and flooded conditions that leads to root rotting and leaf fall, besides sweeping away of part of the crop thus reduced crop yields. Furthermore, there occurs an overemphasis on maize growing during rainy seasons as compared to vegetable crops, a practice that leads to reduced African Nightshade yields (Leal et al., 2015). As appreciated by Amponsah et al. (2021) and Ekpa et al. (2019), maize and maize products are needed for human intake, and are raw materials for alcoholic beverage and livestock feeds companies.

Rainfall magnitude and Maize, Beans and African Nightshade production during short rain seasons

The study further sought to establish the extent at which change in rainfall magnitude affected Maize, Beans, and African Nightshade production during short rains. The results were as presented in Table 4.

ISSN No. 2454-6186 | DOI: 10.47772/IJRISS | Volume IX Issue V May 2025

Table 4: Relationship between rainfall magnitude and Maize, Beans, and African Nightshade production during short rains

Model	r^2	df_1	df_2	F statistics	t	ρ – value	N
Maize yield (bags/acre/annum)	0.583	1	383	27.32	-15.224	0.000	384
Bean Yield (bags/acre/annum)	0.392	1	383	21.27	4.115	0.000	384
Nightshade (kg/acre/annum	0.464	1	383	18.24	3.034	0.000	384

Source: Field data, 2022

Simple linear regression analysis from Table 4 showed that there was significant effect between rainfall magnitude during short rains and Maize yield (F = 27.32, $\rho < .001$, $r^2 = 0.58$), Beans yield (F = 21.27, $\rho < 0.001$, $r^2 = 0.39$), and African Nightshade yield (F = 29.68, $\rho < 0.001$, $r^2 = 0.46$). Maize had significant negative linear association (t = -15.22, $\rho < 0.001$), while Beans and African Nightshade revealed a significant positive linear relationship (t = 4.12, $\rho < 0.001$), and (t = 3.034, $\rho < 0.001$), respectively, with rainfall magnitude. About 58 percent, 39 percent, and 46 percent of the variation in Maize, Beans and African Nightshade yields were explained by change rainfall magnitude during short rain season. There was a strong negative linear relationship between maize yields and rainfall magnitude (mm/h) during the short rain season. Reduced millimeters per hour of rainfall during the short rains were insufficient for the growing of maize, a crop that required at least 40mm/hour of rainfall during the short rains. With the reduced hours of rainfall, the soil moisture depreciated leading to failure of most maize crops. The photograph in Plate 1 shows the extent of reduced rainfall magnitude leading to the failure in maize crop production. Clearly, the millimeter per hour of rainfall was insufficient to sustain maize production. As such, most maize crops failed to attain maximum maturity.

Plate 1: A section of a maize farm in East Kano, Nyando sub-County

Source: Field data, 20/09/2022

Beans and African Nightshade performed positively with short rain season's rainfall magnitude. The 30mm/hour of rainfall received during the short rains was sufficient for the maturity of Beans and African Nightshade. The *Nyota bean* variety was famous among the farmers since it required less rainfall compared to *Rosecoco bean* that did well during long rain season. The *black nightshade*, a type of African Nightshade, increased in the yields since it was drought tolerant. A section of a bean farm is displayed on the photograph in Plate 2.

ISSN No. 2454-6186 | DOI: 10.47772/IJRISS | Volume IX Issue V May 2025

Plate 2: A section of a bean farm in East Kano, Nyando sub-County

Source: Field data, 20/09/2022

The findings on maize yields are consistent with findings of other studies (Kiprono et al., 2024; Omoyo et al., 2015 and Kgathi et al., 2006) which established that reduced millimeter per hour of rainfall affected the soil moisture thus reducing maize yield. Low magnitude rainfall led to insufficient soil moisture that hampered maize crop germination and normal plant growth (Kiprono et al., 2024) besides contributing to maize crop mortality (Omoyo et al., 2015). Similar sentiments were shared by a key informant attached to Ministry of Agriculture at Nyando sub-County:

"Even though maize can withstand excess water for a short period, the crop is adversely affected by drought. Due to the few hours that rainfall is experienced, the soils become dry making crops such as maize crop to dry up. However, some vegetables can be harvested since they are not majorly affected with reduced hours of rainfall."

Against other findings (Onzima et al., 2019; Maundu, 2007), and in agreement with the findings of a study by Leal et al. (2015), results of the current study showed that beans performed significantly well during short rains. Beans have shallow rooting system that is able to utilize shallow sub-surface moisture given short rains. However, extremely low magnitude rainfall leaves behind moisture-deficient soils that are incapable of supporting proper beans growth (Maundu, 2007). A study by Omondi (2018) indicated that about 30mm/hour rainfall was enough for the production of beans and vegetables.

The results from studies by Ooko et al. (2015) and Owino (2008) agreed with the findings of the current study that reported an increase in drought-tolerant vegetables with decrease in rainfall magnitude. Their studies reported that reduced rainfall hours prompted farmers to use irrigation in production. For instance, the high demand for vegetables during the dry season had greatly motivated farmers to use irrigation thus the positive fluctuation in African Nightshade yields.

CONCLUSIONS

This study adopted a quasi-longitudinal research design to investigate the influence of rainfall magnitude on maize, beans and African nightshade production in Nyando sub-County of Kisumu County, Kenya. Primary data were collected using questionnaire, key informant interview, and observation and photography. Secondary data were obtained from Kenya Meteorological Department, Kisumu Chapter, and sub-County and County

Agricultural Offices. Qualitative data was analyzed through themes. Quantitative data was analyzed using descriptive statistics and simple regression analysis.

Findings of the linear regression model showed that there was a significant effect between rainfall magnitude and maize yield ($F = 13.68$, $\rho < 0.001$, $r^2 = 0.44$), beans yield ($F = 21.24$, $\rho < 0.001$, $r^2 = 0.38$), and African Nightshade yield ($F = 14.45$, $\rho < 0.001$, $r^2 = 0.34$). About 44 percent, 38 percent, and 34 percent of the variation in maize, beans, and African Nightshade yields, respectively, could be explained by change in rainfall magnitude. There was a significant effect between rainfall magnitude during long rains and maize yield ($F = 22.31$, $\rho < 0.001$, $r^2 = 0.38$), beans yield ($F = 18.34$, $\rho < 0.001$, $r^2 = 0.29$), and African Nightshade yield ($F = 16.41$, $\rho < 0.001$, $r^2 = 0.24$). Further, there was significant effect between rainfall magnitude during short rains and maize yield ($F = 27.32$, $\rho < 0.001$, $r^2 = 0.58$), beans yield ($F = 21.27$, $\rho < 0.001$, $r^2 = 0.39$), and African Nightshade yield ($F = 29.68$, $\rho < 0.001$, $r^2 = 0.46$). Evidently, rainfall magnitude affected the production of the three crops. This points to the need to engage precision agriculture, minimize absolute reliance on rain-fed farming, adopt climate-smart farming and use hybrid seeds for early crop maturity. Future research should investigate the contribution of rainfall timing on crop production.

ACKNOWLEDGEMENTS

We would want to acknowledge our respondents for their willing participation in this study. Their responses made this study a success.

Conflict of interest

The authors declare no conflict of interest in the production, presentation and dissemination of this study findings.

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