Vaccine 42 (2024) 126225

Contents lists available at ScienceDirect

Vaccine

journal homepage: www.elsevier.com/locate/vaccine

Predictors of the willingness to accept a free COVID-19 vaccine among households in Nigeria

Oghenowede Eyawo [a,b,*], Uchechukwu Chidiebere Ugoji [c], Shenyi Pan [d], Patrick Oyibo [e,f], Amtull Rehman [a], Mishel Mahboob [b], Olapeju Adefunke Esimai [g]

[a] School of Global Health, York University, Toronto, ON, Canada
[b] School of Kinesiology and Health Science, York University, Toronto, ON, Canada
[c] Salem Clinic and Maternity, Salem City, Warri, Delta State, Nigeria
[d] Department of Statistics, University of British Columbia, Vancouver, BC, Canada
[e] Department of Health Services Research and Management, School of Health and Psychological Sciences, City University of London, London, United Kingdom
[f] Department of Community Medicine, Faculty of Clinical Medicine, Delta State University, Abraka, Nigeria
[g] Department of Community Health, Obafemi Awolowo University, Ile-Ife, Nigeria

ARTICLE INFO

Keywords:
COVID-19
Vaccine hesitancy
Vaccine acceptance
Nigeria
Predictors of COVID-19 vaccine acceptance

ABSTRACT

Background: To inform vaccination policy and programmatic strategies to increase COVID-19 vaccine uptake, an understanding of the factors associated with the willingness to vaccinate is needed.
Methods: We analyzed data collected from the sixth and tenth round of the Nigerian COVID-19 National Longitudinal Phone Survey conducted by the National Bureau of Statistics and the World Bank in 2020 and 2021, respectively. Exploratory data analysis and feature selection techniques were used to identify important variables. Multivariable logistic regression models were fitted to assess the association between socio-demographic and economic factors and the willingness to receive a free COVID-19 vaccine among Nigerian households at two different time points before vaccines became widely available.
Results: Data from 1,733 and 1,651 Nigerian households who completed the sixth and tenth round of the survey, respectively, were included. Most respondents (>85% of households) were willing to receive a free COVID-19 vaccine from both survey rounds. The median household size was 6 (IQR: [4, 8]) with females heading about 18% of the households. Approximately 22% of the household heads had not received any formal education. Compared to households whose head had no education, households whose heads had completed tertiary education or higher had significantly lower odds of willingness to be vaccinated ($OR_{round\ 6}$: 0.46, 95% CI: [0.31, 0.68], $OR_{round\ 10}$: 0.49, 95% CI: [0.34, 0.71]). An increasing proportion of male household members was associated with greater willingness to receive a free COVID-19 vaccine ($OR_{round\ 6}$: 1.84, 95% CI: [1.01, 3.33], $OR_{round\ 10}$: 5.25, 95% CI: [2.86, 9.65]). Significant associations with vaccine willingness were also observed across geopolitical zones of residence with households in South-East Nigeria ($OR_{round\ 6}$: 0.16, 95% CI: [0.10, 0.24]; $OR_{round\ 10}$: 0.29, 95% CI: [0.19, 0.43]) and South-South Nigeria ($OR_{round\ 6}$: 0.57, 95% CI: [0.36, 0.90], $OR_{round\ 10}$: 0.32, 95% CI: [0.22, 0.48]) less likely to be willing to receive a free vaccine compared to households in North-Central Nigeria.
Conclusion: These findings from two different time points before vaccine roll-out suggest that the educational level of household head, proportion of male household members, and the geopolitical zone of residence are important baseline predictors of the willingness to receive a free COVID-19 vaccine in Nigeria. These factors should be carefully considered and specifically targeted when designing public health programs to inform early-stage strategies that address underlying vaccine hesitancy, improve vaccine uptake, promote ongoing COVID-19 vaccination efforts, and potentially enhance other immunization programs in Nigeria.

* Corresponding author at: School of Global Health, York University, Victor Dahdaleh Building, 88 The Pond Road, Toronto, ON, M3J 2S5, Canada.
E-mail address: oeyawo@yorku.ca (O. Eyawo).

https://doi.org/10.1016/j.vaccine.2024.126225
Received 28 January 2024; Received in revised form 19 June 2024; Accepted 12 August 2024
Available online 30 August 2024

1. Introduction

The COVID-19 pandemic caused by the SARS-CoV-2 virus has unfolded as a major global health crisis with far-reaching implications [1–4]. Since its emergence in late 2019, this unprecedented pandemic has disrupted societies, overwhelmed healthcare systems, and resulted in substantial morbidity and mortality [5], including an estimated 6.9 million deaths globally as of November 8, 2023 [4]. With decreasing trends in COVID-19 hospitalizations and deaths and increasing levels of community immunity, the World Health Organization (WHO) recently declared that COVID-19 no longer constitutes a public health emergency of international concern as of May 2023 [6]. Nevertheless, this declaration was accompanied by a cautionary guidance that COVID-19 remains a global health threat and requires continuing efforts to increase vaccination coverage globally [6].

The reducing trend in COVID-19 disease burden is most likely attributable to high population-level immunity from prior infection and vaccination [6]. According to the WHO, vaccines are a critical tool for promoting public health and controlling disease outbreaks [7]. They are widely acknowledged as one of the most effective strategies for preventing severe illness, hospitalization, and mortality from infectious diseases [1,8]. With increasing recognition that COVID-19 is becoming endemic, access to COVID-19 vaccines, including widespread vaccination and coverage, will continue to be a vital part of the long-term disease management strategy. However, access to COVID-19 vaccines and essential diagnostics has been plagued by global vaccine inequity [9], where a limited proportion of the world's population mostly in wealthy countries have had up to 95% of the global COVID-19 vaccine supply compared to about 5% in the rest of the world [10]. For example, despite representing 17% of the world's population, Africa had administered the lowest number of vaccine doses relative to its population size as of November 2023 [11,12].

Despite recording 267,146 confirmed cases and 3,155 deaths as of November 8, 2023, [13] the percentage of fully vaccinated people in Africa's most populous nation and the world's sixth most populous country, Nigeria, remains as low as 37% as of October 1, 2023 [11,12,14]. This falls short of the country's aspiration and goal to fully vaccinate 40% of its eligible population by 2021 and 70% by the end of 2022 [15,16]. Given its sheer population size – an estimated 223.8 million people as of July 1, 2023 – and position as one of Africa's largest economies [14], vaccination uptake in Nigeria is an important issue of global relevance and its significance to global health security cannot be overstated. Ensuring high vaccination coverage rates in Nigeria contributes to achieving worldwide immunization goals and global herd immunity, reduces the likelihood of new variants emerging, and helps prevent future outbreaks within the country and beyond. An inability to break the chain of transmission and manage an infectious disease with pandemic potential in a country like Nigeria has broader implications within the region and poses a significant global threat [17,18].

Vaccine hesitancy – the reluctance or refusal to vaccinate despite the availability of vaccines [19] which is driven by low vaccine confidence among other determinants [20], is affecting the acceptance and uptake of COVID-19 vaccines across the world [21]. In Nigeria, vaccine hesitancy is an increasing threat to the uptake of COVID-19 vaccines [22] and has historically been a longstanding problem [20,23–25], leading, for example, to the boycott of the polio vaccination program in Northern Nigeria in 2003 [26]. Low vaccine confidence that is fuelling COVID-19 vaccine hesitancy is not fully understood, but has been suggested to be driven by a variety of dynamic, context-specific, and multifaceted factors, including concerns about the speed of development, safety, potential long-term effects of the COVID-19 vaccines [27], and among Nigerians/Africans, is compounded by personal health beliefs, misinformation, and a history of mistrust in the health system [15,20,23–25,28]. To guide policy and programming around COVID-19 and maximize the potential of vaccination to overcome the challenges posed by COVID-19, we need to better understand what motivates people to vaccinate. This is particularly important as reported vaccine acceptance rate in Nigeria ranged from 20 % to 58 % [15].

Although a number of studies have attempted to identify factors associated with the intent to vaccinate against COVID-19 in Nigeria [29–34] most of these studies were cross-sectional and conducted at a single point in time. Moreover, in Nigeria and most African societies where patriarchal gender and cultural norms hold strong [35,36], there is limited insight into how intra-household structure/dynamics influence vaccine decision making within households. The aim of this study was to examine the association between socio-demographic and economic factors and the willingness to receive a free COVID-19 vaccine among households in Nigeria at two time points during the pandemic and prior to the widespread availability of COVID-19 vaccines in Nigeria. To our knowledge, this is the first study that seeks to understand the factors associated with vaccine willingness among households at two different time points before the vaccines became widely available in Nigeria. This allows us to better understand baseline vaccine willingness needed to address initial hesitancy and concerns, and to generate evidence-driven responses, particularly given the evolving nature of the pandemic and the importance of proactive strategies to mitigate vaccine hesitancy before the roll-out phase.

2. Methods

2.1. Setting

This study was conducted in Nigeria. Geopolitically, Nigeria is divided into six geographical zones or administrative groupings of its 36 states, namely: North-Central, North-East, North-West, South-East, South-South, and South-West zones. Specific to COVID-19 vaccination intentions, we hypothesize that these geopolitical zones may exhibit important differences based on historical precedents with other vaccination programs in the past [26].

2.2. Study design and data

We conducted a secondary analysis of data from the Nigeria COVID-19 National Longitudinal Phone Survey (NLPS) Phase 1, conducted by the National Bureau of Statistics and the World Bank [37]. The objective of the Nigeria COVID-19 NLPS survey is to monitor the socio-economic impact of COVID-19 in Nigeria in real time. The NLPS Phase 1 data were collected through monthly telephone surveys conducted over 12 rounds from April 2020 (baseline, or round 1) to April 2021 (round 12). In the baseline round, 3,000 households were contacted, and 1,950 were successfully interviewed, constituting the initial panel sample. While this initial panel was targeted for follow-up in subsequent rounds, the specific households successfully interviewed varied due to attrition and replenishment from the initial panel. The number of households successfully completing each round of the survey ranged from 1,820 in round 2 to 1,699 in round 10. Starting from round 3, additional households not previously interviewed were included to maintain a sufficiently large sample size. A balanced sampling approach using the cube method was adopted to obtain a nationally representative sample of the Nigerian population and to ensure balance across several key dimensions such as age, sex, state, setting (urban, rural), and household size. Detail information on the survey and the sampling methodology is publicly available on the World Bank Microdata Library (https://microdata.worldbank.org/index.php/catalog/3712/).

Our analyses used data from rounds 6 (October 2020) and 10 (February 2021) of the survey, as questions related to the willingness to be vaccinated against COVID-19 were only asked in these rounds. Specifically, the question about households' willingness to receive free COVID-19 vaccine, which captures the primary outcome variable in this study, was phrased in the questionnaire as: "*If an approved vaccine to prevent coronavirus was available right now at no cost, would you agree to be vaccinated?*" with response options of "no", "not sure", and "yes". For

those who selected "no" or "not sure", a follow-up question offered the following options to capture their reasons for not wanting to be vaccinated: 'I don't think it will work', 'I don't think it will be safe', 'I am worried about the side effects', 'I am not enough at risk of contracting COVID-19', 'I am against vaccines in general', 'It is against my religion', and 'Other (specify)'. For analytic purposes, we combined "no" and "not sure" into a single "no" class. After removing observations with missing values, there were 1,733 and 1,651 households in rounds 6 and 10, respectively, which formed the basis of our analytical sample. Of the 1,733 households included in the sample for round 6, 1,646 were also included in the sample for round 10, meaning that 87 households were unique to round 6 and 5 households were unique to round 10. Surveys in rounds 6 and 10 were conducted approximately four and one month, respectively, before the start of the COVID-19 vaccine rollout in Nigeria in March 2021.

2.3. Covariates

Socio-demographic and economic characteristics included household size, age of household head, average age of household members, sex of household head, proportion of male household members, employment status of household head, education level of household head, residential setting (rural/urban), geopolitical zone of household (North-Central, North-East, North-West, South-East, South-South and South-West), frequency of handwashing, frequency of mask wearing, access to health care, and concerns about COVID-19. The proportion of male household members was analyzed as a continuous variable and was derived from the survey by dividing the number of male household members by the total number of household members, with both quantities available in the raw survey data. Most of the covariates were measured at baseline (round 1), round 6, and round 10, but some (e.g., frequency of handwashing, mask wearing) were assessed only in round 10 and are summarized in Table 1.

2.4. Weighting

Household level weights for the Nigeria COVID-19 NLPS were provided by the National Bureau of Statistics for each round of the sampled data and were applied to successfully interviewed households. This was necessary in order to produce valid national estimates from the survey sample, mitigate potential selection bias and generalize results to the Nigerian population. We used the NLPS cross-sectional household weights in our analysis as these apply to the entire sample for a given round of the survey.

2.5. Statistical analysis

Exploratory data analysis and univariate analysis were conducted to assess the association between households' willingness to receive free COVID-19 vaccine and the available socio-demographic and economic factors. Descriptive statistics stratified by the willingness to receive a free COVID-19 vaccine in rounds 6 and 10 were reported as frequencies or as medians with interquartile range (IQR). Chi-square (χ^2) tests for categorical variables and Wilcoxon rank-sum tests for continuous variables were used to compare covariates. Graphs were used to characterize the reasons why households had concerns about receiving free COVID-19 vaccine in these two rounds. Multivariable logistic regression models with household weights were fitted to identify important predictor variables and estimate their effects. These results are presented as unadjusted and adjusted odds ratios (OR) with 95% confidence intervals (CI). When fitting the multivariable logistic regression models, we employed a stepwise Akaike Information Criterion (AIC) selection algorithm to identify the important predictors [38]. The algorithm started with the full model including all available predictors (i.e., 9 and 14 variables in rounds 6 and 10, respectively) and iteratively added or removed variables based on the AIC as the model selection criterion.

Table 1
Characteristics of the study sample categorized by household willingness to receive free COVID-19 vaccine in survey rounds 6 and 10

Characteristics	Round 6			Round 10		
	Willing to receive free COVID-19 vaccine?		*P*-value	Willing to receive free COVID-19 vaccine?		*P-value*
	No (n = 245)	Yes (*n* = 1488)		No (n = 245)	Yes (*n* = 1406)	
Age of household head, median (Q1, Q3) years	50 (40, 60)	48 (39, 59)	0.382	49 (39, 61)	49 (39, 59)	0.924
Size of household. median (Q1, Q3)	5 (3, 7)	6 (4, 8)	**<0.001**	5 (3, 7)	6 (4, 9)	**<0.001**
Average age of household members, median (Q1, Q3) years	26 (20, 34)	23 (18, 31)	**<0.001**	27 (20, 35)	23 (18, 30)	**<0.001**
Proportion of male household members, median (Q1, Q3)	0.5 (0.3, 0.6)	0.5 (0.4, 0.6)	**0.007**	0.5 (0.3, 0.6)	0.5 (0.4, 0.6)	**<0.001**
Sex of household head, n (%)			**<0.001**			**0.016**
Male	176 (71.8)	1242 (83.5)		187 (76.3)	1167 (83.0)	
Female	69 (28.2)	246 (16.5)		58 (23.7)	239 (17.0)	
Geopolitical zone, n (%)			**<0.001**			**<0.001**
North-Central	23 (9.4)	264 (17.7)		30 (12.2)	238 (16.9)	
North-East	13 (5.3)	293 (19.7)		11 (4.5)	287 (20.4)	
North-West	18 (7.4)	246 (16.5)		16 (6.5)	233 (15.6)	
South-East	99 (40.4)	214 (14.4)		85 (34.7)	217 (15.4)	
South-South	39 (15.9)	186 (12.5)		47 (19.2)	162 (11.5)	
South-West	53 (21.6)	285 (19.2)		56 (22.9)	269 (19.1)	
Residence area, n (%)			**0.001**			**<0.001**
Urban	121 (49.4)	560 (37.6)		123 (50.2)	528 (37.6)	
Rural	124 (50.6)	928 (62.4)		122 (49.8)	878 (62.4)	
Employment status in the past week, n (%)			0.119			**0.008**
Unemployed	16 (6.5)	73 (4.9)		23 (9.4)	69 (4.9)	
Employed	229 (93.5)	1415 (95.1)		222 (90.6)	1337 (95.1)	
Education level of household head, n (%)			**<0.001**			**<0.001**
None	38 (15.5)	344 (23.1)		42 (17.1)	324 (23.0)	
Primary school / artisan training	69 (28.2)	337 (22.7)		73 (29.8)	313 (22.3)	
Secondary school	64 (26.1)	489 (32.9)		54 (22.0)	467 (33.2)	
Tertiary education or higher	74 (30.2)	318 (21.4)		76 (31.0)	302 (21.5)	

(*continued on next page*)

Table 1 (*continued*)

Characteristics	Round 6			Round 10		
	Willing to receive free COVID-19 vaccine?		*P*-value	Willing to receive free COVID-19 vaccine?		*P-value*
	No (n = 245)	Yes (*n* = 1488)		No (n = 245)	Yes (*n* = 1406)	
How often do you wash hands with soap after being in public in past week, n (%)						0.153
All the time	131 (53.5)	831 (59.1)				
Most of the time / about half of the time / some of the time	102 (41.6)	531 (37.8)				
None of the time	8 (3.3)	22 (1.6)				
I have not been in public during the last 7 days	4 (1.6)	22 (1.6)				
How often do you wear a mask when in public in past week, n (%)						**0.042**
All the time	138 (56.3)	899 (63.9)				
Most of the time / about half of the time / some of the time	87 (35.5)	436 (31.0)				
None of the time	16 (6.5)	49 (3.5)				
I have not been in public during the last 7 days	4 (1.6)	22 (1.6)				
Have any household member needed any medical services in past month, n (%)						**<0.001**
Yes	75 (30.6)	647 (46.0)				
No	170 (69.4)	759 (54.0)				
Worried about COVID-19, n (%)						**<0.001**
Very worried	108 (44.1)	943 (67.1)				
Somewhat worried	13 (5.3)	130 (9.3)				
Not too worried	37 (15.1)	104 (7.4)				
Not worried at all	87 (35.5)	229 (16.3)				
Threat of COVID-19 to household's finances, n (%)						**<0.001**
A substantial threat	130 (53.1)	968 (68.9)				
A moderate threat	44 (18.0)	223 (15.9)				
Not much of a threat	31 (12.7)	108 (7.7)				
Not a threat at all	40 (16.3)	107 (7.6)				

P-values are obtained by performing a chi-squared test for the association between each categorical factor and the response variable, or a Wilcoxon rank-sum test for the association between each continuous factor and the response variable.

This process continued until further additions or removals did not significantly improve the AIC. The final multivariable logistic regression models included the 5 and 9 variables identified as important predictors in rounds 6 and 10, respectively, and the adjusted ORs were reported accordingly. In the exploratory analysis, households' employment status in the past week showed a strong association with their willingness to receive a free COVID-19 vaccine in round 10 (Table 1). However, the employment-related variables were only available for employed households during the survey. To examine the potential confounding effects of the employment-related variables on the associations between socio-demographic and economic predictors and vaccine willingness, we conducted a sensitivity analysis on the subset of employed households for both rounds. Test of statistical significance was two-sided and 0.05 was used as the significance level. All the analyses were conducted using the R Statistical Program, version 3.6.2 (Vienna, Austria).

Ethical approval for the study was obtained from the National Bureau of Statistics and the World Bank, which provided access to the dataset under its Open Data policy. The study did not require informed consent as it is conducted retrospectively for research and statistical purposes only using anonymized data.

3. Results

Our analysis was based on data collected from 1,733 and 1,651 households in rounds 6 and 10 of the NLPS Phase 1, respectively. The primary objective of comparing the two rounds is to provide insight into how the evolution of COVID-19 and the increased knowledge about the pandemic at two time points (2020 for round 6 vs. 2021 for round 10) may have influenced the effects of socio-demographic and economic factors on the willingness to receive a free COVID-19 vaccine. Table 1 shows the characteristics of the study sample categorized by household willingness to receive free COVID-19 vaccine. Most households (85.9% in round 6; 85.2% in round 10) expressed willingness to receive a free COVID-19 vaccine. With an overall median household size of 6 members (IQR: 4–8), the median age of the household heads was 48 years (IQR: 39–59) and 49 years (39 – 60) in rounds 6 and 10 respectively. The average age of the household members was similar (median age: 23 years) in both rounds. The North-Eastern part of Nigeria had the highest percentage of households willing to be vaccinated (95.8% in round 6, 96.3% in round 10) and the lowest percentage was in the South-East zone (68.4% in round 6, 71.9% in round 10). A higher proportion of rural dwellers were willing to receive free vaccine than urban dwellers (88.2% vs. 82.2% in round 6; 87.8% vs. 81.1% in round 10). The proportion of households willing to receive COVID-19 vaccine was higher among households with male heads than among those with female heads (87.6% vs. 78.1% in round 6, 86.2% vs. 80.5% in round 10). In round 6, the proportion of households willing to be vaccinated was 90.1% for those with household heads having no formal education, 83.0% for those with primary education, 88.4% for those with secondary education, and 81.1 %for those with tertiary education or higher. Similarly, in round 10, the proportions were 88.5%, 81.1%, 89.6%, and 79.9% for no formal education, primary, secondary, and tertiary education or higher, respectively (Table 1). Notably, households with heads who had completed tertiary education or higher consistently had the lowest proportions of willingness to be vaccinated among the four subgroups. These data indicate in both rounds, households with heads who had completed secondary education or lower were more likely to be willing to be vaccinated than households with heads who had completed tertiary education or higher. The two-way tables of educational level and sex of the household heads in both rounds show that female household heads had significantly less access to higher-level education than male household heads (Table 2). In both rounds, households with larger sizes

Table 2
Two-way table of educational level and sex of the household heads

Characteristics, n (%)	Round 6			Round 10		
	Male (*n* = 1418)	Female (*n* = 315)	*P-value*	Male (*n* = 1354)	Female (*n* = 297)	*P-value*
No education	270 (19.0)	112 (35.6)	**<0.001**	260 (19.2)	106 (35.7)	**<0.001**
Primary school / artisan training	310 (21.9)	96 (30.5)		297 (21.9)	89 (30.0)	
Secondary school	487 (34.3)	66 (21.0)		457 (33.8)	64 (21.6)	
Tertiary education or higher	351 (24.8)	41 (13.0)		340 (25.1)	38 (12.8)	

P-values are obtained by performing a chi-squared test for the association between these two factors.

and higher proportions of male members were more willing to be vaccinated against COVID-19. In round 10, more frequent hand washing, use of mask, and households with members requiring medical services (89.6% vs. 81.7%) were associated with greater willingness to receive free COVID-19 vaccine. Households that expressed concerns about COVID-19 or perceived COVID-19 as a threat to their financial situation were also more likely to receive free COVID-19 vaccine in round 10.

We found that 245 households were reluctant to receive free COVID-19 vaccine among the 1,733 and 1,651 households in rounds 6 and 10, respectively. The reasons for their concerns about COVID-19 vaccination are summarized in Fig. 1. The most common reason was concern about the safety of the vaccine. In round 6, 39.6% of the 245 households expressed concern for this reason. This percentage increased further to 45.7% in the round 10 survey that was conducted one month before the start of the vaccine rollout in Nigeria. In contrast, the proportion of households who cited their belief of not being at sufficient risk as their reason for the reluctance to receive COVID-19 dropped from 29.8% in round 6 to 20.4% in round 10, indicating that more households understood the seriousness of COVID-19 over time. Due to some households being unique to either round 6 or 10, it was not possible to determine the precise proportion of the 245 participants in round 6 that remained reluctant to receive the vaccine in round 10. However, among the 1,646 households that participated in both rounds, we observed dynamic changes in vaccination willingness. In round 6, 225 households (13.7%) were unwilling to receive a free COVID-19 vaccine, increasing slightly to 243 households (14.8%) in round 10. There were 20 unwilling households unique to round 6 and 2 unique to round 10. Of the 1,646 households, 116 (7.0%) remained consistently unwilling across both rounds. Notably, we observed bi-directional changes in willingness: 109 households (6.6%) shifted from unwilling in round 6 to willing in round 10, while 127 households (7.7%) changed from willing in round 6 to unwilling in round 10. In total, 236 households, representing 14.3% of the 1,646 households present in both rounds, changed their willingness status between rounds 6 and 10. These data demonstrate the dynamic nature of vaccine willingness over time in our study population.

Table 3 shows the unadjusted and adjusted ORs and 95% CIs of the weighted logistic regression models of factors associated with the willingness to receive free COVID-19 vaccine in rounds 6 and 10. After adjusting for the effects of other socio-demographic and economic predictors, education level of household head, proportion of male household members, and geopolitical zone remain significant factors predicting household willingness to receive free COVID-19 vaccine in both rounds 6 and 10. Households whose heads had completed tertiary education or higher had significantly lower odds of willingness to be vaccinated compared to households whose heads had no formal education ($OR_{round\ 6}$: 0.46, 95% CI: [0.31, 0.68], $OR_{round\ 10}$: 0.49, 95% CI: [0.34, 0.71]). Furthermore, increasing proportion of male household members was associated with a greater willingness to receive free COVID-19 vaccine ($OR_{round\ 6}$: 1.84, 95% CI: [1.01, 3.33], $OR_{round\ 10}$: 5.25, 95% CI: [2.86, 9.65]). Compared to households living in North-Central Nigeria – which includes the capital city, Abuja –, households living in the South-East ($OR_{round\ 6}$: 0.16, 95% CI: [0.10, 0.24]; $OR_{round\ 10}$: 0.29, 95% CI: [0.19, 0.43]) and South-South ($OR_{round\ 6}$: 0.57, 95% CI: [0.36, 0.90], $OR_{round\ 10}$: 0.32, 95% CI: [0.22, 0.48]) geopolitical zones of Nigeria were less likely to be willing to receive free vaccine. Some predictor variables were only significantly associated with vaccination intentions at one time point only (round 6 or 10), but not in both. For example, after adjusting for covariates in round 6, households living in rural areas were more likely to be willing to receive a free COVID-19 vaccine compared to urban dwelling household ($OR_{round\ 6}$: 1.48, 95% CI: [1.14, 1.92]). Similar results were observed with household setting (rurality) in the unadjusted analysis in round 10 ($OR_{round\ 10}$: 1.62, 95% CI: [1.31, 2.01]) but was not selected in the final adjusted model (Table 3). In round 10, the more concerned households were about COVID-19 in general or its impact on their financial situation, the more likely they were willing to receive free COVID-19 vaccine.

The sensitivity analysis among a subset of the sample (1,360 and 1,204 households in rounds 6 and 10, respectively) showed that employment-related variables, including employment sector and employer type, were significantly associated with households' willingness to receive free COVID-19 vaccine. The unadjusted and adjusted ORs and 95% CIs of the weighted logistic regression models of factors associated with the willingness to receive free COVID-19 vaccine among the employed households in these two rounds are shown in Table 4. In particular, compared to households working in agriculture, hunting, and fishing sectors, households working in education, health, culture, services, and public administration sectors were significantly less willing to receive free COVID-19 vaccines (Table 4). This is consistent with the findings on the effect of education level on COVID-19 vaccine

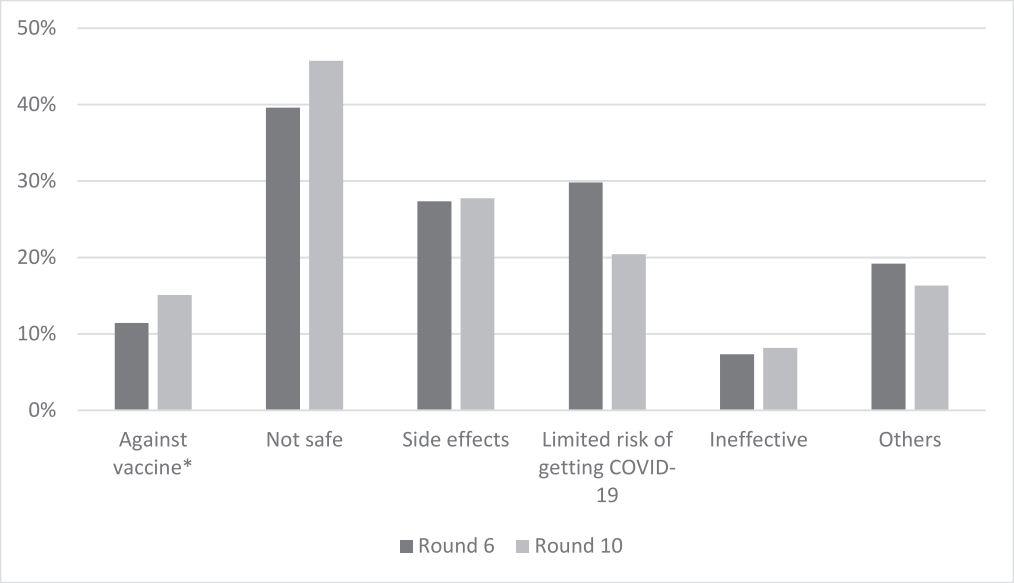

Fig. 1. Reasons and proportion of households with specific concerns about receiving the COVID-19 vaccine ($n = 245$ in both rounds).
'Against vaccine*' includes those who are generally against vaccines or have concerns about vaccines based on religious reasons. This category was derived from responses to the following options in the original questionnaire: "I am against vaccines in general" and "It is against my religion".

Table 3
Estimated unadjusted and adjusted odds ratio (OR) and 95% confidence interval (CI) from weighted logistic regression models for the willingness to receive free COVID-19 vaccine among Nigerian households

Variables	Round 6				Round 10			
	Unadjusted OR		Adjusted OR		Unadjusted OR		Adjusted OR	
	OR (95% CI)	*P-value*	OR (95% CI)	*P-value*	OR (95% CI)	*P-value*	OR (95% CI)	*P-value*
Geopolitical zone								
North Central*	(Reference level)		(Reference level)		(Reference level)		(Reference level)	
North East	1.05 (0.59, 1.88)	0.864	0.93 (0.52, 1.67)	0.809	8.24 (2.95, 23.00)	**<0.001**	7.53 (2.67, 21.24)	**<0.001**
North West	1.13 (0.69, 1.85)	0.641	0.99 (0.60, 1.64)	0.978	2.29 (1.39, 3.75)	**0.001**	2.06 (1.23, 3.45)	**0.006**
South-East	0.13 (0.09, 0.20)	**<0.001**	**0.16 (0.10, 0.24)**	**<0.001**	0.24 (0.17, 0.35)	**<0.001**	0.29 (0.19, 0.43)	**<0.001**
South-South	0.51 (0.33, 0.81)	**0.004**	0.57 (0.36, 0.90)	**0.017**	0.34 (0.23, 0.50)	**<0.001**	0.32 (0.22, 0.48)	**<0.001**
South-West	0.55 (0.35, 0.87)	**0.01**	0.66 (0.41, 1.06)	0.087	0.42 (0.29, 0.61)	**<0.001**	0.44 (0.29, 0.68)	**<0.001**
Residence area								
Urban	(Reference level)		(Reference level)		(Reference level)			
Rural	1.62 (1.29, 2.03)	**<0.001**	1.48 (1.14, 1.92)	**0.003**	1.62 (1.31, 2.01)	**<0.001**		
Employment status in the past week								
Unemployed	(Reference level)				(Reference level)		(Reference level)	
Employed	1.04 (0.65, 1.68)	0.862			1.99 (1.37, 2.90)	**<0.001**	1.47 (0.96, 2.26)	0.076
Sex of household head								
Male	(Reference level)		(Reference level)		(Reference level)		(Reference level)	
Female	0.49 (0.38, 0.63)	**<0.001**	0.74 (0.51, 1.01)	0.059	0.72 (0.56, 0.92)	**0.009**	1.63 (1.18, 2.26)	**0.003**
Education level of household head								
None	(Reference level)		(Reference level)		(Reference level)		(Reference level)	
Primary school / artisan training	0.36 (0.26, 0.50)	**<0.001**	0.53 (0.37, 0.75)	**<0.001**	0.66 (0.49, 0.89)	**0.007**	1.11 (0.79, 1.56)	0.557
Secondary school	0.78 (0.56, 1.09)	0.146	0.89 (0.62, 1.28)	0.54	0.86 (0.64, 1.15)	0.311	1.26 (0.89, 1.78)	0.198
Tertiary education or higher	0.42 (0.29, 0.59)	**<0.001**	0.46 (0.31, 0.68)	**<0.001**	0.38 (0.28, 0.51)	**<0.001**	0.49 (0.34, 0.71)	**<0.001**
How often do you wash hands with soap after being in public in past week								
All of the time					(Reference level)		(Reference level)	
Most of the time / about half of the time / some of the time					1.03 (0.83, 1.27)	0.802	1.08 (0.85, 1.38)	0.534
None of the time					0.69 (0.34, 1.41)	0.306	0.62 (0.28, 1.41)	0.256
I have not been in public during the last 7 days					1.71 (0.59, 4.90)	0.322	4.03 (1.28, 12.68)	**0.017**
How often do you wear a mask when in public in past week								
All of the time					(Reference level)			
Most of the time / about half of the time / some of the time					0.64 (0.51, 0.79)	**<0.001**		
None of the time					0.63 (0.39, 1.02)	0.059		
I have not been in public during the last 7 days					1.42 (0.49, 4.08)	0.518		
Have any household member needed any medical services in past month								
Yes					(Reference level)			
No					0.49 (0.39, 0.61)	**<0.001**		
Worried about COVID-19								
Very worried					(Reference level)		(Reference level)	
Somewhat worried					1.06 (0.66, 1.69)	0.822	1.26 (0.77, 2.07)	0.361
Not too worried					0.27 (0.20, 0.38)	**<0.001**	0.39 (0.26, 0.57)	**<0.001**
Not worried at all					0.26 (0.20, 0.33)	**<0.001**	0.40 (0.31, 0.53)	**<0.001**
Threat of COVID-19 to household's finances								
A substantial threat					(Reference level)		(Reference level)	
A moderate threat					0.56 (0.43, 0.74)	**<0.001**	0.90 (0.66, 1.22)	0.483
Not much of a threat					0.37 (0.26, 0.51)	**<0.001**	0.47 (0.32, 0.69)	**<0.001**
Not a threat at all					0.56 (0.40, 0.79)	**<0.001**	0.73 (0.50, 1.08)	0.116
Size of household	1.12 (1.08, 1.16)	**<0.001**			1.11 (1.07, 1.14)	**<0.001**		
Average age of household members	0.98 (0.97, 0.99)	**<0.001**			0.98 (0.97, 0.98)	**<0.001**		
Proportion of male household members	3.14 (1.88, 5.25)	**<0.001**	1.84 (1.01, 3.33)	**0.045**	5.06 (3.07, 8.34)	**<0.001**	5.25 (2.86, 9.65)	**<0.001**
Age of household head	0.99 (0.98, 1.00)	0.097			1.00 (0.99, 1.00)	0.21	1.01 (1.00, 1.02)	0.067

Note: blank cells in the adjusted OR column represent variables not selected by the AIC algorithm for inclusion in the final model.
* We designated the North-Central geopolitical zone as the reference as it is home to the country's capital city, Abuja.

willingness, as people working in the tertiary sector of the economy were generally better educated than those in the primary sector. However, no significant changes were observed in the direction and magnitude of the effects of the other predictors (Table 3), confirming that their effects were not confounded with the employment-related variables (Table 4).

4. Discussion

Our study utilizing COVID-19 survey data from the National Bureau of Statistics and the World Bank found that most Nigerians, especially rural dwellers would be willing to receive COVID-19 vaccine, if it were freely available. Our analysis demonstrated that the willingness to receive a free COVID-19 vaccine among households in Nigeria was independently associated with the education level of household head, proportion of male household members, and the geopolitical zone of residence. Households whose head had tertiary education or higher had a decreased likelihood in excess of 50% of the willingness to vaccinate against COVID-19 compared to those with no formal education. Increasing proportion of male household members was associated with a significant increase in the willingness to vaccinate against COVID-19. People living in Southern Nigeria had significantly lower odds of willingness to vaccinate against COVID-19 compared to those living in the North-Central zone. These findings were consistent at both time points of the survey at round 6 and 10, immediately prior to the rollout of COVID-19 vaccines in Nigeria.

The proportion of Nigerian households willing to receive free COVID-19 vaccine in our study (85%) was comparable to the vaccine willingness rates reported between 2020 and 2021 in Canada (83%) [39], United Kingdom (89%) [40], China (81%) [41], India (80%) [42], lower than rates in Brazil (90%) [43], Indonesia (93%) [44], Japan (96%) [45], but higher than rates reported in other countries including

Table 4
Estimated unadjusted and adjusted odds ratio (OR) and 95% confidence interval (CI) from weighted logistic regression models for the willingness to receive free COVID-19 vaccine among **employed** Nigerian households (sensitivity analysis)

Variables	Round 6				Round 10			
	Unadjusted		Adjusted		Unadjusted		Adjusted	
	OR (95% CI)	*P-value*	OR (95% CI)	*P-value*	OR (95% CI)	*P-value*	OR (95% CI)	*P-value*
Geopolitical zone								
North Central*	(Reference level)		(Reference level)		(Reference level)		(Reference level)	
North East	0.64 (0.33, 1.23)	0.179	0.57 (0.29, 1.13)	0.11	8.49 (2.83, 25.48)	**<0.001**	10.19 (3.3, 31.49)	**<0.001**
North West	0.65 (0.36, 1.18)	0.158	0.53 (0.29, 0.96)	**0.036**	3.46 (1.92, 6.21)	**<0.001**	3.47 (1.87, 6.44)	**<0.001**
South East	0.10 (0.06, 0.17)	**<0.001**	0.12 (0.07, 0.22)	**<0.001**	0.32 (0.21, 0.49)	**<0.001**	0.36 (0.22, 0.58)	**<0.001**
South South	0.32 (0.18, 0.56)	**<0.001**	0.39 (0.22, 0.70)	**0.002**	0.39 (0.25, 0.59)	**<0.001**	0.38 (0.24, 0.60)	**<0.001**
South West	0.31 (0.17, 0.55)	**<0.001**	0.36 (0.20, 0.65)	**0.001**	0.55 (0.35, 0.87)	**0.01**	0.57 (0.35, 0.93)	**0.025**
Residence area								
Urban	(Reference level)				(Reference level)			
Rural	1.68 (1.29, 2.18)	**<0.001**			1.30 (1.00, 1.68)	0.051		
Sex of household head								
Male	(Reference level)		(Reference level)		(Reference level)		(Reference level)	
Female	0.43 (0.32, 0.56)	**<0.001**	0.63 (0.46, 0.88)	**0.006**	0.78 (0.57, 1.07)	0.119	1.43 (0.96, 2.13)	0.076
Education level of household head								
None	(Reference level)		(Reference level)		(Reference level)		(Reference level)	
Primary school / artisan training	0.35 (0.24, 0.49)	**<0.001**	0.46 (0.32, 0.68)	**<0.001**	0.69 (0.49, 0.99)	**0.042**	1.25 (0.83, 1.88)	0.288
Secondary school	0.99 (0.67, 1.46)	0.945	0.99 (0.65, 1.53)	0.975	1.13 (0.79, 1.61)	0.502	1.91 (1.25, 2.92)	**0.003**
Tertiary education or higher	0.47 (0.31, 0.70)	**<0.001**	0.52 (0.34, 0.82)	**0.004**	0.39 (0.27, 0.56)	**<0.001**	0.80 (0.51, 1.25)	0.327
Employment sector								
Agriculture, hunting, fishing	(Reference level)		(Reference level)		(Reference level)		(Reference level)	
Buying/selling goods, repair of goods, hotels & restaurants	0.63 (0.45, 0.87)	**0.006**	0.79 (0.55, 1.14)	0.205	0.87 (0.64, 1.19)	0.379	0.57 (0.31, 1.03)	0.062
Construction, mining, manufacturing, gas, electricity, water supply	0.76 (0.38, 1.51)	0.432	1.2 (0.57, 2.52)	0.631	0.74 (0.44, 1.24)	0.246	0.50 (0.24, 1.06)	0.071
Personal services, health, education, culture, sport, domestic work, other	0.49 (0.34, 0.72)	**<0.001**	0.52 (0.35, 0.79)	**0.002**	0.58 (0.42, 0.81)	**0.002**	0.45 (0.24, 0.83)	**0.011**
Public administration	0.46 (0.23, 0.91)	**0.026**	0.38 (0.18, 0.78)	**0.008**	0.65 (0.36, 1.19)	0.167	0.39 (0.14, 1.14)	0.086
Transport, driving, post, travel agencies, professional activities (finance, legal, analysis, computer, real estate)	0.81 (0.38, 1.71)	0.577	0.86 (0.38, 1.92)	0.713	1.41 (0.71, 2.81)	0.332	1.18 (0.48, 2.92)	0.718
Employer								
Private company or another individual (not household member)	(Reference level)				(Reference level)		(Reference level)	
Government	0.98 (0.50, 1.93)	0.962			3.22 (1.72, 6.03)	**<0.001**	2.58 (1.09, 6.15)	**0.032**
Family farm, growing crops, raising livestock, or fishing	2.13 (1.38, 3.29)	**0.001**			2.03 (1.28, 3.21)	**0.003**	1.31 (0.51, 3.31)	0.574
Non-farm business	1.44 (0.93, 2.22)	0.105			1.91 (1.23, 2.98)	**0.004**	1.46 (0.82, 2.60)	0.316
How often do you wash hands with soap after being in public in past week								
All of the time					(Reference level)			
Most of the time / about half of the time / some of the time					1.21 (0.94, 1.56)	0.142		
None of the time					0.50 (0.20, 1.24)	0.135		
I have not been in public during the last 7 days					7.19 (0.03, 1810.2)	0.484		
How often do you wear a mask when in public in past week								
All of the time					(Reference level)			
Most of the time / about half of the time / some of the time					0.50 (0.39, 0.64)	**<0.001**		
None of the time					0.54 (0.28, 1.04)	0.066		

(*continued on next page*)

Table 4 (*continued*)

Variables	Round 6				Round 10			
	Unadjusted		Adjusted		Unadjusted		Adjusted	
	OR (95% CI)	*P-value*	OR (95% CI)	*P-value*	OR (95% CI)	*P-value*	OR (95% CI)	*P-value*
I have not been in public during the last 7 days					5.03 (0.02, 1266.9)	0.567		
Have any household member needed any medical services in past month								
Yes					(Reference level)			
No					0.44 (0.34, 0.58)	**<0.001**		
Worried about COVID-19								
Very worried					(Reference level)		(Reference level)	
Somewhat worried					1.17 (0.68, 2.01)	0.564	1.34 (0.75, 2.39)	0.316
Not too worried					0.37 (0.25, 0.55)	**<0.001**	0.44 (0.28, 0.70)	**<0.001**
Not worried at all					0.26 (0.19, 0.35)	**<0.001**	0.41 (0.29, 0.58)	**<0.001**
Threat of COVID-19 to household's finances								
A substantial threat					(Reference level)		(Reference level)	
A moderate threat					0.63 (0.45, 0.87)	**0.005**	1.08 (0.75, 1.57)	0.683
Not much of a threat					0.34 (0.23, 0.49)	**<0.001**	0.38 (0.24, 0.59)	**<0.001**
Not a threat at all					0.64 (0.41, 1.00)	**0.05**	0.96 (0.58, 1.59)	0.866
Size of household	1.14 (1.10, 1.19)	**<0.001**			1.15 (1.11, 1.20)	**<0.001**		
Average age of household members	0.97 (0.96, 0.98)	**<0.001**	0.99 (0.98, 1.00)	0.06	0.98 (0.97, 0.98)	**<0.001**		
Proportion of male household members	3.11 (1.65, 5.86)	**<0.001**			2.22 (1.16, 4.27)	**0.016**	1.82 (0.85, 3.89)	0.124
Age of household head	0.99 (0.98, 0.99)	**0.001**			1.00 (0.99, 1.00)	0.372	1.01 (1.00, 1.02)	0.056

Note: blank cells in the adjusted OR column represent variables not selected by the AIC algorithm for inclusion in the final model.

* We designated the North-Central geopolitical zone as the reference as it is home to the country's capital city, Abuja.

Germany (67%) [46] and USA (75%) [47]. It was also higher than that of most African countries including Ethiopia (31%) [48], Uganda (54%) [49], South Africa (71%) [50], and the global average (66%) [51]. While these estimates serve as a useful proxy for comparisons between countries, it is important to note that these proportions are not static and are impacted by the risk perception of COVID-19 in specific population, education level and health literacy, perception of the vaccine safety, infection incidence/burden of COVID-19, and timing of measurement [52–57] all of which could influence the willingness to vaccinate. Moreover, within countries, reported rates can vary across distinct demographic groups such as healthcare workers, students, patients, etc. [46,58]. Our finding that the proportion reporting willingness to receive the COVID-19 vaccine (85%) differs significantly from the proportion of the Nigerian population estimated to have been fully vaccinated (37%) as of October 2023 [12] is not uncommon, as the literature has shown substantial gaps between stated vaccine intentions and actual behaviour/vaccine uptake [50,59,60]. After one year of the COVID-19 vaccine roll-out (2022), the national uptake was estimated at only 4% [11,12], despite our observed high willingness rates. By the end of 2023, uptake had risen to just below 40% [11–13], still significantly lower than the willingness rates we observed. We speculate that this observed discrepancy may be driven by various factors. These include supply chain issues, such as logistical challenges related to inadequate distribution networks, power supply issues affecting cold chain maintenance requirements, and stockouts or demand-supply mismatches leading to missed opportunities for vaccination. Geographical barriers, particularly limited access to vaccination centres in rural areas, may also play a role. Furthermore, inadequate health infrastructure and personnel can impede vaccine distribution and administration. Information and communication barriers, such as limited information on where to get vaccinated and its importance, may contribute to the gap between willingness and uptake. Additionally, evolving COVID-19 risk perception can influence vaccine decision-making. Finally, economic and practical barriers, including prohibitive indirect costs such as transportation, taking time off work or business, or arranging childcare, may prevent individuals from acting on their stated willingness to be vaccinated.

As supported by a growing body of evidence [25,45,61–67], the observed shifts in vaccine willingness status (i.e., reversal) over time can be attributed to various complex, interrelated, and evolving factors. These include the dissemination of new information and misinformation about vaccine safety and efficacy, incidence of new infections, personal experiences and observations of others' vaccination outcomes, and fluctuating levels of trust in authorities and the healthcare system. Social and cultural influences, such as endorsements or opposition from community leaders or celebrities, also play a significant role. Additionally, changes in vaccine accessibility, logistical challenges related to economic and practical considerations, and shifting perceptions of COVID-19 risk have contributed to these changes. Personal health changes, social pressure dynamics, and the implementation or relaxation of government and employer mandates have further influenced household decisions regarding vaccination.

Our observation of reduced odds of vaccination willingness among households whose head had tertiary education or higher compared to those whose heads had no formal education may be attributed to information overload among the highly educated. Information overload has been identified as a significant consequence of social media usage in the context of the COVIID-19 pandemic and has been shown to promote vaccine misinformation [68,69]. In Nigeria, education levels were found to be a significant predictor of variation in internet use, with 62.2% of

individuals with a post-secondary education having used the internet compared to 7.6% of individuals below secondary education [70]. In one report, 44% of more educated individuals in Nigeria owned a smartphone compared with 8% among less educated individuals, and are thus more actively engaged in social media [71]. Consequently, they are exposed to a constant stream of information and misinformation [72], which, may in turn influence their likelihood of not willing to accept the vaccine. This disparity in exposure to misinformation could be a significant contributing factor underlying the observed results. Studies in South Africa and elsewhere have found similar results where tertiary education levels were associated with lower vaccine willingness [50,73,74]. This finding may be explained by the confounding effect of digital misinformation on education levels among those with access to social media [70,75].

Our study found that increasing proportion of male household members was associated with a significant increase in the willingness to accept a free COVID-19 vaccine. Households made up of mostly women were less likely to receive a vaccine. This confirms the findings of previous studies that women were less likely than men to accept the COVID-19 vaccine [43,47,76–78]. Specific to Nigeria, gender norms, roles, and the patriarchal nature of the society, particularly as it pertains to decision making at the household level, may partly explain this observation [35]. This may also be exacerbated by the spread of gender-specific misinformation suggesting a link between COVID-19 vaccines and infertility [79]. These rumours, which may disproportionately affect households with higher proportions of women, could contribute to a lower likelihood of COVID-19 vaccine acceptance among such households [32].

Although one study from Nigeria reached similar conclusions as ours demonstrating geographical zone as a predictive factor for the willingness to vaccinate against COVID-19 [34], others did not [30,31,33]. Conflicting findings on the influence of geopolitical zoning on COVID-19 vaccine acceptance in a country is not uncommon, and have been reported in Ethiopia [80], India [81], USA [82], China [83,84], and South Africa [85]. Nevertheless, our finding of a higher odds of willingness to receive a free COVID-19 vaccine in Northern Nigeria was unexpected given the history of boycott of polio immunization programs in 2003 [26], an overall distrust of western medicines in general as seen with the Pfizer Trovan trial scandal in 1996 [86], and previous reports of low COVID-19 vaccine acceptance intentions (29% rate) very early in the pandemic [87]. The lower willingness to vaccinate against COVID-19 among households in Southern Nigeria compared to the North-Central region might be driven by the profound levels of online dis−/mis-information about the COVID-19 vaccines in the country [32,72,79,88–90], compounded by the high rate of internet and social media usage in the Southern regions compared to the North [91]. Furthermore, epidemiological estimates from the Nigeria Centre for Disease Control and Prevention around the peak of the pandemic suggest a relatively high number of confirmed COVID-19 cases in the Northern part of the country, including in the capital city of Abuja, compared to the South [92]. We speculate that this may have increased the risk perception of COVID-19 in the North and potentially influenced people's willingness to want to accept the vaccine when it became available [30,33].

Strengths and limitations

This study analyzes data from a nationally administered survey covering a large and diverse population from all six geopolitical zones of Nigeria, making the findings of the study generalizable to the general population. To reduce potential bias due to non-response or sampling error, cross-sectional household weights were applied to ensure that they are nationally representative. Readers should interpret the results bearing in mind that the NLPS survey was conducted at the household level, with a knowledgeable adult member or head per household responding on behalf of the entire household. While most of the data were collected for households rather than individuals, attitudes towards COVID-19 vaccine may vary from person to person. Therefore, further analysis using a nationally representative sample among all adult members in a household is needed to confirm these finding. Additionally, the results of the analysis may be biased towards households with access to telephones.

We acknowledge that the reported COVID-19 cases and deaths analyzed in our study may underestimate the true burden due to the global decline in testing and surveillance efforts over the past few years [93]. While the absolute numbers of the COVID-19 burden may be underestimated, we believe the relative patterns and associations identified are likely to hold true based on the available data. We recognize the need for continuous improvement of surveillance and reporting systems to obtain a more comprehensive understanding of the pandemic's impact.

Importantly, our study data were collected prior to the availability of COVID-19 vaccine in Nigeria. Consequently, the associations found in our analysis may not fully reflect the current context in which vaccines are available, COVID-19 infection rates have changed, testing and surveillance efforts have reduced, public health policies have evolved, and the volume of information and misinformation potentially influencing public perceptions has increased. These factors, together with the socio-economic impacts of the pandemic, may have altered risk perceptions, public awareness, and attitudes towards vaccination. Given these changes, it is challenging to assume that the associations identified in our analysis would remain identical today. For instance, factors related to vaccine safety concerns might be less prominent due to widespread vaccine use and accumulated safety data. Trust in health authorities and exposure to misinformation could have evolving influences on willingness. Conversely, socio-economic factors might play a larger role due to the prolonged economic impact of the pandemic. Although the degree of influence of some fundamental factors such as education level, health literacy, and geographic location might change, their relevance is likely to persist.

Despite these limitations that may affect direct generalizability to the current period, we believe our findings offer valuable insights. Our study provides a crucial baseline for understanding pre-vaccine attitudes and factors influencing vaccine willingness in Nigeria. It can complement and inform future research efforts that analyze more recent data, providing a comprehensive understanding of the evolving factors influencing vaccine acceptance. To build upon our findings and address these limitations, we recommend that future research conduct follow-up surveys to investigate the impact of vaccine availability, real-life vaccination experiences, and evolving pandemic dynamics on vaccine willingness and uptake. Such studies would be particularly valuable in tracking how vaccine attitudes have changed over time and identifying which factors remain influential.

5. Conclusion

In conclusion, our analysis shows that the education level of household heads, proportion of male household members, and geopolitical zone of residence consistently and significantly influenced willingness to accept a free COVID-19 vaccine in Nigeria over time. These factors should be carefully considered and targeted when designing public health programs to inform early-stage strategies that address underlying vaccine hesitancy, improve vaccine uptake, promote ongoing COVID-19 vaccination efforts, and potentially enhance other immunization programs in Nigeria. Tailored strategies, targeted communication campaigns, involvement of trusted community figures, and recognition of cultural nuances are pivotal for navigating the diverse socio-cultural contexts relevant to the success of vaccination programmes. By understanding and addressing these multifaceted influences, policymakers can refine resource allocation and program design decisions for vaccination initiatives. This approach can foster greater public acceptance and contribute significantly to successful pandemic preparedness and response.

Funding

This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

Disclaimer

All interpretations, opinions, and conclusions drawn in this manuscript are those of the authors, and do not reflect the opinions or policies of the data collector or the funders.

Credit authorship contribution statement

Oghenowede Eyawo: Writing – review & editing, Writing – original draft, Visualization, Validation, Supervision, Software, Resources, Project administration, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Uchechukwu Chidiebere Ugoji:** Writing – review & editing, Visualization, Validation, Methodology, Data curation, Conceptualization. **Shenyi Pan:** Writing – review & editing, Writing – original draft, Visualization, Validation, Software, Methodology, Formal analysis, Data curation, Conceptualization. **Patrick Oyibo:** Writing – review & editing, Visualization, Validation, Software, Methodology, Investigation, Data curation. **Amtull Rehman:** Writing – review & editing, Visualization, Validation, Software, Methodology, Investigation, Data curation. **Mishel Mahboob:** Writing – review & editing, Visualization, Validation, Software, Methodology, Investigation, Data curation. **Olapeju Adefunke Esimai:** Writing – review & editing, Visualization, Validation, Software, Methodology, Investigation, Data curation.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability statement

The data used for this study are publicly available upon request from the World Bank Microdata Library (https://microdata.worldbank.org/index.php/catalog/3712/).

All authors attest they meet the ICMJE criteria for authorship.

Acknowledgement

We thank the National Bureau of Statistics and the World Bank for providing access to the data used in this analysis.

References

[1] Watson OJ, Barnsley G, Toor J, Hogan AB, Winskill P, Ghani AC. Global impact of the first year of COVID-19 vaccination: a mathematical modelling study. Lancet Infect Dis 2022;22(9):1293–302.
[2] Pollard CA, Morran MP, Nestor-Kalinoski AL. The COVID-19 pandemic: a global health crisis. Physiol Genomics 2020;52(11):549–57.
[3] Fineberg HV. The toll of COVID-19. JAMA 2020;324(15):1502–3.
[4] World Health Organization. Coronavirus (COVID-19) Dashboard [Available from, https://covid19.who.int/; 2023.
[5] Sacco PL, De Domenico M. Public health challenges and opportunities after COVID-19. Bull World Health Organ 2021;99(7):529–35.
[6] World Health Organization. Statement on the fifteenth meeting of the IHR. Emergency Committee on the COVID-19 pandemic 2023 [Available from: https://www.who.int/news/item/05-05-2023-statement-on-the-fifteenth-meeting-of-the-international-health-regulations-(2005)-emergency-committee-regarding-the-coronavirus-disease-(covid-19)-pandemic; 2005.
[7] World Health Organization. Vaccines and Immunization. Available from: https://www.who.int/health-topics/vaccines-and-immunization#tab=tab_1; 2023.
[8] Bloom DE. The value of vaccination. Adv Exp Med Biol 2011;697:1–8.
[9] World Economic Forum. This is how much work is left to vaccinate the world against COVID-19. Available from: https://www.weforum.org/agenda/2021/08/this-is-how-much-work-is-left-to-vaccinate-the-world/; 2021.
[10] Tatar M, Shoorekchali JM, Faraji MR, Wilson FA. International COVID-19 vaccine inequality amid the pandemic: perpetuating a global crisis? J Glob Health 2021;11:03086.
[11] Mathieu E, Ritchie H, Rodés-Guirao L, Appel C, Giattino C, Hasell J, et al. Coronavirus (COVID-19) Vaccinations. Available from: https://ourworldindata.org/covid-vaccinations; 2020.
[12] Mathieu E, Ritchie H, Ortiz-Ospina E, Roser M, Hasell J, Appel C, et al. A global database of COVID-19 vaccinations. Nat Hum Behav 2021;5(7):947–53.
[13] World Health Organization. WHO COVID-19 dashboard: COVID-19 vaccination. Nigeria Data 2023 [cited 2024 June 15]. Available from: https://covid19.who.int/region/afro/country/ng.
[14] Worldometer. Countries in the world by population 2023. Available from: https://www.worldometers.info/world-population/population-by-country/; 2024.
[15] Olu-Abiodun O, Abiodun O, Okafor N. COVID-19 vaccination in Nigeria: a rapid review of vaccine acceptance rate and the associated factors. PLoS One 2022;17(5):e0267691.
[16] Nigeria Centre for Disease Control. COVID-19 Nigeria. Available from: https://covid19.ncdc.gov.ng; 2021.
[17] Adesegun OA, Binuyo T, Adeyemi O, Ehioghae O, Rabor DF, Amusan O, et al. The COVID-19 crisis in sub-Saharan Africa: knowledge, attitudes, and practices of the Nigerian public. Am J Trop Med Hyg 2020;103(5):1997–2004.
[18] Lucero-Prisno 3rd DE, Adebisi YA, Lin X. Current efforts and challenges facing responses to 2019-nCoV in Africa. Glob Health Res Policy 2020;5:21.
[19] World Health Organization. Ten threats to global health in 2019. Available from: https://www.who.int/news-room/spotlight/ten-threats-to-global-health-in-2019; 2021.
[20] Larson HJ, Jarrett C, Eckersberger E, Smith DM, Paterson P. Understanding vaccine hesitancy around vaccines and vaccination from a global perspective: a systematic review of published literature, 2007-2012. Vaccine 2014;32(19):2150–9.
[21] World Health Organization. Vaccine acceptance is the next hurdle. Available from: https://www.who.int/news-room/feature-stories/detail/vaccine-acceptance-is-the-next-hurdle; 2020.
[22] Akande OW, Igumbor EU, Elimian KO, Ohonsi CE, Nwozor L, Oden O, et al. COVID-19 vaccine effectiveness studies in Nigeria: quo vadis? J Glob Health 2022;12:03055.
[23] Taylor S, Khan M, Muhammad A, Akpala O, van Strien M, Morry C, et al. Understanding vaccine hesitancy in polio eradication in northern Nigeria. Vaccine 2017;35(47):6438–43.
[24] Ogundele OA, Ogundele T, Beloved O. Vaccine hesitancy in Nigeria: contributing factors – way forward. Nigerian J General Practice 2020;18(1):1–4.
[25] Afolabi AA, Ilesanmi OS. Dealing with vaccine hesitancy in Africa: the prospective COVID-19 vaccine context. Pan Afr Med J 2021;38:3.
[26] Jegede AS. What led to the Nigerian boycott of the polio vaccination campaign? PLoS Med 2007;4(3):e73.
[27] Hooper M, Napoles AM, Perez-Stable EJ. No populations left behind: vaccine hesitancy and equitable diffusion of effective COVID-19 vaccines. J Gen Intern Med 2021;36(7):2130–3.
[28] Harapan H, Anwar S, Yufika A, Sharun K, Gachabayov M, Fahriani M, et al. Vaccine hesitancy among communities in ten countries in Asia, Africa, and South America during the COVID-19 pandemic. Pathog Glob Health 2022;116(4):236–43.
[29] Eze UA, Ndoh KI, Ibisola BA, Onwuliri CD, Osiyemi A, Ude N, et al. Determinants for acceptance of COVID-19 vaccine in Nigeria. Cureus 2021;13(11):e19801.
[30] Adejumo OA, Ogundele OA, Madubuko CR, Oluwafemi RO, Okoye OC, Okonkwo KC, et al. Perceptions of the COVID-19 vaccine and willingness to receive vaccination among health workers in Nigeria. Osong Public Health Res Perspect 2021;12(4):236–43.
[31] Adedeji-Adenola H, Olugbake OA, Adeosun SA. Factors influencing COVID-19 vaccine uptake among adults in Nigeria. PLoS One 2022;17(2):e0264371.
[32] Oyekale AS. Factors influencing willingness to be vaccinated against COVID-19 in Nigeria. Int J Environ Res Public Health 2022;19(11).
[33] Al-Mustapha AI, Okechukwu O, Olayinka A, Muhammed OR, Oyewo M, Owoicho SA, et al. A national survey of COVID-19 vaccine acceptance in Nigeria. Vaccine 2022;40(33):4726–31.
[34] Adigwe OP. COVID-19 vaccine hesitancy and willingness to pay: emergent factors from a cross-sectional study in Nigeria. Vaccine X 2021;9:100112.
[35] Okafor IP, Chukwudi CL, Igwilo UU, Ogunnowo BE. "men are the head of the family, the dominant head": a mixed method study of male involvement in maternal and child health in a patriarchal setting, Western Nigeria. PLoS One 2022;17(10):e0276059.
[36] Dogo S. The Nigerian patriarchy: when and how. Cultural and Religious Study 2014;2(5):263–75.
[37] National Bureau of Statistics. Nigeria COVID-19 National Longitudinal Phone Survey (COVID-19 NLPS) 2020–2021, Phase 1. Dataset downloaded from World Bank Microlibrary on Oct. 20, 2023. Available from: https://microdata.worldbank.org/index.php/catalog/3712; 2021.
[38] Venables WN, Ripley BD. Modern applied statistics with S. 4th ed. Springer; 2002.
[39] Syan SK, Gohari MR, Levitt EE, Belisario K, Gillard J, DeJesus J, et al. COVID-19 vaccine perceptions and differences by sex, age, and education in 1,367 community adults in Ontario. Front Public Health 2021;9:719665.
[40] Chaudhuri K, Chakrabarti A, Chandan JS, Bandyopadhyay S. COVID-19 vaccine hesitancy in the UK: a longitudinal household cross-sectional study. BMC Public Health 2022;22(1):104.

[41] Liu D, Luo L, Xie F, Yu Z, Ma ZF, Wang Y, et al. Factors associated with the willingness and acceptance of SARS-CoV-2 vaccine from adult subjects in China. Hum Vaccin Immunother 2021;17(8):2405–14.
[42] Islam F, Agarwalla R, Panda M, Alvi Y, Singh V, Debroy A, et al. Assessment of the knowledge, preferences and concern regarding the prospective COVID-19 vaccine among adults residing in New Delhi, India - a cross-sectional study. J Family Med Prim Care 2021;10(6):2369–75.
[43] Moore D, Nehab MF, Camacho KG, Reis AT, Junqueira-Marinho MF, Abramov DM, et al. Low COVID-19 vaccine hesitancy in Brazil. Vaccine 2021;39(42):6262–8.
[44] Harapan H, Wagner AL, Yufika A, Winardi W, Anwar S, Gan AK, et al. Acceptance of a COVID-19 vaccine in Southeast Asia: a cross-sectional study in Indonesia. Front Public Health 2020;8:381.
[45] Ghaznavi C, Yoneoka D, Kawashima T, Eguchi A, Murakami M, Gilmour S, et al. Factors associated with reversals of COVID-19 vaccination willingness: results from two longitudinal, national surveys in Japan 2021-2022. Lancet Reg Health West Pac 2022;27:100540.
[46] Umakanthan S, Lawrence S. Predictors of COVID-19 vaccine hesitancy in Germany: a cross-sectional, population-based study. Postgrad Med J 2022;98(1164):756–64.
[47] Kelly BJ, Southwell BG, McCormack LA, Bann CM, MacDonald PDM, Frasier AM, et al. Predictors of willingness to get a COVID-19 vaccine in the U.S. BMC Infect Dis 2021;21(1):338.
[48] Belsti Y, Gela YY, Akalu Y, Dagnew B, Getnet M, Abdu Seid M, et al. Willingness of Ethiopian population to receive COVID-19 vaccine. J Multidiscip Healthc 2021;14:1233–43.
[49] Echoru I, Ajambo PD, Keirania E, Bukenya EEM. Sociodemographic factors associated with acceptance of COVID-19 vaccine and clinical trials in Uganda: a cross-sectional study in western Uganda. BMC Public Health 2021;21(1):1106.
[50] Burger R, Kohler T, Golos AM, Buttenheim AM, English R, Tameris M, et al. Longitudinal changes in COVID-19 vaccination intent among South African adults: evidence from the NIDS-CRAM panel survey, February to may 2021. BMC Public Health 2022;22(1):422.
[51] Nehal KR, Steendam LM, Campos Ponce M, van der Hoeven M, Smit GSA. Worldwide vaccination willingness for COVID-19: a systematic review and Meta-analysis. Vaccines (Basel) 2021;9(10).
[52] Daly M, Robinson E. Willingness to vaccinate against COVID-19 in the U.S.: representative longitudinal evidence from April to October 2020. Am J Prev Med 2021;60(6):766–73.
[53] Malik AA, McFadden SM, Elharake J, Omer SB. Determinants of COVID-19 vaccine acceptance in the US. EClinical Medicine 2020;26:100495.
[54] Ridenhour BJ, Sarathchandra D, Seamon E, Brown H, Leung FY, Johnson-Leon M, et al. Effects of trust, risk perception, and health behavior on COVID-19 disease burden: evidence from a multi-state US survey. PLoS One 2022;17(5):e0268302.
[55] Nusair MB, Arabyat R, Khasawneh R, Al-Azzam S, Nusir AT, Alhayek MY. Assessment of the relationship between COVID-19 risk perception and vaccine acceptance: a cross-sectional study in Jordan. Hum Vaccin Immunother 2022;18(1):2017734.
[56] Joshi A, Kaur M, Kaur R, Grover A, Nash D, El-Mohandes A. Predictors of COVID-19 vaccine acceptance, intention, and hesitancy: a scoping review. Front Public Health 2021;9:698111.
[57] Freeman D, Loe BS, Chadwick A, Vaccari C, Waite F, Rosebrock L, et al. COVID-19 vaccine hesitancy in the UK: the Oxford coronavirus explanations, attitudes, and narratives survey (oceans) II. Psychol Med 2022;52(14):3127–41.
[58] Holzmann-Littig C, Braunisch MC, Kranke P, Popp M, Seeber C, Fichtner F, et al. COVID-19 vaccination acceptance and hesitancy among healthcare workers in Germany. Vaccines (Basel) 2021;9(7).
[59] Thomson A, Robinson K, Vallee-Tourangeau G. The 5As: a practical taxonomy for the determinants of vaccine uptake. Vaccine 2016;34(8):1018–24.
[60] Dube E, Bettinger JA, Fisher WA, Naus M, Mahmud SM, Hilderman T. Vaccine acceptance, hesitancy and refusal in Canada: challenges and potential approaches. Can Commun Dis Rep 2016;42(12):246–51.
[61] Ekwebelem OC, Yunusa I, Onyeaka H, Ekwebelem NC, Nnorom-Dike O. COVID-19 vaccine rollout: will it affect the rates of vaccine hesitancy in Africa? Public Health 2021;197:e18–9.
[62] Nachega JB, Sam-Agudu NA, Masekela R, van der Zalm MM, Nsanzimana S, Condo J, et al. Addressing challenges to rolling out COVID-19 vaccines in African countries. Lancet Glob Health 2021;9(6):e746–8.
[63] Adeniyi OV, Stead D, Singata-Madliki M, Batting J, Wright M, Jelliman E, et al. Acceptance of COVID-19 vaccine among the healthcare Workers in the Eastern Cape, South Africa: a cross sectional study. Vaccines (Basel) 2021;9(6).
[64] Loomba S, de Figueiredo A, Piatek SJ, de Graaf K, Larson HJ. Measuring the impact of COVID-19 vaccine misinformation on vaccination intent in the UK and USA. Nat Hum Behav 2021;5(3):337–48.
[65] Kreps SE, Kriner DL. Model uncertainty, political contestation, and public trust in science: evidence from the COVID-19 pandemic. Sci Adv 2020;6(43).
[66] Warren RC, Forrow L, Hodge Sr DA, Truog RD. Trustworthiness before trust - Covid-19 vaccine trials and the black community. N Engl J Med 2020;383(22):e121.
[67] Schmelz K. Enforcement may crowd out voluntary support for COVID-19 policies, especially where trust in government is weak and in a liberal society. Proceedings of the National Academy of Sciences of the United States of America118(1); 2021.
[68] Apuke OD, Omar B. Social media affordances and information abundance: enabling fake news sharing during the COVID-19 health crisis. Health Informatics J 2021;27(3):14604582211021470.
[69] Obi-Ani Ngozika A, CAMCI.. Social media and the Covid-19 pandemic: observations from Nigeria. Cogent Arts & Humanities 2020;7(1).
[70] U.S. Agency for Global Media. Contemporary Media Use in Nigeria 2014. Available from: https://www.usagm.gov/2014/04/30/bbg-research-series-contemporary-media-use-in-nigeria/.
[71] Silver, L.J.C. Internet connectivity seen as having positive impact on life in sub-saharan africa: Pew research center 2018. Available from: https://www.pewresearch.org/global/2018/10/09/majorities-in-sub-saharan-africa-own-mobile-phones-but-smartphone-adoption-is-modest/.
[72] Wonodi C, Obi-Jeff C, Adewumi F, Keluo-Udeke SC, Gur-Arie R, Krubiner C, et al. Conspiracy theories and misinformation about COVID-19 in Nigeria: implications for vaccine demand generation communications. Vaccine 2022;40(13):2114–21.
[73] Runciman CR. Benjamin & Alexander, Kate & Bohler-Muller, Narnia & Bekker, Martin. Willingness to take a Covid-19 vaccine: A research briefing. 2021.
[74] Tlale LB, Gabaitiri L, Totolo LK, Smith G, Puswane-Katse O, Ramonna E, et al. Acceptance rate and risk perception towards the COVID-19 vaccine in Botswana. PLoS One 2022;17(2):e0263375.
[75] Silver L. Smartphone ownership is growing rapidly around the world, but not always equally. 2019.
[76] Ahmed MAM, Colebunders R, Gele AA, Farah AA, Osman S, Guled IA, et al. COVID-19 vaccine acceptability and adherence to preventive measures in Somalia: results of an online survey. Vaccines (Basel) 2021;9(6).
[77] Acheampong T, Akorsikumah EA, Osae-Kwapong J, Khalid M, Appiah A, Amuasi JH. Examining vaccine hesitancy in sub-Saharan Africa: a survey of the knowledge and attitudes among adults to receive COVID-19 vaccines in Ghana. Vaccines (Basel) 2021;9(8).
[78] Wong LP, Alias H, Wong PF, Lee HY, AbuBakar S. The use of the health belief model to assess predictors of intent to receive the COVID-19 vaccine and willingness to pay. Hum Vaccin Immunother 2020;16(9):2204–14.
[79] Pertwee E, Simas C, Larson HJ. An epidemic of uncertainty: rumors, conspiracy theories and vaccine hesitancy. Nat Med 2022;28(3):456–9.
[80] Yehualashet DE, Seboka BT, Tesfa GA, Mamo TT, Yawo MN, Hailegebreal S. Prevalence and determinants of COVID-19 vaccine hesitancy among the Ethiopian population: a systematic review. Risk Manag Healthc Policy 2022;15:1433–45.
[81] Kumar G, Jena S, Snigdha NT, Basha S, Narayanan JK, Luke AM. Acceptance of COVID-19 vaccines in India: a systematic review and Meta-analysis. Vaccines (Basel) 2023;11(5).
[82] Matas JL, Landry LG, Lee L, Hansel S, Coudray MS, Mata-McMurry LV, et al. Demographic determinants and geographical variability of COVID-19 vaccine hesitancy in underserved communities: cross-sectional study. JMIR Public Health Surveill 2023;9:e34163.
[83] Wang J, Ji Q, Dong S, Zhao S, Li X, Zhu Q, et al. Factors influencing vaccine hesitancy in China: a qualitative study. Vaccines (Basel) 2021;9(11).
[84] Shui X, Wang F, Li L, Liang Q. COVID-19 vaccine acceptance among healthcare workers in China: a systematic review and meta-analysis. PLoS One 2022;17(8):e0273112.
[85] Kollamparambil U, Oyenubi A, Nwosu C. COVID19 vaccine intentions in South Africa: health communication strategy to address vaccine hesitancy. BMC Public Health 2021;21(1):2113.
[86] Wise J. Pfizer accused of testing new drug without ethical approval. BMJ 2001;322(7280):194.
[87] Reuben RC, Danladi MMA, Saleh DA, Ejembi PE. Knowledge, attitudes and practices towards COVID-19: an epidemiological survey in north-Central Nigeria. J Community Health 2021;46(3):457–70.
[88] Islam MS, Kamal AM, Kabir A, Southern DL, Khan SH, Hasan SMM, et al. COVID-19 vaccine rumors and conspiracy theories: the need for cognitive inoculation against misinformation to improve vaccine adherence. PLoS One 2021;16(5):e0251605.
[89] Osuagwu UL, Mashige KP, Ovenseri-Ogbomo G, Envuladu EA, Abu EK, Miner CA, et al. The impact of information sources on COVID-19 vaccine hesitancy and resistance in sub-Saharan Africa. BMC Public Health 2023;23(1):38.
[90] Roozenbeek J, Schneider CR, Dryhurst S, Kerr J, Freeman ALJ, Recchia G, et al. Susceptibility to misinformation about COVID-19 around the world. R Soc Open Sci 2020;7(10):201199.
[91] Adeleke R. Digital divide in Nigeria: the role of regional differentials. Afr J Sci Technol Innov Dev 2021;13(3).
[92] Nigeria Centre for Disease Control and Prevention. Situation Reports: An update of COVID-19 outbreak in Nigeria. Available from: https://ncdc.gov.ng/diseases/sitreps/?cat=14&name=An%20update%20of%20COVID-19%20outbreak%20in%20Nigeria.
[93] World Health Organization (WHO). Weekly epidemiological update on COVID-19 - 10 August 2023. 155 2023 Available from:. https://www.who.int/publications/m/item/weekly-epidemiological-update-on-covid-19—10-august-2023.