International Journal of Multidisciplinary Research in Biotechnology, Pharmacy, Dental and Medical Sciences (IJMRBPDMS)

Interplay of Glucose, Vitamin C, and Adiponectin in Gestational Diabetes Mellitus: Insights from Kaduna State, Nigeria

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ABSTRACT

Background: Gestational diabetes mellitus (GDM) is a pregnancy-related metabolic disorder characterized by glucose intolerance and insulin resistance, usually diagnosed during the second or third trimester. It increases the risk of adverse maternal and fetal outcomes if not properly managed. This study evaluated glucose, vitamin C, and adiponectin levels among women with GDM in Kaduna State, Nigeria.

Methods: A case-control study involving 160 women aged 18–40 years was conducted, comprising 60 women with GDM, 50 healthy pregnant women, and 50 healthy non-pregnant women. Participants were recruited from selected hospitals in Kaduna State. Socio-demographic and clinical data were collected using a structured questionnaire. GDM was diagnosed using a 50 g oral glucose challenge test followed by a 75 g oral glucose tolerance test. Venous blood samples were collected for biochemical analysis. Data were analyzed using appropriate statistical methods, with significance set at $p < 0.05$.

Results: Women with GDM had significantly lower adiponectin levels than both control groups ($p < 0.05$). During the oral glucose challenge test, adiponectin levels were highest in healthy pregnant women (10.13 ± 0.28), followed by healthy non-pregnant women (6.51 ± 0.24), and lowest in women with GDM (4.33 ± 0.22). Similar trends were observed following the oral glucose tolerance test.

Conclusion: Reduced adiponectin levels were strongly associated with GDM, suggesting that adiponectin may serve as a potential biomarker for early detection and improved metabolic monitoring of women at risk of gestational diabetes in Nigeria.

Keywords: *Gestational diabetes mellitus, adiponectin, vitamin C, glucose, oxidative stress, Nigeria*

Article Info
Received: 15 August 2026, received in revised form: 25 Agust 2026, accepted: 05 September 2026,
available online: 08 September 2026; Volume: 2; Issue: 9; Pages: 01-11.

Citation: Dennis, A., 2026. Interplay of Glucose, Vitamin C, and Adiponectin in Gestational Diabetes Mellitus: Insights from Kaduna State, Nigeria. *International Journal of Multidisciplinary Research in Biotechnology, Pharmacy, Dental and Medical Sciences (IJMRBPDMS)* 2(9): 01-11.
DOI:

Introduction

The ever-increasing prevalence of diabetes mellitus (DM) which is grossly linked to urbanization and industrialization possess a serious global health challenge and most likely increases the risk for GDM (Macaulay *et al.*,2014). Gestational Diabetes Mellitus predisposes the fetus to abnormal glucose intolerance which may in turn predispose the child into developing type 2 Diabetes Mellitus later in life (Kim *et al.*, 2011). The epidemiology, morbidity and mortality figures for GDM in Africa are believed to be under-reported. Due to poor funding for health, inefficiency in policy implementation and lack of political will, most facilities in Africa still under take selective screening for pregnant women. Past histories or risk factors are commonly used during plasma glucose determination, even though this approach is not usually sufficient for sensitive and specific detection of GDM and often there is no optimal management of this disorder (Saunders *et al.*, 2017). However, early intervention requires an appropriate detection procedure in which blood glucose monitoring is always necessary, so as to evaluate the effectiveness of care and the need for modifications.

Pregnancy-induced glucose intolerance (GDM) is a condition where the body cannot digest carbohydrates effectively and 14% of pregnant women have been documented to have GDM in Bangladesh (Lu, et al., 2019).Those who develop glucose intolerance during pregnancy as well as those who were not diagnosed before becoming pregnant are also included in this definition of GDM. There are 131,000 American women already recorded, who had complicated pregnancies which is likely due to Diabetes Mellitus representing about 3.3% of all live births in 2002 and these women tended to have GDM with a large proportion likely not to have been previously diagnosed of Type 2 DM (Monteiro et al., 2022). Women within childbearing age are at the greatest risk of complications related to gestational diabetes, which can lead to serious complications for the mother and her baby (Crowther et al., 2022). Although, for offspring from GDM mothers, A greater incidence of congenital abnormalities and perinatal mortality as well as morbidity has been seen in them with respiratory distress syndrome, hypoglycemia, and hyperbilirubinemia (Plows, Reynolds, Vickers, Baker, & Stanley, 2019). Mothers may suffer physical insults and become hypertensive and polyhydramniotic as a result of that, obesity cases have increased in recent years, diabetes mellitus and cardiovascular diseases are becoming more prevalent also (Ottanelli, *et al.*, 2022).

Adiponectin (a protein derived from adipose tissue) has been highlighted to play a pivotal role in breakdown of glucose and lipid. It also serves as a measure for metabolic disorders, insulin sensitivity, and adiposity also (Koszowska et al., 2014). It is a fat-derived hormone whose circulatory levels and functionality have been associated with obesity-linked diseases, insulin secretion and sensitivity as well as blood glucose regulation (Yamauchi and Kadowaki, 2013). The mediating role of Adiponectin has to do with its metabolic functions and the changes in Adiponectin levels which is usually observed after a meal, exercise and lipid-lowering treatment (Christou and Kiortsis, 2013).

Adiponectin is known to plays a crucial role in chronic diseases, food intake as well as energy metabolism. Over-secretion of this hormone is found to be associated with obesity-related complications. Most of the available kinds of literature concerning Adiponectin were from studies on other races aside from Africans and the few African studies, there is paucity of data on Nigerians. There is also the continuous effort to identify as well as to provide the best treatment plan for GDM not with 75g OGTT alone but with 50g OGCT, having increased sensitivity for GDM analysis, it can also be applied in low to medium prevalence setting (Bogdanet, O'Shea, Lyons, Shafat, & Dunne, 2020; Landon et al., 2002; Shub et al., 2019).

The increasing trend of GDM and its associated complications makes it pertinent to investigate the pattern and relationship(s) that may exist between TAS, Adiponectin, Lipid profiles Vit. C and the antioxidant enzymes levels in GDM subjects

Materials and Methods

Study Area

Figure 1 showed the location of Kaduna State in Nigeria Coordinates: 10°20′N7°45′E and . Figure 2 showed the Map of Kaduna State showing all the Local Government Areas. The study area is Kaduna, the capital of Kaduna State. The state is located at the Northern part of Nigeria's High Plains. The vegetation cover is Sudan Savannah type, characterized by scattered short trees, shrubs and grasses. The soil is mostly loamy to sandy type. A substantial amount of clay is found also Kaduna State consists of twenty-three (23) Local Government Areas. It consist of a total of 46,053 km2 (17,781 sq meter) Area rank 4th of 36. Its population (2006 census) recorded a total of 6,113,503, rank 3rd of 36.

Fig. 1: Location of Kaduna State in Nigeria Coordinates: 10°20′N7°45′E

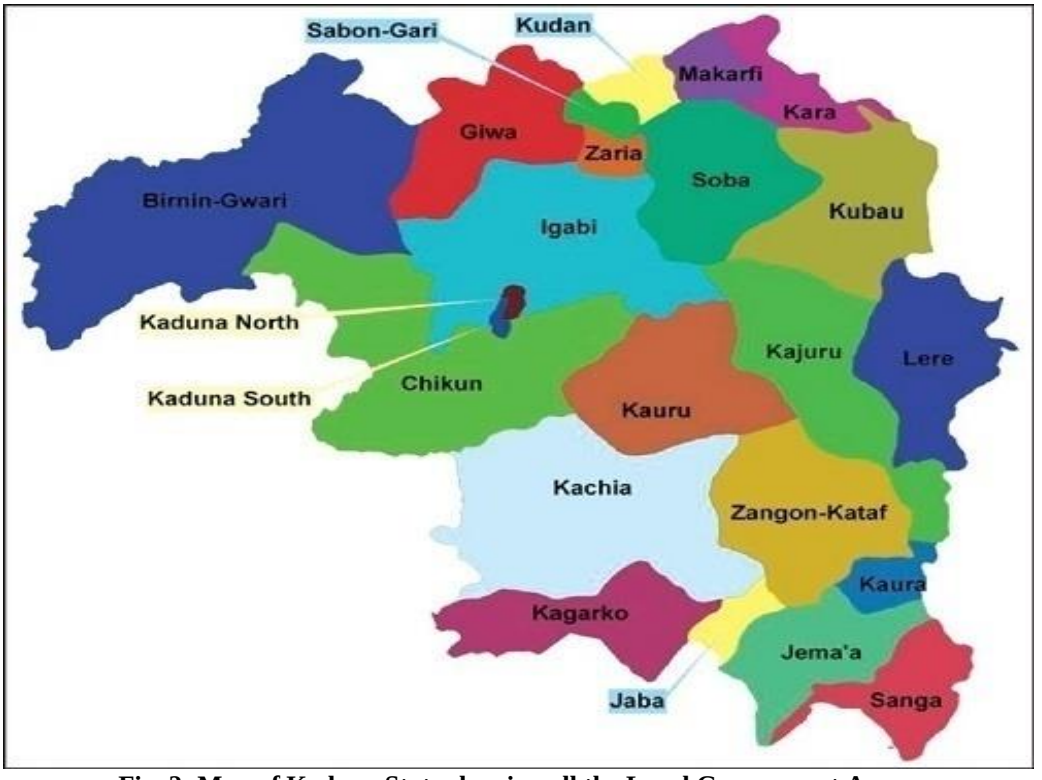

Fig. 2: Map of Kaduna State showing all the Local Government Areas. (Kdsg.gov.ng)

Study Design

This is a case-controlled study, in which a total of 160 subjects between the ages of 18- 40 years were recruited for the study. However, 60 subjects were gestational diabetic women, 50 non-diabetic pregnant women as Control1 all attending Antenatal clinics at Barau Dikko Teaching Hospital, Yusuf Dantsoho Memorial Hospital and Gwamna Awan General Hospital Kaduna State, while 50 apparently healthy non-pregnant non diabetic staff as Control2. Arrangements were made with the clinicians whereby subjects who satisfy the study inclusion criteria were selected. A structured questionnaire developed by the authors for this study was used to collect socio-demographic and clinical data. Vital information including the name, age, ethnic group,

height, weight, blood pressure and pregnancy induced complications were obtained through personal interview followed by blood sample collection.

Inclusion Criteria

All pregnant women within the age of 18–40 years, permanent residents of Kaduna Metropolis, within 24–28 weeks of gestation according to the WHO diagnostic criteria, who give their consent and underwent GDM universal screening, were included in the study. Women who are non- hypertensive and who agreed to participate were also included in the study, were also included. Apparently healthy aged matched non-GDM pregnant women as well as apparently healthy non-pregnant- non-Diabetic women too were included in the study as Control1 & Control2 respectively.

Exclusion Criteria

Primigravidas, Obesse subjects, women who are ≤18 or ≥45 years, pregnant women with chronic hypertension, multiple gestation, pre-eclamsia and eclamsia were excluded in the study. All those who personally declined to give consent for inclusion were also excluded from the study.

Informed Consent

Informed written consent was obtained from all subjects before inclusion using approved protocol given by the Kaduna State Ministry of Health ethical committee.

Ethical Approval

Ethical approval of the study was obtained from the Ethics Committees of the Kaduna State Ministry of Health in accordance with Helsinki declaration (Appendix III).

Sample Size Determination

The sample size would be determined from a standard formula (Kyriazos, 2018).

$$n = \frac{(\mathrm{Z1 - a})2\ \ (\mathrm{P})\ \ \ (1 - \mathrm{P})}{\mathrm{d2}}$$

Where n= minimum sample size;
Z1-a= value of standard normal deviation which at 95% confidence level has been found to be 1.96,
P = the best estimate of the population prevalence obtained from literature review (3.4%)
d = difference between the true population rate and sample that can be tolerated, that is the absolute precision required (in percentage point) on either side of the population i.e. degree of confidence = 0.05

$$\boldsymbol{n} = \frac{(3.8416\ )\ (0.034)\ \ \ (0.9966)}{0.0025}$$

n = 51
Therefore, a total of 51 with 10% (5) of these subjects will be added to the research for attrition making a total of 56 total subjects but for the purpose of these study 60 samples shall be used.

Sampling Techniques

Sampling

Arrangement was made with the clinicians where those subjects who satisfied the study inclusion criteria were selected. A consecutive sampling method in which subjects meeting the criteria for inclusion, were continuously selected until the desired sample size was obtained. Random 50g oral glucose challenge test was carried out followed by fasting 75g OGTT were performed in pregnant women between 24 and 28 weeks of gestation representing GDM and C1. Samples were also collected from apparently healthy non-pregnant, non-Diabetic staff and Students that served as control (C2). Diagnosis of GDM was established according to the diagnostic criteria of the American Diabetes Association 2015. Findings of the blood samples collected from all subjects were fully documented in the proforma (Appendix I). Assessments such as blood pressure (BP), weight (W), height (H) and body mass index (BMI) were also observed

Specimen Collection and Processing

Blood specimen (5ml) for the biochemical measurements, was collected from peripheral vein (antecubital venepuncture). This was done by cleaning the antecubital fossa with methylated spirit and with the application of a tourniquet a few centimeters above the anticubital fossa to distend the veins, an overnight fasting sample of 5ml venous blood was drawn from each subject

and dispensed into plane containers. The coagulated whole blood was centrifuged at 1,000 rpm (Revolution Per minute) for 15 minutes, within 30 minutes of collection. The serum was removed, transferred to Bijou bottles. The samples for glucose, antioxidants, Vitamins C was analyzed immediately. Specimens for other parameters that would not be assayed within 24 hours of collection were stored frozen at -80 0C until the time for analysis.

Equipment

Hettich Universal 32 Centrifuge (Germany) was used to spin blood samples. Beckman Coulter DU-520, general purpose UV/VIS Spectrophotometer (Germany) was used for the measurements of serum glucose & Bio-rad PR 5100 microplate reader was used for measurements of Adiponectin.

Chemicals/Reagents

The chemicals used in this study were procured from Randox Company Limited. All the chemicals and reagents were of analytical grade or higher.

Analytical Methods

Measurement of Serum Glucose

Serum glucose was measured using enzymatic method .

Principle

Glucose is oxidized to hydrogen peroxide (H2O2) and gluconic acid in the presence of glucose oxidase. Hydrogen peroxide in the presence of peroxidase is broken down to water and oxygen. The oxygen released reacts with 4- aminophenazone (4-aminoantipyrine) and phenol to produce a pink colored qsuinoneimine complex that was measured at 505 nm using a spectrophotometer.

$$\beta\text{-D Glucose} + O_2 + H_2O \xrightarrow{\text{Glucose oxidase}} \text{Gluconic acid} + H_2O_2$$

$$H_2O_2 + \text{4-aminophenazone} \xrightarrow{\text{Peroxidase}} \text{Quinone} + 2H_2O$$

Procedure

Into each of clean test tubes labeled test, standard and blank, 0.5 ml glucose solution was placed. Then 0.05 ml of serum sample, standard solution and distilled water was added respectively. These were incubated at 37 0C for 10 minutes and the absorbances were read at 505 nm.

Measurement of Adiponectin

Serum Adiponectin level was analyzed by ELISA, according to the method described by (Dehdashti, 2020).

Principle

Addition of Purified human Adiponectin to the wells combines the Adiponectin with labelled enzyme, which forms antibody-antigen enzyme-antibody complex. The substrate and sulphuric acid when added gives a blue colour which can be measured spectrophotometrically at 450nm. The concentration of Adiponectin in the samples will then be determined by comparing the optical density (OD) of the samples to the standard curve.

Procedure

This assay employs an antibody specific for Human Adiponectin coated on a 96-well plate. Standards and samples are pipetted into the wells and Adiponectin present in a sample is bound to the wells by the immobilized antibody. The wells were washed and biotinylated anti-Human Adiponectin antibody was added. After washing away unbound biotinylated antibody, HRP-conjugated streptavidin is pipetted to the wells. The wells are again washed, a TMB substrate solution is added to the wells and color develops in proportion to the amount of Adiponectin bound. The Stop Solution changes the color from blue to yellow, and the intensity of the color is measured at 450 nm.

Statistical Analysis

The data obtained was treated accordingly using Statistical Program for the Social Sciences (SPSS 17.0) for windows (SPSS Inc, Chicago, 1L). Serum antioxidant status, MDA and serum glucose levels of all the subjects were assessed, compared against age and BMI groups of the subjects using the two tail student's t-test. ANOVA was then used to compare between different groups. Other analytes estimated along with the TAS were correlated to find relationship between them and their effect in controlling GDM. Correlation between TAS, SOD, Catalase, GPx and glucose as well as MDA was carried out using

Pearson's linear correlation analysis. A p-value of equal to or less than 0.05 ($p \leq 0.05$) was considered significant.

Results

THE MEAN BLOOD GLUCOSE LEVELS OF GDM AND CONTROL SUBJECTS.

Table 1 and 2 shows mean values of biochemical parameters in GDM and Controls1 & Control2 subjects according to OGCT (RBG) type and OGTT (FBG & 2HBG) types. The Serum glucose concentrations in GDM patients were all significantly increased ($p \leq 0.05$) when compared to Control1 & Control2 subjects. However, inter group comparism of C1vsC2 reveals, Serum Glucose (RBG, FBG and 2HBG) levels were all similar ($p \geq 0.05$).

Table 1 The mean blood Glucose Levels of GDM and Control Subjects

Parameter(mmol/L)	**GDM** (n = 60)	**C_1** (n = 50)	**C_2** (n = 50)	**F-value**	**p-value**	**GvC_1**	**GvC_2**	**C_1vC_2**
RBG	8.28 ± 0.11^a	5.92 ± 0.16^b	5.49 ± 0.15^b	126.781	0.000	0.000	0.000	0.036
FBG	6.21 ± 0.14^a	4.46 ± 0.10^b	4.58 ± 0.10^c	70.330	0.000	0.000	0.000	0.492
2HBG	8.70 ± 0.13^a	5.82 ± 0.14^b	5.62 ± 0.13^c	174.401	0.000	0.000	0.000	0.324

n=Number of patients, GDM = gestational diabetes mellitus, Control 1= non GDM pregnant women, Control 2 = non diabetic non pregnant, RBG= Random Blood Glucose, FBG= Fasting Blood Glucose, 2HBG= Two Hours Blood Glucose, SEM=standard error of mean and values with different (ab) superscripts are significantly different ($p \leq 0.05$)

Table 2: Blood glucose levels of the GDM patients according to their age groups in both OGCT and OGTT samples.

Parameters (mmol/L)	**≤ 25** (n =17)	**26-35** (n =28)	**≥35** (n =15)	**F-value**	**p-value**	**≤25vs26-35**	**≤25vs≥35**	**26-35vs≥35**
RBG	8.38±0.31	8.38±0.13	7.97±0.14	1.240	0.297	1.000	0.542	0.443
FBG	6.41±0.40	6.06 ±0.14	6.24±0.25	0.522	0.596	0.948	1.000	1.000
2HBG	8.59±0.41	8.81±0.12	8.59±0.15	0.356	0.702	1.000	1.000	1.000

n=Number of patients, GDM = gestational diabetes mellitus, RBG= Random Blood Glucose, FBG= Fasting Blood Glucose, 2HBG= Two Hours Blood Glucose, SEM=standard error of mean and significantly different= ($p \leq 0.05$)

Table 3: TOTAL ANTIOXIDANT STATUS, ADIPONECTIN AND VITAMIN C (MEAN±SEM) ACCORDING TO AGE OF GDM PATIENTS FOR OGCT AND OGTT SAMPLES

Table 3showed the OGCT and OGTT components, the Adiponectin, TAS and Vitamin C levels in GDM patients according to their age distributions were similar ($p \geq 0.05$) in all the age distributions except for Vitamin C in OGTT (2HBG) that was significantly higher ($p \leq 0.05$) in age range of 26 -35 years as compared to ≥35 and ≤25 years. For Adiponectin, TAS and vitamin C intergroup (≤25v26-35, ≤25vs≥35 & 26-35vs≥35) Comparison, similar levels were observed in all the groups.

Table 3: Total Antioxidant Status, Adiponectin and Vitamin C according to age of GDM Patients for OGCT and OGTT Samples

Parameters	**≤ 25 (n = 17)**	**26-35 (n = 28)**	**≥35 (n = 15)**	**F-value**	**p-value**	**≤25vs26-35**	**≤25vs≥35**	**26-35vs≥35**
RBG TAS (µmol/ml)	4.66±0.36	5.13±0.28	5.32±0.39	0.877	0.421	0.918	0.445	1.000
APN (µg/L)	4.94±0.42	5.00±0.33	4.80±0.42	0.065	0.937	1.000	1.000	1.000
Vit.C(mg/ml)	37.62±4.00	30.20±2.48	38.20±3.28	4.751	0.012	0.042	1.000	0.040
FBG TAS (,,)	5.48±0.25	5.69±0.19	5.52±0.23	0.552	0.579	1.000	1.000	1.000
APN(,,)	9.40±0.84	7.75±0.49	8.49±0.70	1.743	0.184	0.203	1.000	1.000

Vit.C(,,)	36.04±4.86	31.76±3.37	23.76±2.25	0.867	0.426	1.000	1.000	0.627
2BGTAS (,,)	5.48±0.29	5.82±0.36	5.41±0.37	0.401	0.672	1.000	1.000	1.000
APN(,,)	5.88±0.69	7.110.53	7.29±0.74	2.459	0.095	0.156	0.185	1.000
Vit.C(,,)	31.92±2.86	33.67±1.97	38.98±3.75	4.543	0.015	1.000	0.095	0.013

n=Number of patients, GDM = gestational diabetes mellitus, RBG= Random Blood Glucose, FBG= Fasting Blood Glucose, 2HBG= Two Hours Blood Glucose, SEM=standard error of mean and significantly different= (p≤ 0.05).

Table 4: ADIPONECTIN, TAS AND VITAMIN C OF GDM AND CONTROL SUBJECTS

Table 4 showed the OGCT and OGTT mean values of Adiponectin (APN), TAS and Vitamin C in GDM patients and Controls 1 & 2 are shown in Table 4.8. The mean values of Adiponectin for both in OGCT and OGTT, was significantly raised (P≤0.05) in C1 as compared to C2 and GDM. An intergroup comparison for OGCT reveals significant difference in GvsC1, GvsC2 as well as C1vsC2.While for OGTT (FBG), Adiponectin level was statistically different between GvsC1& C1vsC2. However, for OGTT (2HBG), the difference was seen between GvsC1. The TAS and Vitamin C levels in OGCT and OGTT (FBG) was significantly increased in (p≤ 0.05) C2 than G and C2 with similar difference existing across all the groups for OGTT (2HBG). Intergroup comparison reveals significant difference between GvC2 andC1vC2for both OGCT and OGTT (FBG) with an insignificant difference between GvsC1, GvC2 and C1vC2.

Table 4: Total Antioxidant Status, Adiponectin and Vitamin C levels of GDM patients and controls for OGCT (RBG) and OGTT (FBS & 2HBG) samples

Parameter	GDM (n = 60)	C_1(n = 50)	C_2(n = 50)	F-value	p- value	GvC_1	GvC_2	C_1vC_2
RBG TAS (µmol/ml)	**5.04±0.19**	**5.62±0.21**	**7.14±0.24**	**26.261**	**0.000***	**0.051***	**0.000***	**0.000***
APN(µg/L)	**4.33±0.22**	**10.13±0.27**	**6.51±0.24**	**122.481**	**0.000***	**0.000***	**0.000***	**0.000***
Vit.C(mg/ml)	**32.53±1.97**	**30.03±2.78**	**73.80±9.31**	**19.854**	**0.000***	**0.742**	**0.000***	**0.000***
FBG TAS(,,)	**5.64±0.14**	**5.39±0.17**	**7.14±0.24**	**11.430**	**0.000***	**0.511**	**0.000***	**0.000***
APN (µg/L)	**8.40±0.38**	**9.98±0.45**	**8.10±0.47**	**5.292**	**0.006***	**0.009***	**0.608**	**0.003***
Vit.C(mg/ml)	**34.78±2.29**	**39.79±3.51**	**44.06±1.50**	**3.345**	**0.035***	**0.161**	**0.010***	**0.253**
2BG TAS (,,)	**5.62±0.21**	**5.78±0.20**	**5.36±0.29**	**0.762**	**0.468**	**0.641**	**0.422**	**0.225**
APN(µg/L)	**6.66±0.38**	**5.36±0.37**	**6.38±0.23**	**4.072**	**0.019***	**0.007***	**0.562**	**0.039***
Vit.C(mg/ml)	**30.70±1.43**	**30.84±3.36**	**25.82±2.43**	**1.338**	**0.265**	**0.967**	**0.152**	**0.159**

Discussion

This study was carried out to determine the Glucose ,vitamin C and Adiponectin level of Gestational Diabetes Mellitus subjects in Kaduna State. A total of 160 subjects consisting of 60 GDM, 50 non-GDM pregnant women and 50 apparently healthy non pregnant women were used for the study. Standard procedures carried out using the 50g OGCT and 75g OGTT according to WHO, 1999 criteria (Rudra, 2019).

The glucose levels for OGCT and OGTT were significantly higher in GDM patients than in non-GDM (Control1) and apparently healthy non-diabetic non-pregnant (Control2) subjects (p ≤ 0.05). This is similar with other studies by Song, (2022) Parast, (2017) Sun, (2021) Guan, (2021) Agarwal, (2018) Milajerdi, (2019) Abualhamael, (2019) that reported significantly higher concentration of blood glucose in GDM than in non-GDM pregnant control subjects. Furthermore, the statistical difference in the blood glucose levels between intergroup (Control1 vs Control2 as well as GDM vs Control1) for OGCT & OGTT are all similar (p≥0.05). This finding, even though some other studies had contradictory findings, like studies by Yao, (2019); Si, (2019); Zhang, (2022) have revealed that, blood glucose for OGTT at 1Hr is not significant but at 2HrBG the difference is significant (p≤0.05). The FBG is significantly higher (p≤0.01) in GDM than Controls (Zhang, 2017; Marei, 2020;

Chen, 2022; Si, 2019). This is expected because of the Gestational Diabetes Mellitus subjects among the study group who are constantly experiencing both metabolic changes as well as hormonal changes going on in their bodies. However, some studies (Bhavadharini, 2016; She, 2022; Rudra, 2019; Eldem, 2021) have revealed, the efficacy of 50g OGCT that is, the 1hour OGCT. Li, (2020) Leblalta, (2022) observed non-significant difference ($p \geq 0.05$) in fasting blood glucose of GDM Patients and non-GDM pregnant Control subjects.

Adiponectin, and Vitamin C levels of the OGCT and each OGTT, were significantly lower in GDM than in C1&2. this is in agreement with the findings of Bogdanet, 2020; Dias, 2021; Vida &Zam-Zam, 2017 Mohammed, 2018. Furthermore, the mean values of Adiponectin for both OGCT and OGTT, was significantly lower ($p \leq 0.05$) in GDM compared to non-GDM pregnant Control1 and non-pregnant non-diabetic Control2. This is in agreement with the findings of (Qingju, 2020; Khosrowbeygi, 2016; De Bortoli, 2016; Fruscalzo, 2015; Cho, 2015; Bogdanet, 2020; Dias, 2021 and Park, 2013) where plasma Adiponectin concentration was lower in GDM patients than in the non-GDM pregnant Control1 and non-diabetic, non-pregnant Control2. Although, Soheilykhah (2009) and Hershenfeld (2019) also, revealed Adiponectin level to be significantly lower in GDM patients than healthy pregnant subjects. This may be due to pregnancy and gestational age, since placenta also secrete Adiponectin, while at the same time, gestation may induce hyperglycaemia (Qiao, 2021; Cho, 2015). When an intergroup comparison was made for OGCT type, it revealed, significant difference in GDM vs Control1, GDM vsControl2 as well as Control1vsControl2. While for OGTT (FBG), Adiponectin level was statistically different between GDM vs non-GDM pregnant Control1 and non-GDM pregnant Control1 vs non-pregnant non-diabetic Control2. However, for OGTT (2HBG), the difference was seen between GDM vs non-GDM pregnant Control1 and this may be due to Adiponectin concentration and its secretion in pregnancy too (Si, 2019). Adiponectin if considered alone, may not be a good determinant for GDM detection except with other parameters like gestational age and Insulin resistance. Adiponectin, a protein that is exclusively secreted from adipocytes, is a potent modulator of glucose and lipid metabolism (Ciroma, 2017; Kim, 2019). It has been observed, that adiponectin was an independent predictor for GDM. As for GDM screening, adiponectin was not as strong a predictor in OGCT. However, with advantage of being less cumbersome, adiponectin could be used for analysis so as to rule out pregnant subjects that at low risk of having GDM (Qiao, 2021).

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The Vitamin C levels in OGCT and OGTT (FBG) were significantly increased ($p \leq 0.05$) in Control2 than GDM and non-GDM Control1 with insignificant difference existing across all the groups (GDM vs Control1, GDM vs Control2 and Control1vsControl2) for the OGTT (2HBG) type. Intergroup comparison reveals significant decrease between GvsC2 and C1vsC2 for both OGCT and OGTT (FBG) with non-significant difference between GDMvsControl1, GDMvControl2 and non-GDM pregnant Control1vs non-diabetic, non-pregnant Control2. However, the present study is in harmony with previous studies by Usluoğullari, (2017) Karacay, (2010) Farrar, (2017) Herath, (2021) Pieczyńska, (2019) Mohammed, (2018) and Atiba, (2014) with findings of significant decrease ($p \leq 0.05$) in serum TAS in GDM than in normal pregnant women and non-pregnant group. On the other hand, (Nuzzo, 2021; Sheldon, 2016; Beyazit, 2020) reported significant increase ($p \leq 0.05$) in Plasma levels of TAS in diabetic women when compared with the control groups. This increase could be as a result of the enhanced generation of oxidative stress which causes a decrease in the level antioxidant capacity in diabetic patients. Also, in line with the results of this study, reports showed that higher maternal serum level of TAS could be a significant predictor of developing GDM (Nuzzo, 2021).

However, the women diagnosed with GDM by the 75g OGTT (2HBG), the mean values of TAS were similar ($p \geq 0.05$) in GDM patients, non-GDM pregnant Control1 and non-pregnant non-diabetic Control2 subjects. Further studies by (Ott, 2018; Khan, 2020; Usluoğullari, 2017; Ozler, 2019; Khalafallah, 2016; Uysal, 2015) revealed similar ($p \leq 0.05$) level of TAS in both GDM and Control subjects. In addition, this study is in agreement with the study of Manoharan, (2019) and Rajendran, (2022) that revealed increased serum TAS in GDM subjects with lower TAS activity. This reveals the link between TAS and oxidative stress occurring in GDM Patients as well as a predictor for developing GDM (Ozler, 2019 and Demirci-Çekiç, 2022). Demirci-Çekiç, (2022) also revealed that, the difference in the level of TAS in GDM and Controls is not significant. This could be due to the various degrees of oxidative stress the mother goes through during pregnancy.

Vitamin C level was significantly lower in GDM subjects compared to non-GDM pregnant Control1 and non-pregnant non-diabetic Control2 groups. Other findings revealed that, antioxidant capacity is lower in women with GDM than apparently healthy pregnant controls, possibly related to lower intakes of vitamins (Parast, 2017; Lyu, 2022). This finding is similar with other reports of (Machairiotis, 2021; Parast, 2017), that revealed significantly low level of Vitamin C in GDM patients than apparently healthy pregnant controls. However, there is a number of conflicting reports in which vitamins C was found to be similar ($p \geq 0.05$) in both GDM and non-GDM pregnant Control1 and non-pregnant non-diabetic Control2 subjects (Daneshzad, 2020; Machairiotis, 2021). The level of Vitamin C is highly beneficial to the pregnant subjects since it is likely to reduce the chances of becoming diabetic (Aljanahi, 2020)

Conclusion

This study provides important insights into the biochemical and clinical characteristics of gestational diabetes mellitus (GDM) among pregnant women in Kaduna State, Nigeria, with implications for clinical management and health policy.

The findings demonstrated that Blood glucose levels were also markedly elevated in GDM subjects, confirming the metabolic dysregulation associated with the condition.

Notably, total adiponectin level and vitamin C levels were significantly reduced in GDM patients, indicating increased oxidative stress and impaired antioxidant defense.

Overall, the study highlights the complex interplay between metabolic and oxidative in GDM. These findings underscore the importance of early detection, comprehensive metabolic monitoring, and targeted antioxidant strategies in the management of GDM. The results will inform healthcare providers and policymakers in developing effective interventions to reduce the burden of GDM and its associated complications in Kaduna State.

Declarations

Ethics approval and consent to participate

This study was conducted in accordance with the ethical principles outlined in the Declaration of Helsinki and in compliance with the National Code of Health Research Ethics of Nigeria. Ethical approval for this study was obtained from the Health Research Ethics Committee (HREC) of the Kaduna State Ministry of Health.

Permission to conduct the study was also obtained from the management of the participating healthcare facilities in Kaduna

State, Nigeria.

Written informed consent was obtained from all participants prior to enrollment in the study. For participants who were unable to read or write, the consent form was explained in their preferred language, and a thumbprint was obtained in the presence of an impartial witness.

Participation in this study was entirely voluntary, and participants were informed of their right to withdraw at any stage without any consequences to their medical care. Confidentiality and anonymity of participants were strictly maintained by assigning unique identification codes and ensuring that no personal identifiers were included in the data analysis or reporting.

All data collected were securely stored and accessed only by the research team. No financial inducement was provided to participants, and the study posed minimal risk, involving only routine sample collection and biochemical analysis.

Consent for Publication

All authors have reviewed and approved the final version of the manuscript and consent to its publication.

Competing Interests

The authors declare that they have no competing interests.

Funding

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

Author Contributions: S.N.K. and AD. wrote the main manuscript text and F.I. , CCF,G.N.,IPK and D.J.prepared tables 1-4. All authors reviewed the manuscript."

Acknowledgements
The authors acknowledge the contributions of researchers whose work formed the basis of this research.

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