



Prevalence Of Glucose-6-Phosphate Dehydrogenase Deficiency in People Living in Katsina Metropolis

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Received on: October, 2023

Revised and Accepted on: November, 2023

Published on: December, 2023

ABSTRACT

Glucose-6-phosphate dehydrogenase (G6PD) deficiency is one of the most prevalent human enzyme defects observed in malaria endemic areas. The study included 212 participants, with 142 (67%) male and 70 (33%) female, aged between 14 to 59 with a mean age of 24.20 ± 9.35 years. The study was granted ethical approval by the Katsina State Ministry of Health. Each subject gave his/her written informed permission after counseling. G6PD deficiency, malaria parasite, reduced glutathione (GSH), glutathione peroxidase (GPx), packed cell volume (PCV) and hemoglobin (Hb) were assayed using standard procedures. Among the 212 participants tested in the study, 40 (19%) were found to be G6PD deficient and 172 (81%) participants were normal. Among 212 participants tested, 75 (35.4%) were infected with malaria parasite out of which 13 (17.3%) were G6PD deficient and 62 (82.7%) were normal. Among the 40 G6PD deficient subjects, 33 (82.5%) were male while 7 (17.5%) were females. GSH concentration was lowered significantly in G6PD-deficient subjects compared to the normal subjects. GPx, Hb and PCV showed no significant difference ($p > 0.05$) in the deficient subjects compared to the normal subjects. The results of this study suggest that G6PD deficiency is quite common with a prevalence of 19% in the population of Katsina metropolis. The data also shows that males are more likely to be affected by G6PD deficiency than females.

Keywords: Hemoglobin, G6PD, glutathione peroxidase, GSH, malaria,**1.0 INTRODUCTION**

Glucose-6-phosphate dehydrogenase (G6PD) is an enzyme found in the cytoplasm of all cells. The oxidation of glucose-6-phosphate to 6-phosphogluconate is catalysed by glucose-6-phosphate dehydrogenase (G6PD) in the pentose phosphate pathway, which is also known as the hexose monophosphate shunt (Kassahun *et al.*, 2023; Albagshi *et al.*, 2020). In order to achieve this goal, nicotinamide adenine dinucleotide phosphate, often known as NADPH, is synthesised from NADP. As a result of the generation of NADPH, red blood cells are shielded from the effects of oxidative stress (Ibrahim *et al.*, 2022; Tassew *et al.*, 2022). Red blood cells do not have any nuclei, mitochondria, or ribosomes in their structure. Because the pentose phosphate pathway is the principal

source of NADPH in red blood cells, the presence of G6PD is necessary for their protection against oxidative damage (Ibrahim *et al.*, 2022; Bello *et al.*, 2016). Reducing glutathione from oxidised glutathione and keeping the intracellular reduced glutathione pool stable both need NADPH, an important co-factor in many biosynthetic reactions (Satyagraha *et al.*, 2021; Isaac *et al.*, 2013). In the absence of reduced glutathione, oxidised haemoglobin will crystallise into Heinz bodies. On the other hand, reduced glutathione acts as a scavenger for free radicals and assists in the conversion of oxidised haemoglobin into free haemoglobin (Eyo *et al.*, 2023; Satyagraha *et al.*, 2021; Isaac *et al.*, 2013). In the meantime, the function of the G6PD enzyme is depicted in the picture below.

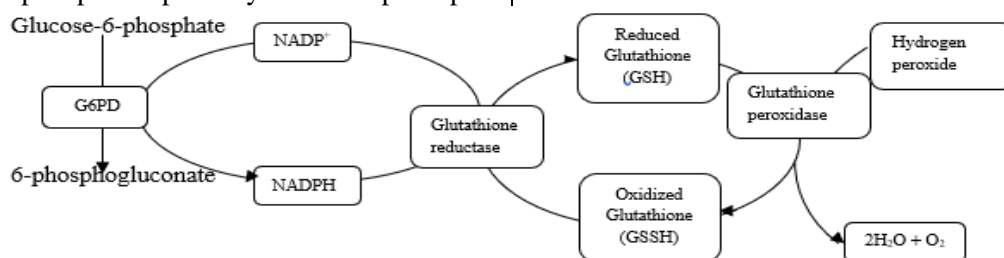


Figure 1: Function of G6PD Enzyme

Glucose-6-phosphate dehydrogenase (G6PD) deficiency is the most familiar enzyme defect in humans (Tassew *et al.*, 2022; Bello *et al.*, 2016; Isaac *et al.*, 2013). Alving and his colleagues in 1956 were the first to discover G6PD deficiency during their research on whether hemolytic anemia would be present in Africans being treated with the anti-malaria, Primaquine. Later, it was known that G6PD deficiency not only occurred in Africans but was also prevalent worldwide. Recently, it was found that more than 400 million people are G6PD deficient globally (Alangari *et al.*, 2023; Ibrahim *et al.*, 2022; Garcia *et al.*, 2021; Jinyoung *et al.*, 2018). It usually affects males and is inherited as an X-linked recessive condition. G6PD deficiency is characterized by neonatal jaundice and hemolytic anaemia, both of which can lead to neurological problems and even mortality (Eyo *et al.*, 2023; Kassahun *et al.*, 2022; Tassew *et al.*, 2022; Eugenia *et al.*, 2019; Isaac *et al.*, 2013).

It is known that G6PD deficiency confers resistance to severe malaria (Oduola *et al.*, 2022; Jinyoung *et al.*, 2018). Although there is no clear understanding of how G6PD deficiency protects against severe malaria, there are postulations that linked it to the effects of G6PD deficiency on the physiology of RBC (Babalola *et al.*, 2022; Tassew *et al.*, 2022; Jinyoung *et al.*, 2018; Bello *et al.*, 2016). Unless exposed to oxidative medicines (primaquine, dapson, sulfamides, quinolones, certain antibiotics and some analgesics), certain diseases, or after eating fava beans, most persons with G6PD deficiency have no symptoms. G6PD deficiency is treated primarily by limiting exposure to oxidative agents that cause haemolytic anaemia (Tassew *et al.*, 2022; Garcia *et al.*, 2021; Jinyoung *et al.*, 2018). Certain medications, including primaquine, dapson, sulfamides, quinolones, certain antibiotics, and some analgesics, have been described as haemolytic triggers that cause haemolytic anaemia in G6PD-deficient individuals (Sathupak *et al.*, 2021; Eugenia *et al.*, 2019; Chu *et al.*, 2018). Primaquine is a very effective anti-malaria drug that can reduce the transmission of malaria by eliminating gametocyte of *P. falciparum* and reducing the number of hypnozoites of *P. Vivax* and *P. Ovale* (Babalola *et al.*, 2022; Sathupak *et al.*, 2021; Eugenia *et al.*, 2019; Chu *et al.*, 2018).

Reactive oxygen species (ROS) cause oxidative stress when their synthesis and buildup in cells and tissues exceeds the body's capacity to

detoxify them (Swastika *et al.*, 2020). To survive with the formation of ROS, red blood cells and all other cells have an antioxidant defence system that includes enzymatic and non-enzymatic antioxidants. The paramount antioxidant molecule of intracellular environment is reduced glutathione (GSH), which has many physiological roles. Glutathione peroxidase (GPx) is a cytosolic enzyme which catalyses the reduction of hydrogen peroxides to water and oxygen using GSH as a co-factor. In red blood cells, GSH-Px is the most effective antioxidant against oxidant stress and has paramount importance in phagocytosis of cells (Swastika *et al.*, 2020). The incidence of G6PD deficiency in Nigeria varies widely between previous researches. G6PD deficiency was discovered to be 14.4% among 118 children requiring paediatric care who were seen at the Emergency Paediatric unit at Usman Danfodiyo University Teaching Hospital in Sokoto, Nigeria (Isaac *et al.*, 2013). In Kano, Nigeria, Sagir & Umma, (2018) found that 20.4% of healthy blood donors lacked the G6PD enzyme. Bello *et al.* (2016) found that G6PD deficiency was present in 16% of Plasmodium falciparum-infected children in Katsina state, Nigeria. However, our study among residents of Katsina metropolis cuts across a wider age bracket and accounts for the deficiency of G6PD in healthy individuals and malaria infected ones.

2.0 MATERIALS AND METHOD

2.1 Study Area

Katsina LGA, Katsina State, was the site of the research. Katsina is one of Nigeria's north-western states. The population of Katsina LGA is 524,000 according to the current metro area population of Katsina in 2023. Its total area is approximately 142km² (55 sq mi), its coordinates are 12°59'20"N and 36°03"E). Katsina is located approximately 260km (160 mi) east of the city of Sokoto and 135km (84 mi) northwest of Kano, close to the border with Niger Republic. Katsina LGA has an annual average temperature of 30.89°C (87.6°F), which is 1.43°F hotter than the rest of Nigeria (Weather and Climate, 2023). The warmest months are March to June, with an average daily temperature above 36.7°C (98°F). The coldest months are December to January, with an average low temperature of 15°C (59°F) and high of 28.9°C (84°F). The rainy season is

from June to October, the month with the most rain in Katsina is August. Malarial transmission is high during the wet season and low during the

dry season. The figure below shows the selected area of the study.

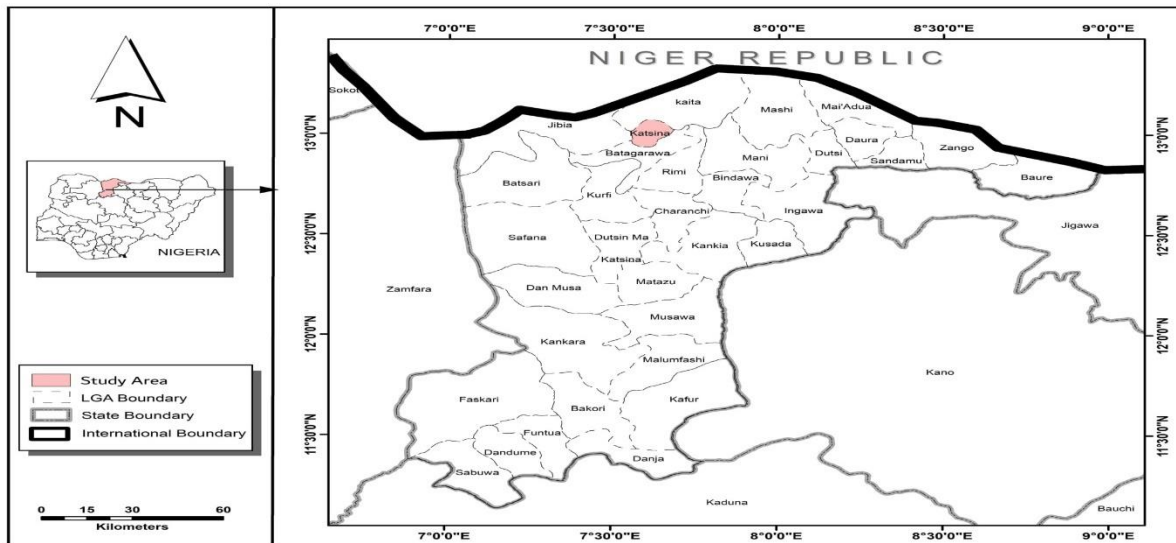


Figure 2: Map of Katsina State Showing the Selected Area of the Study
 Source: Geographic Information System (GIS) Laboratory FUDMA
 (Adapted from Google Earth Imagery 2023)

2.2 Study Design

This study was designed to determine the prevalence of G6PD deficiency in people living in Katsina metropolis which comprises of 212 participant, 142 (67%) males and 70 (33%) females. The participants gave their consent in writing. This research was given ethical approval by the Health Research Ethical Committee (HREC) of the Ministry of Health in Katsina State, Nigeria.

The formula below was used to get the above sample size

$$\text{Sample size} = \frac{Z_{1-\alpha/2}^2 P(1-p)}{d^2} \text{ (Charan \& Biswas, 2013).}$$

$Z_{1-\alpha/2}$ = standard normal variate. At 5% type 1 error ($p < 0.05$) it is 1.96 and at 1% type 1 error ($p < 0.01$) it is 2.58. In majority of studies p values are considered significant below 0.05 hence 1.96 is used in formula.

P = Expected proportion in population based on previous studies or pilot studies.

d = Absolute error or precision. (Charan & Biswas, 2013).

Using the formula above

$$Z_{1-\alpha/2} = 1.96$$

$$P = 0.16 \text{ (Bello et al., 2016)}$$

$$d = 0.05$$

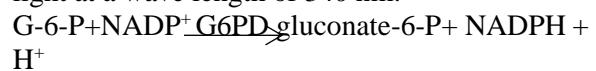
$$\begin{aligned} \text{Sample size} &= \frac{(1.96)^2 \times 0.16 (1 - 0.16)}{0.05^2} \\ &= \frac{3.8416 \times 0.16 \times 0.84}{0.0025} \\ &= 206.52 \end{aligned}$$

2.3 Sample Collection and Method

Three milliliters of whole blood was drawn (Venipuncture sample) from each study subject into Ethylene Diamine Tetra-acetic Acid (EDTA) tubes. The blood samples collected were transported to Ramal medical laboratory, Katsina for the analysis.

G6PD deficiency was detected using the Randox G6PD quantitative in vitro test

Principle: The principle is based on reduction of NADP^+ by G6PD present in red blood cells. The NADPH generated fluoresces under ultraviolet light at a wave length of 340 nm.



The activity of G6PD enzyme was determined by the rate of change in absorbance. Red blood cell G6PD value of ≥ 2.9 U/gHb was regarded as normal, while those with red blood cell G6PD value of < 2.9 U/gHb were regarded as deficient and those with red blood cell G6PD value of < 1.6 U/gHb were regarded as severely deficient (Isaac et al., 2013).

GSH was measured using standard procedure

Principle: The principle is based on the reduction of 5,5'- dithiobis (2-nitrobenzoic acid) (DTNB) with reduced glutathione (GSH) to produce 2-nitro-5-mercapto-benzoic acid (TNB), which possesses its absorption maximum at 412nm (Nse *et al.*, 2022).

GSH concentration was calculated using the formula:

$$\text{GSH mmol/l} = \frac{A_{\text{sample}} \times \text{Conc of standard}}{A_{\text{standard}}}$$

Concentration of standard GSH = 0.20mM
GPx was measured using standard procedure

Principle: The principle is based on the oxidation of pyrogallol to purpurogallin by peroxidase activity, resulting to a deep brown colour disposition that can be detected at 430 nm (Daramola *et al.*, 2018).

The activity of glutathione peroxidase (GPx) was calculated using the formula:

$$\text{GPx activity (mg protein/ml enzyme)} = \frac{\text{OD/min} \times V_t \times \text{Df}}{E \times V_s \times Y}$$

OD/min = Absorbance of test V_t = Total volume of reaction mixture
Df = Dilution factor
 V_s = Volume of sample E = Molar extinction coefficient of purpurogallin ($12\text{M}^{-1}\text{Cm}^{-1}$)
Y = Mg of protein.

The hematocrit technique was used to determine packed cell volume (PCV).

Principle: Packed cell volume (PCV) is a measure of the ratio of the volume occupied by the red cells to the volume of whole blood in a sample of capillary, venous or arterial blood. The ratio is measured after appropriate centrifugation and is expressed as a decimal fraction (Gunn *et al.*, 2002).

The sample was mixed well and the capillary tubes were filled to two-third. The dry end was sealed with plasticine clay. The capillary tubes were placed in opposites slots of microhematocrit centrifuge with the clay-filled ends against gasket. The capillary tubes are centrifuged for five (5) minutes. The capillary tubes were placed unto the hematocrit reader and the results were read and expressed in percentage.

Haemoglobin was determined using Cyanmethemoglobin method

Principle: When blood is diluted in buffered solution of potassium ferrocyanide (KFeCN) and potassium cyanide (KCN), the potassium ferrocyanide converts haemoglobin (Hb) to methemoglobin (metHb). Potassium cyanide further converts metHb to cyanmethemoglobin. The absorbance of the solution is measured at a wavelength of 540nm (Bernard *et al.*, 2011).

Haemoglobin is derived from the formula below

$$\text{Haemoglobin (g/dl)} = \frac{A_{\text{test}}}{A_{\text{standard}}} \times \text{Conc of standard} \times \frac{\text{Dilution factor}}{100}$$

A microscopic technique was used to identify the malaria parasite. Giemsa is a Romanowsky stain that is frequently used in parasitology to stain parasites that feed on blood, including malaria. Giemsa has both basic and acidic dyes, which are attracted to the basic and acidic elements of blood cells, respectively. The cytoplasm, granules, and other essential parts of cells are stained by the acidic dyes Eosin and Azure Variable. The acidic components, particularly the cell nucleus, are stained by the fundamental dye methelene blue. Romanowsky stains' staining responses are pH-dependent, which is why the stains are diluted in buffered water with a certain pH (Cheesbrough, 2010).

Procedure:

- Thin blood smear was prepared and allowed to air dry
- The film was placed on a staining rack and 1–2 drops of moisture-free methyl alcohol (methanol) was added and allowed to dry on the film.
- The blood film was covered with undiluted stain but the slide was not allowed to flood. The number of drops required to cover the film was counted.
- Twice the volume of pH 7.2 buffered water (i.e. twice the number of drops as stain) was added. Without it overflowing, it was allowed to stain for ten minutes. After ten minutes the stain was washed off with tap water.
- The back of the slide was wiped cleaned and it was placed on a draining rack for the smear to dry. After the smear was dried the results were checked microscopically.

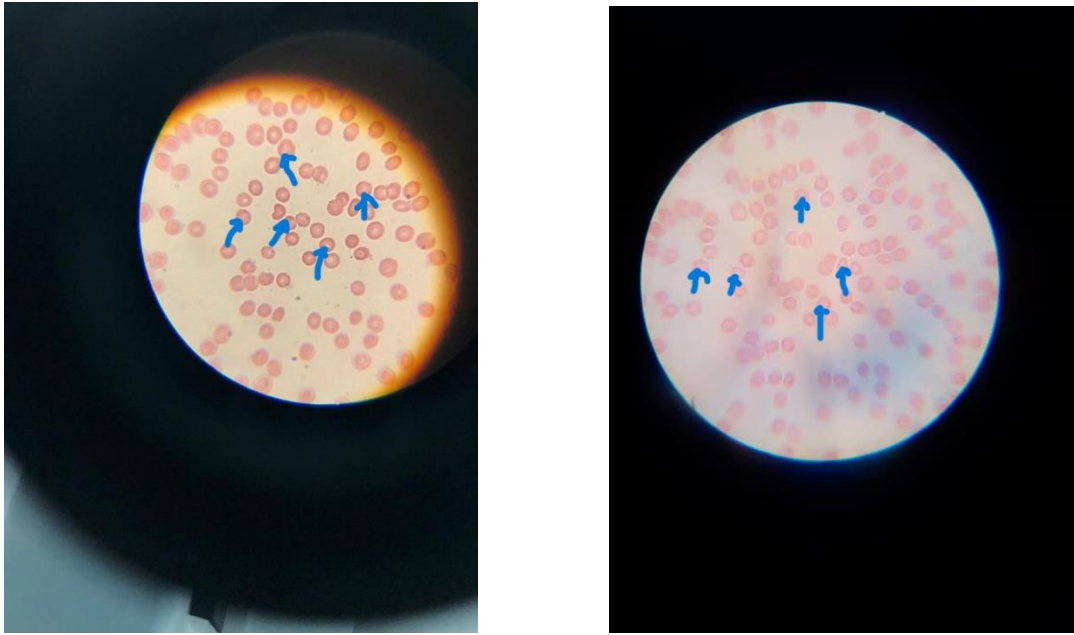


Figure 3: Thin blood smear showing malaria parasite

2.4 Statistical Analysis

Graph Pad and Microsoft Excel 2010 were used to statistically analyze the data. Data were presented as means and standard error of means. The differences between the deficient and normal participants were compared using a student t-test. Differences were considered significant at $P < 0.05$.

3.0 RESULTS

The purpose of this study was to ascertain the prevalence of G6PD deficiency among people living in Katsina metropolis. The study recruited 212 subjects made up of 142 (67%) males and 70 (33%) females, aged 14-59 years with a mean age of 24.20 ± 9.35 years.

3.1 Prevalence of G6PD Deficiency in People Living in The Study Area

Figure 4 depicts the prevalence of G6PD deficiency among the participants. Among the 212 subjects tested in this study, 40 (19%) were found to be G6PD deficient while the remaining 172 (81%) subjects were normal.

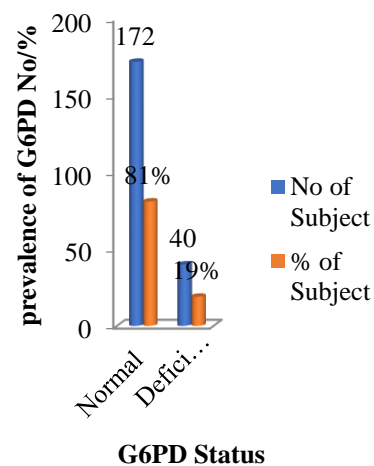


Figure 4: Prevalence of G6PD deficiency in people living in the study area

3.2 Prevalence of G6PD deficiency among malaria infected subject

The study found out that among 212 participants tested, 75 (35.4%) were infected with malaria parasite. Among the 75-subject infected with malaria parasite, 13 (17.3%) were G6PD deficient and 62 (82.7%) were normal (Figure 5). Therefore, prevalence of 17.3% was observed. Among the 62 normal subjects infected with malaria 39 (52%) have a parasitic count of + (1-10 parasite per 100 HPF), 14 (18.7%) have ++ (11-100 parasite per 100 HPF and 9 (12%) have +++ (1-10 parasite per each HPF). 13 (17.3%)

G6PD deficient subject infected with malaria have a parasitic count of + (1-10 parasite per 100 HPF).

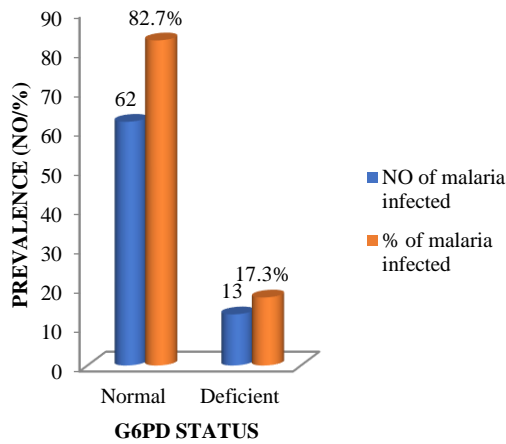


Figure 5: Prevalence of G6PD deficiency among malaria infected subjects

3.3 Prevalence of G6PD deficiency among participants based on sex

According to this study's findings, among the 40 deficient subjects, 33 (82.5%) of the males had G6PD deficiency, compared to 7 (17.5%) of the females (Figure 6).

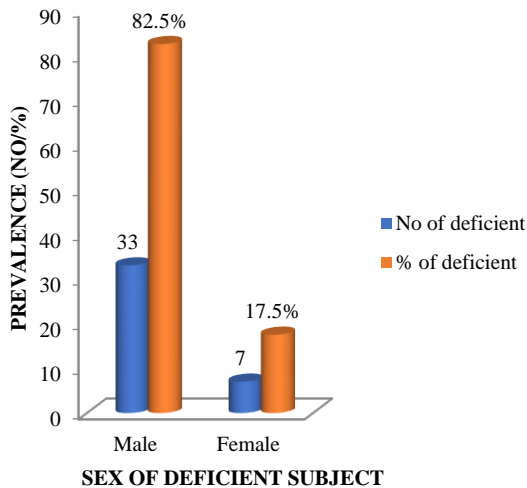


Figure 6: Prevalence of G6PD deficiency based on sex

3.4 Prevalence of G6PD deficiency based on selected areas

The results showed that the percentages of deficient subject among the selected areas of Katsina metropolis were statistically similar; the percentage of deficient patients were: 20.8%, 18.9%, 18.9% and 17% for north, south, east and west respectively (Figure 7).

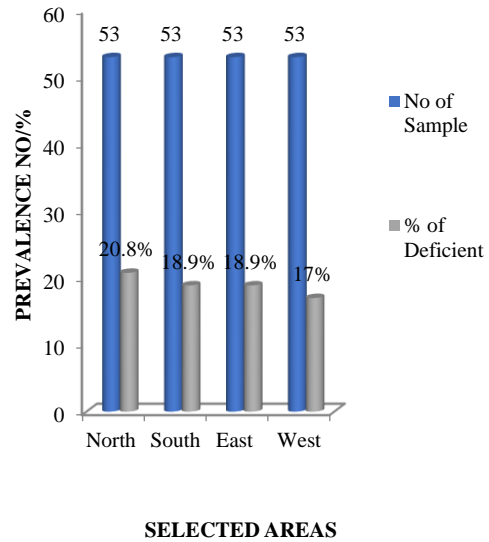


Figure 7: Prevalence of G6PD deficiency based on the selected areas

3.5 G6PD activity, Anti-Oxidant Enzymes and Hematological Indices among the normal and deficient subject.

The results of G6PD activity, reduced glutathione (GSH) and glutathione peroxidase (GPx) are presented in Table 1. Haemoglobin (Hb) and packed cell volume (PCV) concentrations are presented in Table 2.

The activity of G6PD in the deficient subject was significantly ($p < 0.05$) reduced compared the normal subjects. GSH concentration was significantly ($p < 0.05$) decreased in deficient subjects compared to the normal subjects. GPx activity, Hb and PCV levels showed no significant difference ($P > 0.05$) in deficient compared to the normal subjects.

Table 1: G6PD activity, GSH concentration and GPx activity in normal and deficient subject.

Parameters	Normal n=172	Deficient n=40
G6PD (U/gHb)	9.636±0.450 ^a	1.547±0.163 ^b
GSH (mmol/l)	1.344±0.147 ^a	0.659±0.047 ^b
GPx (U/mg)	4.781±0.218 ^b	5.097±0.480 ^b

Values are presented in mean \pm SEM. Significant differences exist between values in the same row with various superscripts. Values in the same row with the same superscript are not substantially different. G6PD = Glucose-6-phosphate dehydrogenase, GSH = Reduced glutathione and GPx = Glutathione peroxidase

Table 2: Hb and PCV levels in normal and deficient subject

Parameters	Normal n=172	Deficient n=40
Hb (g/dl)	13.59 \pm 0.204 ^a	13.59 \pm 0.103 ^a
PCV (%)	40.73 \pm 0.306 ^a	41.10 \pm 0.614 ^a

Values are presented in mean \pm SEM. Significant differences exist between values in the same row with various superscripts. Values in the same row with the same superscript are not substantially different. Hb = Haemoglobin and PCV = Packed cell volume.

4.0 DISCUSSION

In this study, a prevalence rate of 19% G6PD deficiency was observed among residents of the study region. This is consistent with some preceded studies done in Nigeria and other parts of the world. Williams *et al.*, (2013), Isaac *et al.*, (2013), and Bello *et al.*, (2016) published earlier research in Nigeria that suggest a prevalence of 15.3%, 14.4%, and 16%, in the southwestern Nigeria, Sokoto state and Katsina state respectively. Thus, a study by Sagir & Umma (2018) among healthy blood donors in Kano showed a prevalence of 20.4%. G6PD deficiency occurs mostly in people of African heritage and range in from 3.6% to 28.0% (Sagir & Umma, 2018). Report from Assefa *et al.*, 2018 indicated that the incidence in Ethiopia was 8.9%. According to a research, the incidence in malaria-endemic municipalities in Brazil is 5.6% (Jaobi *et al.*, 2022). Moreover, report from Dechyotin *et al.* (2021) among females from previously malaria endemic regions in northeastern Thailand found prevalence of 18% by fluorescent spot test and 27.0% by PCR-based genotyping. The present study recruited 212 participants, among the 212 participants; 75(35.4%) were found to be infected with malaria with parasitic count ranging from + (1-10 parasite per 100 HPF), ++ (11-100 parasite per 100 HPF and +++ (1-10 parasite per each HPF). Out of the 75 participants infected with malaria, it was found that 13 (17.3%) were G6PD deficient with parasitic count of + (1-10 parasite per HPF), this shows that the G6PD deficient subject have low parasitic count. Thus, this is in accordance with the hypothesis that suggest that G6PD deficiency confer resistance against severe malaria (Tassew *et al.*, 2022; Eugenia *et al.*, 2019; Jinyoung *et al.*, 2018; Bello *et al.*, 2016; Isaac *et al.*, 2013). G6PD deficiency is a natural

selection, a number of epidemiological studies report that it is common in areas where malaria is widespread (jinyoung *et al.*, 2018). In this study, male subjects 33 (82.5%) had a higher prevalence of G6PD deficiency than female subjects 7 (17.5%). Because it is an X-linked recessive genetic condition characterized by unusually low levels of G6PD, G6PD deficiency primarily affects males. Because the mutation would need to occur in both copies of the gene to induce the condition in females, the deficiency is uncommon in females, but in males just one defective copy of the gene is required for the disease to emerge (Ibrahim *et al.*, 2022; Isaac *et al.*, 2013). The findings of the study is in accordance with literature that indicate that the sex of the patient is crucial, and men are at higher risk than women (Tassew *et al.*, 2022; Jinyoung *et al.*, 2018; Bello *et al.*, 2016; Isaac *et al.*, 2013). The lack of statistical correlation between G6PD deficiencies among the selected areas in this study demonstrates that G6PD deficiency is independent on the area of the participants within Katsina metropolis. This is also in accordance with a study conducted by Bello and his colleagues that suggested that between the three senatorial zones of Katsina state there is no statistical correlation of G6PD deficiency (Bello *et al.*, 2016). As expected, the activity of G6PD in the deficient subject was significantly ($p < 0.05$) lowered when compared with the normal subjects. This is in consistent with other studies conducted in Nigeria and other part of the world (Tassew *et al.*, 2022; Eugenia *et al.*, 2019; Jinyoung *et al.*, 2018; Bello *et al.*, 2016; Isaac *et al.*, 2013). The reduced concentration of GSH in G6PD-deficient RBC as compared to normal RBC observed in this study was not surprising. It may be due to the fact that in RBC, oxidized glutathione (GSSG) is reduced to reduced

glutathione (GSH) by glutathione reductase, an NADPH dependent enzyme. In RBC NADPH is dependent on G6PD enzyme because NADPH is produced through the conversion of glucose-6-phosphate to 6-phosphogluconate which is catalysed by G6PD. With the reduced activity or deficiency of G6PD, NADPH will either be absent or low therefore reduction of GSSG to GSH will be low (Alangari *et al.*, 2023; Ibrahim *et al.*, 2022; Tassew *et al.*, 2022; Oduola *et al.*, 2018). The non- significant change observed in the levels of Hb and PCV of G6PD deficient subjects as compared to normal subjects in this study show that both the deficient subject and the normal subject have no any sign of anaemia. This may be suggestive of asymptomatic G6PD deficiency (Alangari *et al.*, 2023; Tassew *et al.*, 2022; Oduola *et al.*, 2018; Bello *et al.*, 2016; Isaac *et al.*, 2013).

5.0 CONCLUSION

The results of this study suggest that G6PD deficiency is quite common with a prevalence of 19% in the population of Katsina metropolis. The data also shows that males are more likely to be affected by G6PD deficiency than females. Decrease levels of GSH was observed in G6PD deficient subjects while no any significant variation was observed in GPx activity, Hb levels and PCV levels.

6.0 ACKNOWLEDGEMENTS

We appreciate the staff of Ramal Medical Laboratory Katsina for their support during this study.

REFERENCES

- Alangari, A.S., El-Metwally, A.A., Alanazi, A., Al Khnateeb, B.F., Al Kadri, H.M., Alshdoukhi, I.F., Aldubikhi, A.I., Alruwaili, M. and Alshahrani, A. (2023). "Epidemiology of Glucose-6-Phosphate Dehydrogenase Deficiency in Arab Countries: Insights from a Systematic Review". *J Clin Med*. Vol.12(20):6648. doi: 10.3390/jcm12206648. PMID: 37892786; PMCID: PMC10607133.
- Albagshi, M.H., Alomran, S., Sloma, S., Albagshi, M., Alsuweel, A. and AlKhalaf, H. (2020). "Prevalence of Glucose-6-Phosphate Dehydrogenase Deficiency Among Children in Eastern Saudi Arabia". *Cureus*. Vol 29;12(10):e11235. doi: 10.7759/cureus.11235. PMID: 33269163; PMCID: PMC7704170.
- Assefa, A., Ali, A., Deressa, W., Tsegaye, W., Abebe, G., Sime, H., Kebede, A., Jima, D., Kassa, M., Abreha, T., Teka, H., Solomon, H., Malone, J., Shi, Y.P., Zhou, Z., Reithinger, R, and Hwang, J. (2018). "Glucose-6-phosphate dehydrogenase (G6PD) deficiency in Ethiopia: absence of common African and Mediterranean allelic variants in a nationwide study". *Malar J* 17:388. <https://doi.org/10.1186/s12936-018-2538-4>
- Babalola Oladayo Musa, Alli Adetunji Alabi and Ashiru Mojeed Ayoola1 (2022). "Glucose-6-Phosphate Dehydrogenase Deficiency and its Association with Malaria in the Administrative Divisions of Lagos State, Nigeria". *Nigerian Journal of Experimental and Clinical Biosciences* Vol:10(3) pp 98-103. | DOI: 10.4103/njecp.njecp_14_22
- Bello, I., Abdulsalam, M. Sani and Bulus, T. (2016)." Prevalence of Glucose-6-phosphate Dehydrogenase Deficiency among Children Aged 0-5 years infected with Plasmodium Falciparum in Katsina State, Nigeria". *Advances in Biochemistry*. 4(6): 66-73. Doi 10. 11648/j.ab.20160406.11.
- Bernard Nkrumah, Samuel Blay Nguah, Nimako Sarpong, Denise Dekker, Ali Idriss, Juergen May and Yaw Adu-Sarkodie (2011). "Hemoglobin estimation by the HemoCue ® portable hemoglobin photometer in a resource poor setting". *BMC Clin Pathol*. Vol: 21 pp 11-15.
- Charan, J. and Biswas, T. (2013). "How to calculate sample size for different study designs in medical research". *Indian J Psychol Med*. Apr; 35(2): 121-126.
- Cheesbrough, M. (2010). "District Laboratory Practice in Tropical Countries". Part 2. Cambridge University press, pp 320-323. ISBN-13 978-0-511-34935-5.
- Chu, C.S., Bancone, G., Nosten, F., White, N.J. and Luzzatto, L. (2018). "Primaquine-induced haemolysis in females heterozygous for G6PD deficiency". *Malar J* 17:101. <https://doi.org/10.1186/s12936-018-2248-y>
- Daramola, O.O., Oyeyemi, W.A., Beka, F.U. and Ofutet, E.A. (2018). "Protective Effects of Aqueous Extract of Citrullus lanatus Fruit on Reproductive Functions and Antioxidant Activities in Arsenic-treated Male Wistar Rats". *Afr. J. Biomed. Res*. Vol: 21, pp 65- 72.
- Dechyotin, S., Sakunthai, K., Khemtonglang, N., Yamsri, S., Sanchaisuriya, K., Kitcharoen, K. and Kitcharoen, S. (2021). "Prevalence and molecular characterization of glucose-6-

- phosphate dehydrogenase (G6PD) deficiency in females from previously malaria endemic regions in Northeastern Thailand and identification of a novel G6PD variant". *Mediterr J Hematol Infect Dis* 13:e2021029. <https://doi.org/10.4084/MJHID.2021.029>
- Eugenia, L.O., Daibin, Z., Beka, R., Kareen, P., Cristian, K., Ming-Chich L., Delenasaw, Y. and Gulyun, Y. (2019). "Prevalence and Distribution of G6PD Deficiency: Implication for the use of Primaquine in Malaria treatment in Ethiopia". *Malaria journal* Edition 18: 340.
- Eyo Ita, E.U., Ogunsanya, B., Osazee, E.M., Eyo Ita, I.A. and Omoigberale, A. (2023). "Glucose-6-Phosphate Dehydrogenase Deficiency In A Nigerian Neonate With Acute Bilirubin Encephalopathy Triggered By Ciprofloxacin". *J Med Case Rep Case Series* 4(13): <https://doi.org/10.38448/10.38>
- Garcia, A.A., Koperniku, A., Ferreira, J.C.B. and Mochly-Rosen, D. (2021). "Treatment strategies for glucose-6-phosphate dehydrogenase deficiency: past and future perspectives". *Trends Pharmacol Sci.* Vol 42(10):829-844. doi: 10.1016/j.tips.2021.07.002. Epub 2021 Aug 10. PMID: 34389161; PMCID: PMC8448981.
- Gunn, V.L. and Nechyba, C. (2002). "The harriet lane handbook" Mosby book publisher, pp. 284-285.
- Ibrahim Bello, Sharma Arpita and Lawal Mukhtar (2022). "Molecular Detection of Glucose-6-Phosphate Dehydrogenase Deficiency in Katsina State, Northern Nigeria". *Asian Journal of Biotechnology and Bioresource Technology*. Vol:10 pp30-38. [10.9734/ajb2t/2022/v8i230123](https://doi.org/10.9734/ajb2t/2022/v8i230123)
- Isaac, I.Z., Mainasara, A.S., Osaro, E., Omojuyigbe, S.T., Dallatu, M.K., Bilbis, L.S. and Adias, T.C. (2013). "Glucose-6-phosphate dehydrogenase deficiency among children attending the emergency pediatric unit of Usmanu Danfodio University Teaching Hospital, Sokoto Nigeria". *International Journal of General Medicine*. 6: 557-562.
- Joabi Rocha Nascimento, Jose Diego Brito-Sousa, Anne Cristine Gomes Almeida, Marly M Melo, Monica Regina Farias Costa, Laila Rowena Albuquerque Barbosa, Reinaldo Nery Ramos, Alexandre Vilhena Silva-Neto, Patricia Carvalho da Silva Balieiro, Erick Frota Gomes Figueiredo, Emanuelle Lira Silva, Djane Clarys Baia-da-Silva, Quique Bassat, Gustavo Romero, Gisely Cardoso Melo, Vanderson Souza Sampaio, Marcus Lacerda and Wuelton Monteiro (2022). "Prevalence of glucose 6-phosphate dehydrogenase deficiency in highly malaria-endemic municipalities in the Brazilian Amazon: A region-wide screening study, The Lancet Regional Health - Americas, Volume 12, 100273, ISSN 2667-193X, <https://doi.org/10.1016/j.lana.2022.100273>.
- Jinyoung, L., Tae, I.K., Jung-mi, K., Hojong, J., Huang G.L., Thi L.T., Woon-mok, S., Moe, K.M., Khin Lin, T. K. and Byoung-Kuk, N. (2018). "Prevalence of Glucose-6-phosphate dehydrogenase (G6PD) deficiency among malaria patients in upper Myanmar". *BMC infectious Diseases*. 18: 131.
- Kassahun, W., Tunta, A., Abera, A. and Shiferaw, M. (2023). "Glucose-6-phosphate dehydrogenase deficiency among neonates with jaundice in Africa; systematic review and meta-analysis". *Heliyon*. Vol 19;9(7):e18437. doi: 10.1016/j.heliyon.2023.e18437. PMID: 37539282; PMCID: PMC10393755.
- Nse Udoka Ebe, Grace Sylvester Effiong, Oboso Edem Etim, Uduak Onofiok Luke, Othuke Bensandy Odeghe and Jessie Idongesit Ndem (2022). "Biochemical determination of reduced glutathione concentration in pig liver and kidney in the presence of chlorinated aquatic humic materials". *GSC Advanced Research and Reviews* vol: 10(03): 111–121.
- Oduola, T., Bunza, F., Temitope Yusuf, M., Kabiru Dallatu, M., Alhaji Ndakotsu, M., Panti, A., Onankpa, B. and Adeniji, A. (2018). "Prevalence of Glucose-6-Phosphate Dehydrogenase Deficiency among Neonates in Usmanu Danfodiyo University Teaching Hospital (UDUTH), Sokoto, Nigeria: Oxidative Stress Markers in G6pd Deficient Neonates". *International Blood Research & Reviews*, 8(2), 1–6. <https://doi.org/10.9734/IBRR/2018/42009>.
- Oduola, T., Dallatu, M. K., Umar, Z. U., Mazai, F. O., Bello, M., Oduola, K. O., Isah, I. B., & Muhammad, M. A. (2022). Glucose-6-Phosphate Dehydrogenase (G-6-PD) Status and Kidney Functions Evaluation in Patients with Acute Kidney Injury in Two Tertiary Hospitals, Sokoto. *Asian Journal of Research in Nephrology*, 5(1), 131–137. Retrieved from <https://journalajrn.com/index.php/AJRN/article/view/53>
- Sagir, G. Ahmed and Umma, A. Ibrahim (2018). "Prevalence and Clinical Significance of Glucose-6-Phosphate Dehydrogenase Deficiency among Apparently Healthy Blood

- Donors in Kano, North-West Nigeria". *Orient Journal of Medicine* / Vol. 30 No. 3-4.
- Sathupak, S., Leecharoenkiat, K. and Kampuansai, J. (2021). "Prevalence and molecular characterization of glucose-6-phosphate dehydrogenase deficiency in the Lue ethnic group of northern Thailand". *Sci Rep* 11, 2956. <https://doi.org/10.1038/s41598-021-82477-w>
- Satyagraha, A.W., Sadhewa, A., Panggalo, L.V., Subekti, D., Elyazar, I., Soebianto, S., Mahpud, N., Harahap, A.R and, Baird, J.K. (2021). "Genotypes and phenotypes of G6PD deficiency among Indonesian females across diagnostic thresholds of G6PD activity guiding safe primaquine therapy of latent malaria". *PLoS Negl Trop Dis* 15:e0009610. <https://doi.org/10.1371/journal.pntd.0009610>
- Swastika, M., Harahap, A.R., Panggalo, L.V., Jusman W.A. and Satyagraha A.W. (2020). "Determining a critical threshold for G6PD activity below which red blood cell response to oxidative stress is poor". *Malar J* 19, 208. <https://doi.org/10.1186/s12936-020-03272-y>
- Tassew Tefera Shenkutie, Desalegn Nega, Asrat Hailu, Daniel Kepple, Logan Witherspoon, Eugenia Lo, Meshesha Tsigie Negash, Aderaw Adamu, Shewayiref Geremew Gebremichael, Bokretsion Gidey, Geremew Tasew, Sindew M. Feleke and Tadesse Kebede (2022). "Prevalence of G6PD deficiency and distribution of its genetic variants among malaria-suspected patients visiting Metehara health centre, Eastern Ethiopia". *Malar J* 21, 260 <https://doi.org/10.1186/s12936-022-04269-5>.
- Weather and climate, (2023). weatherandclimate.com. <https://weatherandclimate.com/amp/nigeria/katsina>.
- Williams, O., Gbadero, D., Edowhorhu, G., Brearley, A., Slusher, T. and Lund, T. (2013). "Glucose-6-Phosphate Dehydrogenase Deficiency in Nigerian Children". *PLoS ONE* 8(7): pp. e68800