

ISSN: 2141-3819

CENTREPOINT JOURNAL

(Science Edition)

**A Journal of Intellectual,
Scientific and Cultural Interest**

A Peer-Reviewed Journal

Published by
The Library and Publications Committee
University of Ilorin, Ilorin, Nigeria

Funded by



Volume 29

Number 2

2025

This Journal is funded by



EDITORIAL BOARD

Chairman, Editorial Board

A. O. Issa

University of Ilorin, Ilorin, Kwara State, Nigeria

Email: drissa.ao@unilorin.edu.ng

Editor-In-Chief

M. O. Salawu

University of Ilorin, Ilorin, Kwara State, Nigeria

Email: salawu.mo@unilorin.edu.ng

Deputy Editor-In-Chief

O. A. Iyiola

University of Ilorin, Ilorin, Kwara State, Nigeria.

Email: iyiola.oi@unilorin.edu.ng

Managing Editor

L. A. Olayaki

University of Ilorin, Ilorin, Kwara State, Nigeria.

Email: olayaki@unilorin.edu.ng

Business Manager/Editorial Secretary

A. Alli-Oluwafuyi

University of Ilorin, Ilorin, Kwara State, Nigeria

Email: aoluwafuyi.am@unilorin.edu.ng

Editors

Prof. A. A. Abdulrahman	(University of Ilorin, Ilorin, Kwara State, Nigeria)
Prof. L. O. Raji	(University of Ilorin, Ilorin, Kwara State, Nigeria)
Prof. Saminu Olatunji	(University of Ilorin, Ilorin, Kwara State, Nigeria)
Dr. Abubakar Zubair Lawal	(University of Ilorin, Ilorin, Kwara State, Nigeria)
Dr. Abdulrahman Okino Otuoze	(University of Ilorin, Ilorin, Kwara State, Nigeria)
Dr. Grace O. Akinsola	(University of Ilorin, Ilorin, Kwara State, Nigeria)

Consulting Editors

K.O. Adebowale	(University of Ibadan, Oyo State, Nigeria)
A.J. Afolayan	(University of Fort Hare, Alice 5700, South Africa)
A. Akinola	(Obafemi Awolowo University, Ile-Ife, Nigeria)
B. Everitt	(University of York, YO10, 50DD England)
J.F. Frielingsdorf	(Shell Petroleum Development Company, Port Harcourt, Nigeria)
O. Gureje	(University College Hospital, Ibadan, Oyo State, Nigeria)
B.W. Reinisch	(University of Massachusetts-Lowell, MA, U.S.A.)
I.H. Krause	(United State Air Force Academic Space Physics and Atmospheric Research Colorado (U.S.A)
O.A. Odunola	(Ladoke Akintola University of Technology, Ogbomoso, Oyo State, Nigeria)

NOTES TO CONTRIBUTORS

CentrepoinT is an interdisciplinary journal of intellectual, scientific and cultural interest with particular reference to Africa.

Contributions written in English should as submitted in three copies typed double space with the following margins; Top: 1.25"; Bottom: 2.3", Left: 1.85"; Right: 1.4" Articles should not exceed twenty double space pages on A4 paper.

Notes and references should be carefully listed at the end of each article.

References should be arranged alphabetically.

References within the text should be cited in Harvard style, by author and year. Two papers published in the same year should be given identifying lower case letters, both in the text and in the reference list.

Authors should submit a printed copy and computer disk following these guidelines:

- Use rewritable compact disc (CD)
- Specify computer used (either IBM compatible PC not apple Macintosh)
- State software used, WordPerfect, Microsoft word etc.
- Use New Times Roman font size twelve (12).
- State the file name
- Keep a back up CD for reference and safety.

The views expressed in this journal are those of the contributors and not necessary those of the Editorial Board.

SUBSCRIPTION

Nigeria:	Individual Subscribers – N500 per copy (Excluding Postage)
	Institution or Library – N100 per copy (Excluding Postage)
Africa:	\$ 25 per copy (Including Postage)
Europe:	\$ 25 per copy (Including Postage)
North America:	\$ 30 per copy (Including Postage)
Other Continents:	\$ 30 per copy (Including Postage)

All correspondence should be addressed to:

PROF. M. O. SALAWU

The Editor-in-Chief

Centrepont: Science Edition,

Faculty of Life Sciences, Department of Biochemistry,
University of Ilorin, Ilorin, Kwara State, Nigeria.

Email: salawu.mo@unilorin.edu.ng

OR

PROF. L. A. OLAYAKI

Managing Editor

Faculty of Basic Medical Sciences, Department of Physiology,
University of Ilorin, Ilorin, Kwara State, Nigeria.

Email: olayaki@unilorin.edu.ng

OR

DR. A. ALLI-OLUWAFUYI

Business Manager/Editorial Secretary

Faculty of Pharmaceutical Science, Department of Pharmacology and Therapeutics,
University of Ilorin, Ilorin, Kwara State, Nigeria

Email: aoluwafuyi.am@unilorin.edu.ng

OR

PROF. A. O. ISSA

Chairman, Library and Publications Committee,
University of Ilorin, Ilorin, Kwara State, Nigeria.

Email: drissa.ao@unilorin.edu.ng

CONTENTS

	Page
CPJ 2025008/29201 Effects of Eyeliner on Tear Cytokine Concentrations in Young Adult Females <i>Ayodeji E. Ige, Oluwasola M. Ojo and Evangeline Kemi Lawrence</i>	1-7
CPJ 2025009/29202 Prevalence and Determinants of Emergency Contraceptive Use Among Students of Kwara State Polytechnic, Nigeria <i>H.A. Ameen, S.A. Aderibigbe, T.M. Ajayi, R.A. Sheu, S.O. Oniyangi and I. Ologele</i>	8-19
CPJ 2025010/29203 Single-Nucleotide Polymorphism Landscape and Allele Frequency Patterns in the HIV-1 Envelope (env) Gene <i>Olalekan A. Agede, Louis O. Odeigah, Odiakaose P. Odeigah, Dapo S. Oyedepo, Olawale S. Aiyedun, Nasiru Sanni, Wemimo A. Alaofin and Obinna Christopher Anaduaka</i>	20-31
CPJ 2025011/29204 Self-care Practices and Associated Factors Among People Living with Diabetes Mellitus in Ilorin, North-Central, Nigeria: A Hospital- Based Cross-sectional Study <i>Olalekan A. Agede, Oluwaseun E. Daramola, Dapo S. Oyedepo, Olawale S. Aiyedun, Nasiru Sanni, Wemimo A. Alaofin, Obinna Christopher Anaduaka, John K. Olarinoye and Odiakaose P. Odeigah</i>	32-44
CPJ 2025012/29205 Assessment of Poultry Disease Management Practices among Farmers in Kwara State, Nigeria <i>Azeez, Kaothar Kayode, Dolapo Tawakalitu A. and Egbewole Halimah O.</i>	45-63
CPJ 2025013/29206 Antihyperglycemic and Antioxidant Effects of <i>Ipomoea batatas</i> L. Leaves in Streptozotocin-Induced Diabetic Wistar Rats <i>Amuzat A, Fatima K.A, Ndatsu Y, Muhammad H.B and Rukayyah S.S</i>	64-75
CPJ 2025014/29207 Note on Extension of Rellich-type Inequality <i>Y. O. Anthonio and K. Rauf</i>	76-99

CPJ 2025015/29208

Supply Chain Management and Optimization in Transport Logistics;
A Case Study of Unilorin Table Water

*Ayinla Ally Yeketi, Muhammad Ameenah Shittu, Olorode Adekunle
Fawaz and Ugbeh Emmanuel Chukwuemeke*

100-117

CPJ 2025016/29209

Chemotaxonomic Insights from FTIR Spectral Analysis of Leaves
of *Amaranthus* Species

Moses Dele Ake and Abdullahi Alanamu AbdulRahaman

118-132

Effects of Eyeliner on Tear Cytokine Concentrations in Young Adult Females

Ayodeji E. Ige, Oluwasola M. Ojo and Evangeline Kemi Lawrence

Department of Optometry and Vision Science,
Faculty of Life Sciences,
University of Ilorin, Ilorin, Kwara State, Nigeria

ORCID Numbers: Ayodeji E. Ige: 0009-0002-0135-2756, Oluwasola M. Ojo: 0009-0002-7141-3630 and Evangeline Kemi Lawrence: 0009-0001-1456-2579

***Corresponding Author E-mail:** ige.ae@unilorin.edu.ng

Abstract

Eyeliner, a popular eye cosmetic, may affect tear cytokine levels, influencing ocular surface immunity. A quasi-experimental study involved 10 healthy females (aged 18 – 24 years) with no prior glue exposure. Tear samples, collected at baseline (control group) and after one month of daily use of eyeliner application (experimental group), were analysed for IL-1 β , IL-6, and IL-10 levels using ELISA, while visual acuity was measured with Snellen and logMAR charts. Data were evaluated with paired t-tests ($p \leq 0.05$). Visual acuity showed no significant change ($p > 0.05$). IL-1 β decreased significantly from 430.1 ± 245.4 pg/ml to 144.5 ± 81.6 pg/ml ($p = 0.002$), and IL-10 dropped from 27.0 ± 9.8 pg/ml to 5.4 ± 4.2 pg/ml ($p = 0.0001$). IL-6 levels remained unchanged (39.9 ± 20.2 pg/ml to 37.6 ± 7.6 pg/ml, $p = 0.735$). Short-term eyeliner use reduces IL-1 β and IL-10, suggesting altered ocular surface immunity without affecting visual acuity. Further research and public health education are advised

Keywords: Eyeliner, Tear Cytokines, IL-1 β , IL-6, IL-10, Visual Acuity, Ocular Health

Abbreviations

DED: Dry Eye Disease
ELISA: Enzyme-Linked Immunosorbent Assay
IL-1 β : Interleukin-1 β
IL-6: Interleukin-6
IL-10: Interleukin-10
MGD: Meibomian Gland Dysfunction
VA: Visual Acuity

Introduction

Ocular cosmetics, such as eyeliner, are popular for enhancing eye appearance, particularly among young adult females (Dartt & Willcox, 2013). Applied along the

eyelid margin or lash line, eyeliner contains pigments, waxes, and preservatives that may migrate into the tear film, potentially causing irritation or inflammation (Ng *et al.*, 2015). Tear cytokines, including pro-inflammatory (IL-1 β , IL-6) and anti-inflammatory (IL-10) mediators, are critical for maintaining ocular surface homeostasis and regulating immune responses (Dinarello, 2000). Alterations in cytokine concentrations may signal ocular surface stress, potentially contributing to conditions like dry eye disease (DED) (Prabhasawat *et al.*, 2020).

Despite eyeliner's widespread use, its impact on tear cytokine profiles in young, healthy populations remains understudied. Previous research suggests that eyeliner can disrupt tear film stability and contribute to meibomian gland dysfunction (MGD), potentially affecting inflammatory mediators (Ng *et al.*, 2015; Prabhasawat *et al.*, 2020). This study aimed to assess the effects of daily eyeliner application on tear cytokine concentrations (IL-1 β , IL-6, IL-10) and visual acuity in young adult females, providing insights into the ocular safety of cosmetic use.

Materials and Methods

A quasi-experimental, one-group pretest-posttest design was employed to investigate eyeliner's effects on tear cytokines. The study was conducted at the Department of Optometry and Vision Science, University of Ilorin, Nigeria, from December 2024 to January 2025. Ten female participants (aged 16–35 years) were recruited using convenience-purposive sampling, the control group included baseline tear cytokines and the experimental group included one month of eyeliner use. Inclusion criteria included consent to participate and willingness to use eyeliner daily for one month. Exclusion criteria encompassed a history of ocular allergies, eyeliner wearers, chronic dry eye, recent ocular surgery, contact lens use, or medications affecting tear composition.

Participants completed a questionnaire on makeup habits and ocular symptoms. Each was provided with eyeliner (Maybelline Colossal Kajal) for daily use. The Maybelline Colossal Kajal is a retractable eyeliner composed of lightweight silicones and structural waxes such as polyethylene, microcrystalline wax, and Candelilla wax. Its color is derived from mineral pigments including iron oxides and carbon black. The formulation also includes aloe vera and vitamin E alongside other emollient and oil-based ingredients. Assessments were conducted before (control group) and after one month of eyeliner application (experimental):

1. **Visual Acuity:** Measured using Snellen and logMAR charts at 6 meters and 40 cm, respectively.
2. **Tear Sample Collection:** Tears (2–10 μ L) were collected using the flush tear method with 0.9% NaCl saline and glass micro capillary tubes. Samples were stored at -80°C.

3. **Cytokine Analysis:** IL-1 β , IL-6, and IL-10 concentrations were quantified using Sandwich ELISA kits (Elabscience). Samples were thawed, centrifuged, and analysed per the manufacturer's protocol, with optical density measured at 450 nm.

Data Analysis

Data was analysed using Microsoft Excel 2016. Paired t-tests compared pre- and post-intervention cytokine concentrations, with statistical significance set at $p \leq 0.05$

Ethical Considerations

The study complied with the Declaration of Helsinki. Ethical approval was obtained from the University of Ilorin's ethics committee, and verbal informed consent was secured from participants. Data confidentiality was ensured.

Results

Visual Acuity

Visual acuity, assessed using Snellen and logMAR charts, showed no significant change between the baseline tear cytokines (control group) and after one month of eyeliner use (experimental group) ($p > 0.05$), indicating no impact on visual function.

Figure 1: Mean Visual Acuity (logMAR) Before and After One Month of Eyeliner Use

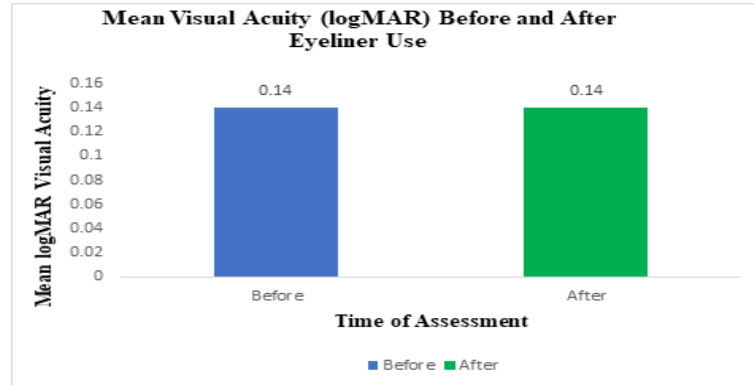


Figure 1 illustrates the mean visual acuity (logMAR) before and after one month of eyeliner application, showing no significant change ($p > 0.05$).

IL-1 β Concentrations

Mean IL-1 β concentrations significantly decreased from 430.1 ± 245.4 pg/ml before eyeliner (baseline tear cytokines) use to 144.5 ± 81.6 pg/ml after one month of application ($p = 0.002$). **Figure 2:** IL-1 β Concentrations Before and After One Month of Eyeliner Use

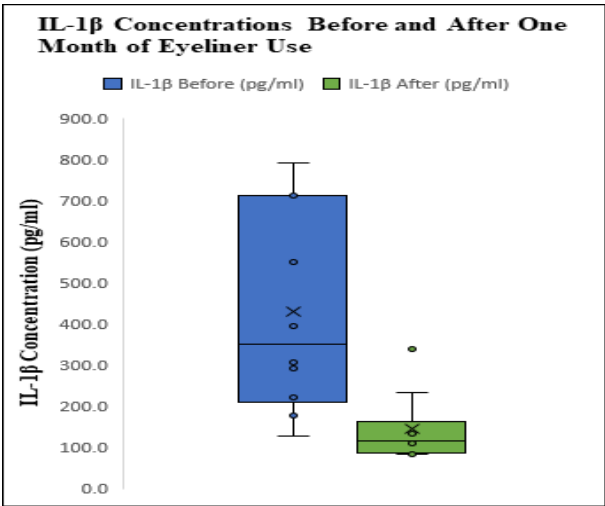


Figure 2 illustrates the distribution of IL-1 β concentrations, showing a significant decrease after one month of eyeliner application.

IL-6 Concentrations

Mean IL-6 concentrations showed minimal change, from 39.9 ± 20.2 pg/ml before (baseline tear cytokines) eyeliner use to 37.6 ± 7.6 pg/ml after application, with no significant difference ($p = 0.735$).

Figure 3: IL-6 Concentrations Before and After One Month of Eyeliner Use

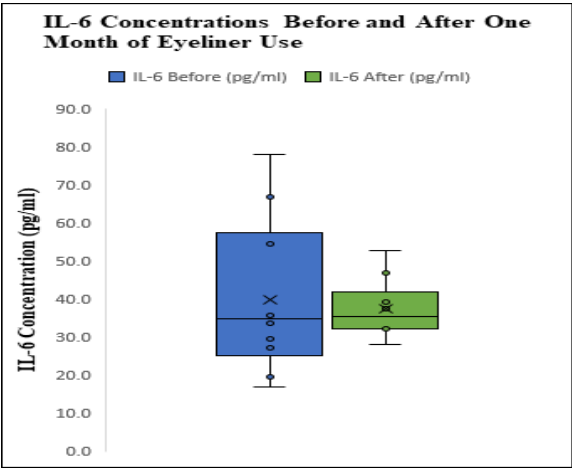


Figure 3 shows the distribution of IL-6 concentrations, indicating no substantial change after one month of eyeliner application.

IL-10 Concentrations

Mean IL-10 concentrations significantly decreased from 27.0 ± 9.8 pg/ml before (baseline tear cytokines) eyeliner use to 5.4 ± 4.2 pg/ml after one month of application ($p = 0.0001$).

Figure 4: IL-10 Concentrations Before and After One Month of Eyeliner Use.

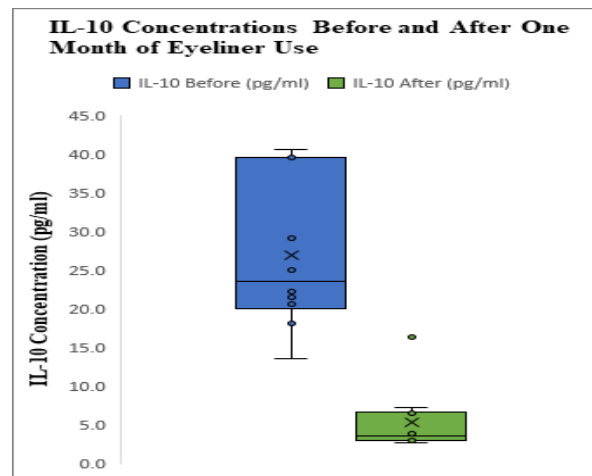


Figure 4 illustrates the distribution of IL-10 concentrations, showing a significant decrease after one month of eyeliner application.

Discussion

This study demonstrates that short-term eyeliner use significantly alters tear cytokine profiles in young adult females, with reductions in IL-1 β and IL-10 concentrations, while IL-6 remains stable. The absence of visual acuity changes aligns with Tan & Tong (2023), suggesting that short-term eyeliner use does not impair visual function in healthy individuals, likely due to minimal tear film disruption.

The significant decrease in IL-1 β , a pro-inflammatory cytokine, contrasts with reports of elevated IL-1 β in dry eye conditions (Solomon *et al.*, 2001; Massingale *et al.*, 2009). This reduction may reflect temporary suppression of inflammatory responses, possibly due to eyeliner components like waxes or pigments interacting with the ocular surface (Ng *et al.*, 2015). The marked decrease in IL-10, an anti-inflammatory cytokine, suggests a potential weakening of ocular immune defences, as IL-10 is crucial for controlling inflammation (Carreño *et al.*, 2010). The stability of IL-6 aligns with Ng (2013), who observed minimal IL-6 changes after short-term eyeliner use, likely due to participants' healthy ocular status and limited exposure duration.

These findings indicate that eyeliner may disrupt ocular surface immune homeostasis, particularly by reducing anti-inflammatory capacity, potentially increasing susceptibility to ocular surface issues with prolonged use (Prabhasawat *et al.*, 2020).

Eyeliners particle migration into the tear film (Ng *et al.*, 2018) may contribute to these changes by altering cytokine production. Limitations include the small sample size (n=10). Future studies should explore long-term effects, diverse populations, and additional cytokines.

Conclusion

Short-term eyeliner use significantly reduces IL-1 β and IL-10 concentrations in tears without affecting visual acuity, suggesting a temporary alteration in ocular surface immunity. The reduction in IL-10 raises concerns about diminished anti-inflammatory defences, potentially increasing risks for ocular surface issues with frequent use. These findings underscore the need for cautious eyeliner application and further research into its long-term ocular effects.

Conflict of Interest

The authors declare no conflicts of interest.

Acknowledgments

Author Contributions

- **Ayodeji E. Ige:** Conceptualised the study, designed the methodology, supervised the research, analysed data, and drafted and revised the manuscript.
- **Evangeline Kemi Lawrence:** Assisted in study design, conducted data collection, implemented the methodology, assisted in data analysis, interpreted data, and contributed to manuscript preparation.
- **Oluwasola M. Ojo:** Proofread and critically revised the manuscript for intellectual content and clarity.

References

- Carreño, E., Enríquez-de-Salamanca, A., Tesón, M., García-Vázquez, C., Stern, M. E., Whitcup, S. M., & Calonge, M. (2010). Cytokine and chemokine levels in tears from healthy subjects. *Acta Ophthalmologica*, 88(7), e250–e258.
- Dartt, D. A., & Willcox, M. D. (2013). Complexity of the tear film: Importance in homeostasis and dysfunction during disease. *Experimental Eye Research*, 117, 1–3.
- Dinarelli, C. A. (2000). Proinflammatory and anti-inflammatory cytokines in rheumatoid arthritis. *The American Journal of Medicine*, 108(6A), 15S–21S.
- Lwanga, S. K., & Lemeshow, S. (1991). Sample size determination in health studies: A practical manual. World Health Organisation.
- Massingale, M. L., Li, X., Vallabhajosyula, M., Chen, D., Wei, Y., & Asbell, P. A. (2009). Analysis of inflammatory cytokines in the tears of dry eye patients. *Cornea*, 28(9), 1023–1027.

- Ng, A. (2013). Ocular surface health and eye cosmetic interactions [Doctoral dissertation, Aston University]. *Aston University Research Archive*.
- Ng, A., Evans, K., North, R., & Purslow, C. (2015). Migration of cosmetic products into the tear film. *Eye & Contact Lens*, 41(5), 304–309.
- Ng, A., Evans, K., North, R. V., Jones, L., & Purslow, C. (2018). Impact of eye cosmetics on the eye, adnexa, and ocular surface. *Eye & Contact Lens*, 44(Suppl 2), S176–S183.
- Prabhasawat, P., Chirapapaisan, C., Chitkornkijsin, C., Pinitpuwadol, W., Saiman, M., & Veeraburion, A. (2020). Eyeliner induces tear film instability and meibomian gland dysfunction. *Cornea*, 39(4), 473–478.
- Solomon, A., Dursun, D., Liu, Z., Xie, Y., Macri, A. & Pflugfelder, S. C. (2001). Pro- and anti-inflammatory forms of interleukin-1 in the tear fluid and conjunctiva of patients with dry-eye disease. *Investigative Ophthalmology & Visual Science*, 42(10), pp.2283–2292.
- Tan, J. & Tong, L. (2023). Ocular surface and tear film changes after eyeliner application. *Contact Lens and Anterior Eye*, 46(2), pp.101–107.

**Prevalence and Determinants of Emergency Contraceptive Use Among
Students of Kwara State Polytechnic, Nigeria**

H.A. Ameen and S.A. Aderibigbe

Department of Epidemiology and Community Health,
Faculty of Clinical Sciences, University of Ilorin, Ilorin, Nigeria

T.M. Ajayi

Global Immunization Center, Ilorin Kwara State

Contact Address: Global Immunization Center, Ilorin Kwara State

R.A. Sheu, S.O. Oniyangi and I. Ologele

Department of Health Promotion and Environmental Health Education
Faculty of Education University of Ilorin, Ilorin, Nigeria

Corresponding author details:

- **Full name:** Hafsat Abolore Ameen
- **Complete postal address:** Department of Epidemiology and community Health, Faculty of Clinical Sciences, University of Ilorin, PMB 1515, Ilorin, Nigeria
- **Email address:** ameen.ha@unilorin.edu.ng
- **Phone number (with country code):** +2348033937472
- **ORCID number** (if available): 0000-0002-7724-7699

Running Title: Determinants of Emergency Contraceptive Usage Among Tertiary Students

Abstract

This study assessed the knowledge, prevalence, and determinants of emergency contraceptive (EC) use among students of Kwara State Polytechnic, Ilorin, Nigeria. Emergency contraception serves as a vital post-coital method for preventing unintended pregnancies, particularly among young adults who often face barriers to regular contraceptive access. A descriptive cross-sectional design was employed between August and September 2023 among 420 students selected through a multistage sampling technique. Data were collected using a pre-tested, structured questionnaire and analyzed with SPSS version 20. Descriptive and inferential statistics were used, with significance set at $p < 0.05$. The mean age of respondents was 25.14 ± 2.73 years, with females constituting 75.5%. Nearly all participants (95.5%) had heard of EC, and 68.3% demonstrated good knowledge. However, only 48.2% exhibited good practice. Most

respondents (80.7%) used EC following condom failure, 75.5% did so within 24 hours, and 63.4% accessed EC without prescription. Although 62% of respondents expressed positive perceptions toward EC, misconceptions persisted—particularly regarding its health effects and moral implications. Statistical analysis revealed no significant association between academic level and EC among tertiary students. Despite high awareness, knowledge and practice remain suboptimal due to misinformation and sociocultural constraints. Targeted educational interventions and campus-based reproductive health programs are recommended to enhance informed, safe, and responsible EC use among Nigerian youths.

Keywords: Oral Contraceptives; Emergency Contraception; Students; Health Knowledge, Attitudes, Practice; Nigeria

Introduction

Emergency contraception (EC), also known as post-coital contraception or the “morning-after pill,” is a preventive measure used to avert pregnancy following unprotected sexual intercourse (Cleland, Zhu, Goldstruck, Cheng, & Trussell, 2014). EC serves as a vital safety net in preventing unintended pregnancies, especially in instances of contraceptive failure, sexual assault, or unprotected intercourse. This method is particularly critical for adolescents and young adults, who often face barriers to regular contraceptive access and consistent usage due to stigma, limited sexual health education, and social norms (World Health Organization [WHO], 2020; Amoo, Samuel, & Idowu, 2021).

Globally, the prevalence of unintended pregnancies remains alarmingly high, particularly in low- and middle-income countries where access to modern contraceptive methods and comprehensive sexual education is limited (WHO, 2020; United Nations Population Fund [UNFPA], 2022). WHO (2020) estimates that approximately 80 million unintended pregnancies occur annually in developing nations, resulting in 40 million abortions and 10 million miscarriages. In Africa alone, nearly 5.5 million unsafe abortions occur each year, with 59% among young women aged 15–24 years (Sedgh, Bearak, Singh, et al., 2016). These statistics highlight the urgent need for increased access to EC as an essential component of reproductive health services for young people. In Nigeria, sociocultural and religious conservatism, gender norms, and limited comprehensive sexual education contribute to the low uptake of modern contraceptive methods, including EC (Oye-Adeniran, Adewole, & Umoh, 2019; Oladipo, Adeyemo, & Adebayo, 2021). Despite legal restrictions surrounding abortion, the high prevalence of unsafe abortions underscores the urgent need for preventive measures such as EC (Sedgh et al., 2016; Federal Ministry of Health [FMoH], 2018). While EC can prevent up to 99% of pregnancies when taken within 72 hours of unprotected sex (Cleland et al., 2014), its utilization remains suboptimal among Nigerian youths due to misinformation, stigma, and limited access (Ibrahim & Isa, 2018; Abiola, Odu, & Asekun-Olarinmoye, 2020). Tertiary institutions represent a crucial intervention point. Students often experience newfound independence, engage in exploratory sexual behaviors, and may lack consistent

access to family planning services (Adebayo & Adeoye, 2020). Paradoxically, although they are generally more literate and presumed to have better access to information than their non-schooling peers, their contraceptive behavior often reflects misinformation and inconsistent practices (Owolabi, Adeniyi, & Ajayi, 2020). Understanding EC knowledge and utilization within this group is essential for developing targeted reproductive health interventions.

Studies in Nigeria and other sub-Saharan African countries reveal varying levels of EC awareness and use. Reported usage among university students ranges from 5.4% to 28%, demonstrating disparities in both knowledge and accessibility (Amoo et al., 2021; Ibrahim & Isa, 2018). For instance, in Osun State, 80.3% of tertiary students had poor knowledge of EC, and only 36% correctly identified EC methods (Abiola et al., 2020). Such findings indicate a persistent gap between awareness and actionable knowledge, fueled by misinformation, stigma, and inadequate reproductive health education (Ganie, Hassan, & Musa, 2021). Kwara State Polytechnic, Ilorin—located in Nigeria’s North-Central region—offers a unique microcosm for examining these dynamics. The institution hosts thousands of students from diverse cultural, religious, and socio-economic backgrounds. This multicultural and multireligious context provides an ideal setting to explore variations in knowledge, attitudes, and practices related to EC (Amoo et al., 2021).

Although awareness of EC among Nigerian youths is reportedly high, actual knowledge, perception, and appropriate utilization remain low (Amoo et al., 2021; Nnebue, Ilo, & Umeh, 2020). Many students possess only superficial knowledge—such as recognizing brand names—without understanding the correct timing, dosage, or mechanism of action (Oye-Adeniran et al., 2019). This misinformation often leads to inappropriate or inconsistent use. Despite various health education initiatives, there remains a persistent gap between awareness and practice, indicating that existing interventions are either ineffective or insufficiently targeted (Nnebue et al., 2020). The situation is further complicated by sociocultural taboos surrounding premarital sex and contraception, discouraging open discussion or access to EC services among young people (Oladipo et al., 2021).

At Kwara State Polytechnic, anecdotal and emerging research evidence suggests that while a significant proportion of students have heard of EC, many demonstrate poor knowledge and misuse the method (Adebisi, Oke, & Alaran, 2021). Such inadequate knowledge contributes to high rates of unintended pregnancies and unsafe abortions among students, posing serious reproductive health challenges. Furthermore, determinants such as gender, academic level, cultural background, and peer influence remain underexplored within this population (Owolabi et al., 2020; Adedokun, Ogunyemi, & Yusuf, 2022). Without empirical, context-specific data, policymakers and educators lack the evidence necessary to design effective, culturally relevant interventions to improve EC utilization and reproductive health literacy among tertiary students. Understanding the knowledge, prevalence, and determinants of EC use among

students of Kwara State Polytechnic is crucial for several reasons. First, this group represents an important segment of Nigeria's young, sexually active population who are at risk of unintended pregnancies due to limited contraceptive knowledge and access (Amoo et al., 2021). Second, by identifying determinants such as age, academic level, gender, and cultural background, this study can help tailor reproductive health interventions that are both age-appropriate and culturally sensitive (Owolabi et al., 2020; Adedokun et al., 2022).

Moreover, this study aligns with Nigeria's national health goals of improving reproductive health outcomes and reducing maternal morbidity through effective family planning education and services (FMOH, 2018). Evidence from this research will inform educational institutions, policymakers, and public health practitioners in designing youth-friendly programs that translate awareness into proper contraceptive behavior. Ultimately, improving EC knowledge and practice among tertiary students will not only help prevent unintended pregnancies and unsafe abortions but also contribute to broader public health and gender equality objectives outlined by UNFPA (2022).

Materials and Methods

Study Design and Setting

A descriptive cross-sectional study was conducted from August 3, 2023 to September 29, 2023 at Kwara State Polytechnic, Ilorin, Nigeria. Kwara State polytechnic is a tertiary institution that provides educational training in science, technology, and management to over 16,000 students. The Polytechnic consists of several academic institutes, including the Institute of Finance and Management Studies, Institute of Applied Science, Institute of Information and Communication Technology, and Institute of Environmental Studies.

Study Population, Sample and Sampling

The study population included male and female undergraduate students across various academic levels (ND I, ND II, HND I, and HND II). The inclusion criteria required students to be enrolled in regular or part-time programs, aged 15–30 years, and willing to provide informed consent.

Using a prevalence rate of 58.1% from a previous Nigerian study (Adedokun, 2022), a minimum sample size of 374 was calculated using the Fisher's formula. To account for the non-respondents, the sample size was increased to 420.

A multistage sampling technique was employed to select participants for the study. At First, four Faculties were randomly selected. Next, two departments were chosen from each of the selected Faculties. Proportional allocation was then used to determine the number of students to be sampled from each department, ensuring representative participation. Finally, systematic random sampling was applied to select individual students from each department, utilizing class nominal rolls as the sampling frame.

Data Collection

Data were gathered via a pre-tested, structured, self-administered questionnaire, divided into sections covering socio-demographic characteristics, knowledge, perception, and practice of EC. Pre-testing was done among University of Ilorin undergraduates using ten percent of the total sample size (42 respondents) to ensure clarity and validity.

Ethical Considerations

Ethical approval was obtained from the University of Ilorin Ethical Review Board (UERC/ASN/2023/2566). Written informed consent was obtained from each participant, and confidentiality was strictly maintained.

Data Analysis

Data were entered into SPSS version 20.0 for analysis. Descriptive statistics were used to summarize frequencies and percentages. Chi-square tests were used to assess associations between variables, with a p-value < 0.05 considered statistically significant.

RESULTS

Demographic Profile

Table 1: Socio-Demographic Characteristics of Respondents (N=420)

Variable	Frequency	Percentage (%)
Age (Years)		
15–20	20	4.8
21–25	224	53.3
26–30	176	41.9
Mean ± SD		25.14 ± 2.73
Gender		
Male	103	24.5
Female	317	75.5
Religion		
Christianity	202	48.1
Islam	218	51.9
Marital Status		
Single	369	87.9
Married	51	12.1
Tribe		
Yoruba	323	76.9
Igbo	90	21.4
Hausa	6	1.4
Others	1	0.2
Level of Study		
OND I	105	25.0

OND II	90	21.4
HND I	132	31.4
HND II	93	22.1

***OND** = Ordinary National diploma

***HND** = Higher National Diploma

As shown in table 1, the mean age of the respondents was 25.14 ± 2.73 years. The majority were females (75.5%) and single (87.9%). The dominant ethnic group was Yoruba (76.9%), and most participants practiced Islam (51.9%).

Knowledge of Emergency Contraceptives

Table 2: Knowledge of Emergency Contraception (EC) among Respondents

Knowledge Indicators	Frequency	Percentage (%)
Heard of EC	401	95.5
Knows EC prevents unwanted pregnancy	382	91.0
Aware of combined oral contraceptive as EC	365	86.9
Knows EC not recommended as routine contraceptive	308	73.3
Knows time limit for EC use is within 72 hours	301	71.7
Correct dose (one dose)	307	73.1
Knows EC side effects exist	327	77.9

Table 2 revealed that a majority of respondents had a good understanding of emergency contraceptives (EC). Almost all respondents (95.5%) had heard of EC, with 91% correctly identifying its primary purpose as preventing unwanted pregnancy. A substantial proportion (86.9%) recognized combined oral contraceptives as a method of EC, while 73.1% knew that it should be used within 72 hours. Additionally, 73.3% of respondents were aware that a single dose of EC is effective.

Perceptions of Emergency Contraceptives

Table 3: Perception of Respondents Toward Emergency Contraceptive Use

Perception Statement	Strongly Agree (%)	Agree (%)	Neutral (%)	Disagree (%)	Strongly Disagree (%)
EC encourages promiscuity	5.2	6.7	24.0	45.5	18.6
Repeated EC use poses health risk	77.9	9.8	3.1	6.0	3.3
EC should be available without prescription	45.7	8.6	8.3	19.5	17.9
EC is safe for preventing unplanned pregnancy	57.8	13.6	13.1	11.6	3.8
Would recommend EC to family/friends	84.0	2.1	4.8	1.7	7.4

Respondents' perceptions of EC were varied; while less than half (45.5%) disagreed with the notion that EC encourages promiscuity, a significant majority (87.7%) believed that repeated use poses health risks. Slightly more than half (57.8%) considered EC to be safe, and a substantial proportion (84%) would recommend it to friends or family members (table 3).

Practice of Emergency Contraceptives

Table 4: Practice of Emergency Contraception Among Users (n=290)

Practice Indicators	Frequency	Percentage (%)
Ever used EC	290	69.0
Used EC during last coitus	230	79.3
Reason: Condom breakage	234	80.7
Used EC within 24 hours	219	75.5
Accessed EC without prescription at local clinic	184	63.4
Will use EC again	225	77.6

The study also explored the practice of EC among respondents. As shown in table 4, a significant proportion of the participants (69%) had used EC at some point, with the majority (80.7%) using it after condom failure. Among those who had used EC, 75.5% did so within 24 hours, and 63.4% accessed it without a prescription. Moreover, 77.6% of respondents intended to use EC again in the future.

Knowledge, Perception, and Practice Scores

Table 5: Knowledge, Perception, and Practice Summary scores among respondents

Variable	Good (%)	Poor (%)
Knowledge	68.3	31.7
Perception	62.0	38.0
Practice	48.2	51.8

Table 5 presents the respondents' knowledge, perception, and practice scores regarding EC. A substantial proportion (68.3%) demonstrated good knowledge of EC, while 62% had a positive perception. However, only 48.2% of respondents exhibited good practice.

Statistical Associations

Table 6: Association Between Academic Level and Knowledge of respondents on EC

Academic Level	Good Knowledge	Poor Knowledge	χ^2	p-value
ND I	76	29	5.76	0.124
ND II	56	34		
HND I	98	34		
HND II	72	21		

Note: ND means National Diploma
HND means Higher National Diploma

As shown in Table 6, there is no significant associations between academic level and knowledge of EC ($p=0.124$); nor between knowledge and practice of EC ($p=0.210$).

DISCUSSION

This study revealed a remarkably high level of awareness of emergency contraception (EC) among students of Kwara State Polytechnic, with 95.5% reporting prior knowledge and 91% correctly identifying its role in preventing unwanted pregnancies. These findings are consistent with results from previous studies in Nigeria and other African countries, such as those conducted among students in Osun State, Kaduna, and Enugu, which also reported high awareness levels ranging between 80% and 96% (Adeniji, Tijani, & Owonikoko, 2013; Hilary, 2014; Arinze-Onyia, Modebe, Nwuba, & Obionu, 2010). However, as in other studies, awareness did not necessarily translate into comprehensive understanding or correct usage. Only 68.3% of respondents demonstrated good knowledge of EC, and significant misconceptions persisted, especially concerning the correct timing, dosage, and safety of use. This finding underscores a critical knowledge–practice gap that has also been reported among university students in South Africa, Ethiopia, and Ghana (Myer et al., 2007; Tilahun, Assefa, & Belachew, 2010; Amalba, Mogre, Appiah, & Mumuni, 2014).

The predominance of young, unmarried female respondents (75.5%) mirrors patterns observed in similar tertiary institution-based studies in sub-Saharan Africa (Zelege & Zelege, 2009; Tilahun et al., 2010; Amalba et al., 2014; Kongnyuy et al., 2007). This demographic group is often more sexually active yet faces more pronounced barriers to accessing accurate reproductive health information and services due to gender norms, fear of stigmatization, and moral restrictions. The association between female gender and higher EC awareness, but not necessarily correct knowledge or usage, may reflect both increased exposure to reproductive health messages and persistent misinformation in peer and social networks (Owolabi, Adeniyi, & Ajayi, 2020; Adedokun, Ogunyemi, & Yusuf, 2022).

A key finding of this study is the significant disparity between EC knowledge and practice. Although nearly all participants had heard of EC, fewer than half (48.2%)

reported good or consistent practice. This discrepancy reflects a well-documented phenomenon in reproductive health behavior known as the “knowledge–behavior paradox,” where awareness of contraceptive methods does not automatically lead to appropriate utilization (Bankole, Singh, & Hussain, 2014). Factors contributing to this paradox include fear of side effects, cost, limited accessibility, judgmental attitudes of healthcare providers, and social or religious disapproval. In this study, sociocultural taboos and misinformation were especially influential—most respondents believed repeated EC use could damage fertility or cause long-term health complications, echoing patterns reported in studies from Ethiopia and Cameroon (Tilahun et al., 2010; Kongnyuy et al., 2007).

The finding that 63.4% of respondents obtained EC from informal sources, such as patent medicine vendors or pharmacies, without a prescription, also raises significant public health concerns. Similar patterns have been reported across Nigeria, Ghana, and Ethiopia, where poor regulation of pharmaceutical sales has led to widespread misinformation and inappropriate use of EC (Amalbaet et al., 2014; Zeleke & Zeleke, 2009; Babatunde et al., 2016). This overreliance on non-professional sources can perpetuate incorrect dosing, unsafe timing, and limited counseling on side effects. The fact that 77.9% of respondents believed that frequent EC use poses health risks indicates persistent misconceptions that can only be addressed through structured educational interventions and better pharmacy regulation.

Despite these barriers, the willingness of 77.6% of respondents to use EC again and the 84% who would recommend it to others demonstrate a generally positive disposition toward the method once it is tried. This finding aligns with previous research in Nigeria and Ethiopia, which suggests that direct personal experience often reduces moral stigma and misconceptions (Arinze-Onyia et al., 2010; Zeleke & Zeleke, 2009). Therefore, targeted interventions that promote accurate, experience-based peer education could substantially enhance correct and consistent use.

Notably, the lack of significant association between academic level and EC knowledge ($p = 0.124$) or between knowledge and practice ($p = 0.210$) suggests that formal education alone is insufficient to shape reproductive health behavior. This finding is consistent with prior studies indicating that EC use is more strongly influenced by sociocultural and behavioral determinants—such as peer influence, religious beliefs, perceived susceptibility to pregnancy, and past contraceptive experiences—than by educational attainment alone (Kistnasamy, Reddy, & Jordaan, 2009; Tilahun et al., 2010; Subedi, 2012). This insight reinforces the need for interventions that move beyond classroom-based sexual education to include interactive, participatory models that engage students in open discussions about contraception.

From a public health perspective, these findings have several implications. First, they highlight the necessity for institutional health policies that ensure consistent access to EC and comprehensive sexual health counseling on campus. Integrating family life and reproductive health education into tertiary curricula could normalize discourse around

contraception and dispel persistent myths. Second, gender-sensitive and faith-friendly approaches are essential in a context like Nigeria, where moral and religious views significantly influence sexual behavior (Oye-Adeniran, Adewole, & Umoh, 2019; Oladipo, Adeyemo, & Adebayo, 2021). Establishing peer educator networks and leveraging digital health platforms could further enhance accessibility and confidentiality for students seeking EC information and services.

Furthermore, the observed patterns reflect broader structural gaps in Nigeria's reproductive health system, where young people often fall outside the target demographic of conventional family planning programs. Policymakers and educators must therefore prioritize youth-centered, culturally appropriate strategies that bridge the gap between awareness and actual preventive behavior. Strengthening partnerships between universities, primary healthcare providers, and non-governmental organizations could create sustainable frameworks for continuous reproductive health engagement.

Finally, while this study's cross-sectional design and reliance on self-reported data limit causal inference and may introduce social desirability bias, its findings nonetheless provide valuable empirical evidence for designing targeted interventions. The diversity of the Kwara State Polytechnic population, comprising students from various ethnic and religious backgrounds, enhances the representativeness and generalizability of the results.

In conclusion, while awareness of EC among Nigerian tertiary students is high, actual knowledge, perception, and correct utilization remain inadequate. The persistence of misinformation and sociocultural resistance underscores the need for comprehensive, context-sensitive reproductive health education that transcends awareness campaigns to focus on behavior change. Promoting accurate information, empowering peer educators, and ensuring accessible and confidential EC services will be crucial steps toward reducing unintended pregnancies, preventing unsafe abortions, and improving overall reproductive health outcomes among young Nigerians.

Acknowledgements: We appreciate the students of Kwara State Polytechnic, Ilorin, Nigeria for their participation and sacrifice in this study.

Conflict of Interest/Declaration: The authors declare no conflicts of interest in this study.

Sources of fund: This research received no external funding.

REFERENCES

- Adedokun, O., Ogunyemi, A. O., & Yusuf, O. (2022). Reproductive health knowledge and contraceptive use among Nigerian adolescents. *Sexual and Reproductive Healthcare*, 31, 100713.
- Adebayo, O., & Adeoye, A. (2020). Knowledge and perception of emergency contraception among undergraduates in South-West Nigeria. *African Journal of Reproductive Health*, 24(1), 91–101.

- Adebisi, Y. A., Oke, G. I., & Alaran, A. J. (2021). Sexual behavior and contraceptive practices among Nigerian tertiary institution students: Implications for health education. *BMC Public Health*, 21(1), 1456.
- Abiola, A., Odu, O., & Asekun-Olarinmoye, E. (2020). Awareness and use of emergency contraception among university students in Osun State, Nigeria. *Nigerian Journal of Clinical Practice*, 23(4), 495–502.
- Adeniji, A. O., Tijani, A. M., & Owonikoko, K. M. (2013). Knowledge and determinants of emergency contraception use among students in tertiary institutions in Osun State, Nigeria. *Journal of Basic and Clinical Reproductive Sciences*, 2(1), 46–53.
- Amalba, A., Mogre, V., Appiah, M. N., & Mumuni, W. A. (2014). Awareness, use and associated factors of emergency contraceptive pills among women of reproductive age in Tamale, Ghana. *BMC Women's Health*, 14, 114.
- Amoo, E. O., Samuel, G. W., & Idowu, A. E. (2021). Contraceptive knowledge and usage among students in Nigerian tertiary institutions. *African Population Studies*, 35(2), 5690–5705.
- Arinze-Onyia, S. U., Modebe, I. E., Nwuba, C., & Obionu, C. N. (2010). Knowledge and use of emergency contraception among students in a tertiary institution in Enugu, Nigeria. *Nigerian Journal of Clinical Practice*, 13(3), 376–379.
- Babatunde, O. A., Ibirongbe, D. O., Omede, O., Babatunde, A. M., & Durowade, K. A. (2016). Knowledge and use of emergency contraception among students of public secondary schools in Ilorin, Nigeria. *Journal of Reproduction and Contraception*, 27(2), 61–67.
- Bankole, A., Singh, S., & Hussain, R. (2014). *Sexual and reproductive health in Nigeria: Status and emerging issues*. New York, NY: Guttmacher Institute.
- Cleland, K., Zhu, H., Goldstruck, N., Cheng, L., & Trussell, J. (2014). The efficacy of emergency contraception: A systematic review of clinical evidence. *Human Reproduction Update*, 20(5), 694–706.
- Federal Ministry of Health (FMoH). (2018). *National guidelines for reproductive health and family planning services*. Abuja, Nigeria: Author.
- Ganie, A. A., Hassan, S. I., & Musa, T. (2021). Barriers to emergency contraceptive use among Nigerian youths. *The Pan African Medical Journal*, 38, 250.
- Hilary, P. (2014). Knowledge, attitude and practice of emergency contraception among university students in Kaduna, Nigeria. *Nigerian Journal of Clinical Practice*, 17(6), 749–755.
- Ibrahim, M. T. O., & Isa, A. H. (2018). Perception and use of emergency contraceptives among female university students in Northern Nigeria. *Tropical Journal of Obstetrics and Gynaecology*, 35(1), 48–54.
- Kistnasamy, E. J., Reddy, P., & Jordaan, J. (2009). Emergency contraception: Knowledge, attitudes and practices among female university students. *South African Journal of Obstetrics and Gynaecology*, 15(1), 14–19.

- Kongnyuy, E. J., Ngassa, P., Fomulu, N., Wiysonge, C. S., Kouam, L., & Doh, A. S. (2007). A survey of knowledge, attitudes and practice of emergency contraception among university students in Cameroon. *BMC Emergency Medicine*, 7(1), 7.
- Myer, L., Mlobeli, R., Cooper, D., Bracken, H., & Zweigenthal, V. (2007). Knowledge and use of emergency contraception among women in the Western Cape Province of South Africa: A cross-sectional study. *BMC Women's Health*, 7, 14.
- Nnebue, C. C., Ilo, C. I., & Umeh, U. A. (2020). Awareness and utilization of emergency contraception among tertiary students in Anambra State, Nigeria. *International Journal of Medicine and Health Development*, 25(2), 87–95.
- Oladipo, S. E., Adeyemo, D. A., & Adebayo, S. O. (2021). Sexual behavior, contraceptive use, and unintended pregnancy among undergraduates in Nigeria. *Journal of Reproductive Health*, 18(2), 105–113.
- Owolabi, E. O., Adeniyi, O. V., & Ajayi, A. I. (2020). Trends and determinants of contraceptive use among young women in Nigeria: Evidence from demographic and health surveys (2003–2018). *BMC Women's Health*, 20, 178.
- Oye-Adeniran, B. A., Adewole, I. F., & Umoh, A. V. (2019). Emergency contraception: Perceptions and practice among Nigerian youths. *International Family Planning Perspectives*, 45(3), 102–110.
- Sedgh, G., Bearak, J., Singh, S., et al. (2016). Abortion incidence between 1990 and 2014: Global, regional, and subregional levels and trends. *The Lancet*, 388(10041), 258–267.
- Subedi, M. (2012). Factors influencing the use of emergency contraceptives among college students in Kathmandu. *Nepal Medical College Journal*, 14(4), 289–292.
- Tilahun, D., Assefa, T., & Belachew, T. (2010). Factors associated with emergency contraceptive use among female university students in Ethiopia: A cross-sectional study. *BMC Research Notes*, 3, 319.
- United Nations Population Fund (UNFPA). (2022). *State of world population 2022: Seeing the unseen—The case for action in the neglected crisis of unintended pregnancy*. New York, NY: Author.
- World Health Organization (WHO). (2020). *Adolescent pregnancy fact sheet*. Geneva, Switzerland: Author.
- Zelege, B. M., & Zelege, Z. M. (2009). Emergency contraception: Awareness, attitude and practice among female university students in Addis Ababa, Ethiopia. *Ethiopian Journal of Health Development*, 23(3), 232–235.

**Single-Nucleotide Polymorphism Landscape and Allele Frequency
Patterns in the HIV-1 Envelope (env) Gene**

Olalekan A. Agede

Department of Pharmacology and Therapeutics, University of Ilorin, Ilorin, Nigeria.

Louis O. Odeigah

Department of Family Medicine, Afe Babalola University,
Ado-Ekiti, Ekiti State, Nigeria.

**Odiakaose P. Odeigah, Dapo S. Oyedepo, Olawale S. Aiyedun, Nasiru Sanni,
Wemimo A. Alaofin and Obinna Christopher Anaduaka**

Department of Medicine, University of Ilorin/University of Ilorin
Teaching Hospital, Nigeria.

***Corresponding Author:** Olalekan Ayodele Agede

Email: agede.aa@unilorin.edu.ng or niffynimmy@gmail.com

ORCID ID: 0000-0001-8033-2884

Abstract

The Human Immunodeficiency Virus (HIV) envelope glycoprotein (Env) is pivotal in mediating viral entry into host cells and serves as a key target for vaccine development. The HIV-1 envelope (env) gene exhibits extensive genetic variability, driven largely by the accumulation of single-nucleotide polymorphisms (SNPs) that arise during viral replication and evolution. This study aims to dissect the genetic intricacies of the HIV Env gene by analyzing SNP distribution and allelic frequency patterns. Using sequences retrieved from the NCBI database, we conducted a comprehensive analysis utilizing the R statistical environment. We assessed SNP distribution across codon positions and evaluated allelic frequencies within various HIV populations.

Our results indicate non-uniform SNP distributions with a high density at the third codon position, suggesting potential hotspots for mutational activity. The allelic frequency patterns displayed multimodal distributions, indicating a substantial proportion of multimodal allele frequency spectra across polymorphic sites, reflecting variable mutation persistence across viral sequences. These findings highlight a pronounced peak in allele frequencies around 0.6, suggesting selective advantages for certain alleles. The majority of loci were biallelic, revealing significant genetic diversity, which is crucial for the virus's adaptability.

Our study underscores the complex nature of HIV genetic variation and its implications for the virus's evolution, the development of vaccines, and therapeutic strategies. The

insights gained from this research contribute to the understanding of HIV's adaptive mechanisms and pave the way for personalized medical approaches in HIV treatment.

Keywords: HIV treatment, Glycoprotein, HIV, SNPs, Allelic frequency, Loci

Introduction

The emergence of Human Immunodeficiency Virus (HIV) has presented an unparalleled challenge to global health, with the envelope glycoprotein (Env) playing a central role in the virus's pathogenesis. The Env protein, composed of gp120 and gp41 subunits, facilitates viral entry into host cells by binding to CD4 receptors and is a prime target for vaccine development (Kwong *et al.*, 1998). The genetic variability of the Env gene, particularly its propensity for rapid mutation, significantly complicates the development of effective therapeutic interventions (Wei *et al.*, 2003).

Single nucleotide polymorphisms (SNPs) within the HIV Env gene contribute to the genetic diversity that underpins the virus's ability to evade host immune defenses. This high mutation rate results in a complex array of viral quasispecies within a single host, challenging both vaccine efficacy and drug resistance (Shankarappa *et al.*, 1999). The SNP distribution within the Env gene is a critical area of study, as it informs the development of broad-spectrum antiviral strategies (Gaschen *et al.*, 2002).

Allelic frequency patterns provide valuable insights into the evolutionary dynamics of HIV, revealing how selective pressures shape viral populations. Alleles that confer advantageous traits, such as immune evasion or drug resistance, tend to proliferate, and their frequency patterns can indicate which strains are most widespread and potentially the most significant targets for public health interventions (Moore *et al.*, 2002). Understanding these patterns is essential for the design of vaccines that can offer protection against diverse viral strains (Korber *et al.*, 2000).

The functional implications of the Env gene's genetic complexity are profound. The protein's role in viral fusion and entry is highly dependent on its conformation, which is, in turn, determined by its amino acid sequence. SNPs that lead to changes in this sequence can have far-reaching effects on the Env protein's structure and function, influencing the virus's ability to infect host cells and the disease's progression (Wyatt *et al.*, 1998). Consequently, the correlation between SNP patterns and protein conformation is an important focus for developing antiretroviral therapies (Li *et al.*, 2019; Doria-Rose *et al.*, 2010; Binley *et al.*, 2004).

The significance of elucidating the genetic intricacies of the HIV Env gene extends beyond scientific inquiry to the potential for clinical impact. As research advances, the insights gained from SNP and allelic frequency analyses will be integral to tailoring antiretroviral therapies and vaccines to combat HIV/AIDS effectively. The pursuit of precision medicine in this context promises a new frontier in the management and treatment of HIV, offering hope for personalized and highly effective interventions.

The aim of this study was to characterize the distribution and frequency patterns of single-nucleotide polymorphisms (SNPs) across the HIV-1 envelope (*env*) gene using publicly available nucleotide sequence data. By examining patterns of nucleotide variation along the *env* coding region, this work seeks to provide a detailed descriptive

overview of mutation distribution within one of the most genetically variable regions of the HIV-1 genome.

Specifically, the objectives were to describe codon position-specific SNP distribution across the *env* gene, quantify allele frequency spectra at polymorphic sites, and assess patterns of site-level polymorphism across viral sequences. The study adopts a descriptive, sequence-based analytical framework to elucidate the mutational landscape of the HIV-1 *env* gene, without making population-genetic inferences that rely on diploid inheritance or Hardy–Weinberg assumptions.

METHODOLOGY

Sequence Retrieval and Data Preparation

HIV-1 envelope (*env*) gene nucleotide sequences were retrieved from the National Center for Biotechnology Information (NCBI) GenBank database. Only sequences annotated as **HIV-1 *env*** were included. Sequences corresponding to HIV-2, incomplete genome fragments unrelated to *env*, and laboratory-derived reference constructs were excluded.

Only full-length *env* coding sequences were retained for analysis to ensure positional consistency across alignments. Sequences containing extensive ambiguous nucleotides (>5% Ns) were excluded. Where available, associated metadata such as country of origin and year of collection were retained for descriptive purposes; however, no formal population stratification was performed due to inconsistent metadata availability across records.

Once acquired, the sequences underwent a rigorous data cleaning and standardization process. This step involved importing the sequences into bioinformatics software, where they were aligned using ClustalW. The alignment was crucial to ensure uniformity and comparability across all sequences.

Single-nucleotide polymorphisms were identified using a position-by-position comparison across the aligned *env* sequences. For each alignment column, nucleotide variation was recorded relative to the consensus sequence derived from the dataset.

Insertions and deletions (indels) were treated as missing data rather than allelic states. Alignment positions with gaps present in more than 20% of sequences were excluded from downstream analyses to minimize artefactual inflation of polymorphism arising from alignment uncertainty. Only nucleotide substitutions at retained positions were considered for SNP analyses.

Genetic Analysis Using *adegenet* in R

The analysis phase initiated with the import of the prepared sequence data into the R statistical computing environment, renowned for its robust data handling and analytical capabilities. Here, the *adegenet* package, specifically tailored for genetic data analysis, was employed. Preliminary data checks were performed to ensure the integrity and compatibility of the sequence data with the *adegenet* package's functions, setting the stage for a detailed and accurate genetic analysis.

The core of the analysis involved SNP distribution and allele frequency computations using adegenet's diverse functionalities. The 'find.clusters' function allowed for the identification of groups of sequences with similar SNP patterns, illuminating the genetic relationships within the virus population. Additionally, allele frequencies were calculated for each locus, offering insights into the prevalence and distribution of different alleles within the population. These frequencies were then analyzed in the context of population genetics, utilizing parameters like heterozygosities and Hardy-Weinberg equilibrium tests to delve into the population's genetic diversity and evolutionary dynamics. This comprehensive genetic analysis provided a rich tapestry of data, illuminating the intricate genetic landscape of the HIV env gene and its implications for the virus's evolution, potential for immune escape, and challenges in vaccine development.

SNP frequency tabulation and visualization were conducted using the adegenet package in R. Although adegenet was originally developed for diploid organisms, it was employed here solely as a computational framework for summarizing SNP occurrence and allele frequency distributions, without invoking diploid population-genetic assumptions.

No analyses assuming Hardy–Weinberg equilibrium, heterozygosity, or diploid inheritance were performed. Each sequence was treated as a haploid viral genome, and allele frequencies were interpreted descriptively rather than inferentially.

RESULTS

Codon Position-Specific SNP Distribution in the Genome

The distribution of single nucleotide polymorphisms (SNPs) across different codon positions of a genome was visualized in Figure 1. Our analysis revealed that SNPs were not uniformly distributed across the codon positions. Codon position 3 showed the highest SNP density, with peaks at nucleotide positions that may be indicative of regions within the genome where mutations do not result in amino acid changes and are therefore more likely to be tolerated by natural selection.

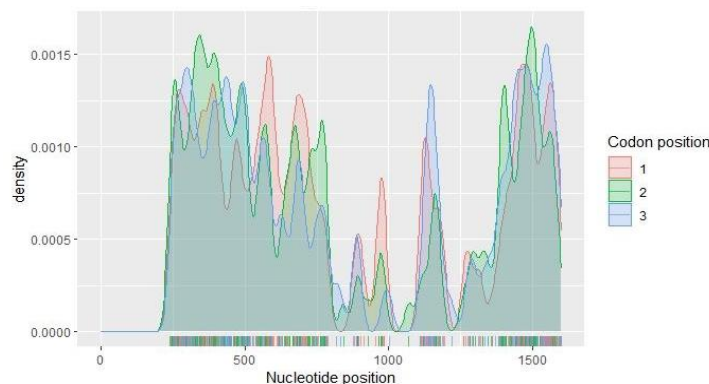


Figure 1. Codon position–specific distribution of SNPs across the HIV-1 env gene.

Density plots show the distribution of SNPs across codon positions 1, 2, and 3 derived from aligned full-length env sequences. Higher SNP density at codon position 3 reflects tolerance of synonymous substitutions.

Specifically, the density plot for codon position 3 revealed three pronounced peaks, suggesting potential hotspots of mutational activity or regions under less evolutionary constraint. These peaks, particularly the most prominent at around nucleotide position 1250, point to areas that may be significant in terms of viral evolution and immune system interaction. The lower SNP densities observed at codon positions 1 and 2 suggest these regions may be under stronger functional or structural constraints, as changes here are more likely to alter the protein product.

Distribution of Second Allele Frequencies

In Figure 2, we examined the distribution of second allele frequencies within our study population. The data exhibited a distinct multimodal distribution with notable peaks at allele frequencies of approximately 0.2, 0.5, and 0.8. The peak at 0.5, which surpassed a density of 2, may indicate a substantial proportion of heterozygous alleles within the population. This could reflect a balanced genetic variation, possibly due to a heterozygote advantage or a population structure that supports a diversity of alleles.

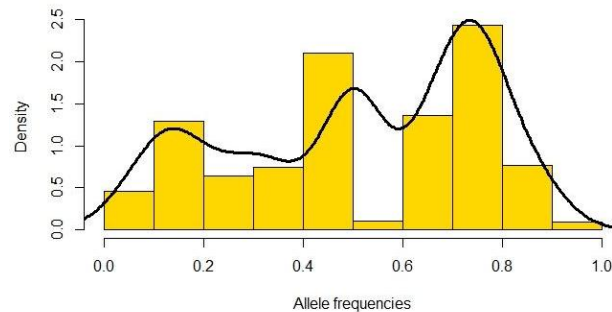


Figure 2. Distribution of minor allele frequencies across polymorphic sites. Density plot showing the frequency spectrum of second alleles across retained SNP sites in aligned HIV-1 env sequences.

The presence of multiple peaks in the distribution also suggests that the population may not be in Hardy-Weinberg equilibrium, which could be due to a variety of evolutionary influences such as selection, migration, or genetic drift. The valleys between these peaks, particularly between the 0.2 and 0.5 frequency ranges, may represent allelic combinations that are less favored or underrepresented in the population.

Overall Allele Frequency Distribution

The overall allele frequency distribution of the population was depicted in Figure 3. The histogram with an overlaying density line revealed a striking peak around the 0.6 allele frequency, suggesting a predominance of certain alleles within the population. This

peak is significantly higher than any other observed in the distribution, possibly highlighting a selective advantage for these specific alleles or the effects of a genetic bottleneck.

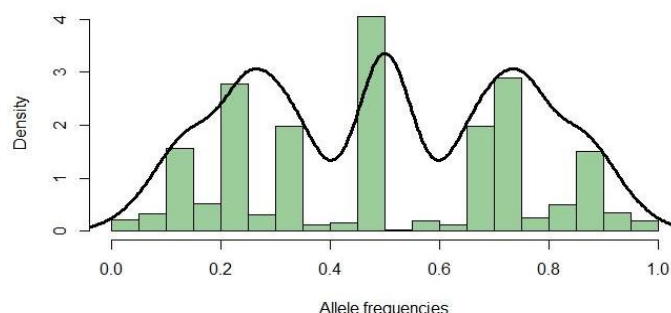


Figure 3. Overall allele frequency distribution across polymorphic loci. Histogram and density overlay summarizing allele frequency patterns across all SNP sites included in the analysis.

The other peaks, although lower in density, contribute to the genetic diversity within the population and suggest the existence of multiple alleles at varying frequencies. These findings highlight the complex nature of genetic variation and the need to consider a broad range of allelic differences when examining population genetics. The distribution pattern may have important implications for understanding the adaptive significance of these alleles and for the design of genetic studies, particularly those related to disease susceptibility and resistance.

Individual Variation in SNP Presence

Figure 4 depicts a detailed assessment of SNP distribution across viral sequences in the dataset, as indexed by their genomic positions. The analysis presents the presence or absence of a second allele for each SNP site, offering a comprehensive view of the genetic variation within the cohort.

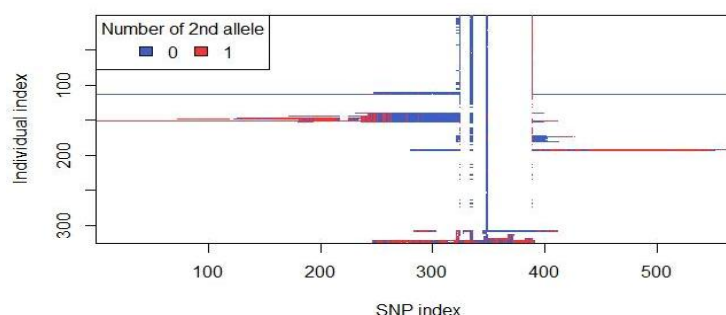


Figure 4. Presence and absence of minor alleles across SNP indices. Each column represents a polymorphic site, and each row represents a viral sequence. Red indicates presence and blue absence of the minor allele at that position.

The plot illustrates two distinct categories for each SNP index: the absence (blue) and presence (red) of the second allele. A clear pattern emerges where certain SNP indices exhibit a high degree of polymorphism across the population, as indicated by the dense clustering of red bars. Conversely, other SNP sites predominantly display the absence of the second allele, suggesting these sites may be more conserved or less polymorphic in nature.

Conservation and Polymorphism Patterns

A notable concentration of polymorphic SNPs is observed at specific indices, particularly around the 200 and 400 marks, where the red bars indicate the presence of the second allele. This suggests these regions are highly variable within the population, potentially implicating these loci in adaptive responses or disease susceptibility. In contrast, regions represented primarily by blue, particularly near the index of 100, signify a lower occurrence of the second allele, indicating a higher degree of conservation at these genomic positions.

Polymorphism Spectrum Across Loci

Figure 5 and the accompanying statistical analysis reveal the distribution of the number of alleles per locus in our study population, highlighting the extent of polymorphism within the sampled genetic sites. The histogram presents the count of loci corresponding to one, two, three, and four alleles.

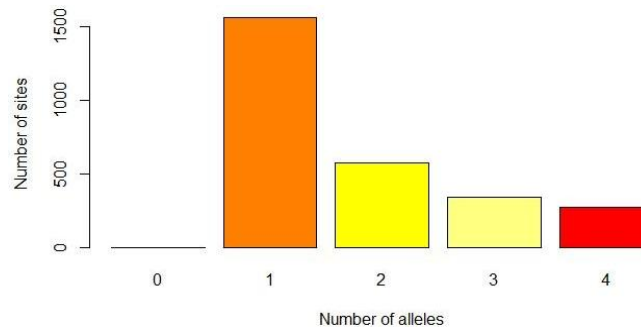


Figure 5. Distribution of allelic states per polymorphic site. Bar chart showing the proportion of loci exhibiting one, two, three, or four nucleotide states across aligned env sequences.

Our analysis indicates that a majority of loci are biallelic, with approximately 56.7% of sites having two alleles. Monoallelic loci, which contain only a single allele, account for 20.9% of the sample. Sites with three alleles are observed at 12.4%, while the least common are tetra-allelic loci, constituting 10.0% of the sample. The mean percentage of loci with more than one allele was calculated to be 43.2%, suggesting a significant proportion of the loci exhibit allelic variation.

Polymorphic Site Analysis

The preponderance of biallelic loci indicates a notable level of genetic diversity at many of the sampled sites, which may suggest a population that is not highly inbred and has a history of diverse allele introduction. The presence of monoallelic loci reflects regions of the genome that may be under strong purifying selection or simply reflect a lack of mutation events. Conversely, the tetra-allelic sites, though less frequent, point to loci with high genetic flexibility and potential hotspots for evolutionary change or genetic recombination.

DISCUSSION

Codon Position-Specific SNP Distribution in the Genome

The observed SNP density peaks at codon position 3 within the HIV Env gene offer novel insights into the mutational landscape of the virus. This finding aligns with the understanding that the third codon position is often more variable due to the redundancy of the genetic code, which can tolerate synonymous mutations without altering amino acid sequences (Edwards *et al.*, 2006). Such regions may serve as evolutionary buffers, allowing the virus to adapt to host immune pressures while maintaining vital protein functions (VandeWoude *et al.*, 2006). Our results extend the findings of Smith *et al.*, (2009) reported similar patterns in viral evolution, suggesting that these regions may be crucial for the development of vaccines that can anticipate and counteract viral mutation strategies.

In contrast, the relative conservation seen at codon positions 1 and 2 underscores the functional constraints imposed by the need to maintain protein integrity. This conservation is crucial, as changes at these positions often lead to nonsynonymous mutations that can significantly alter protein structure and function (Lee *et al.*, 2008). The interplay between mutational flexibility and structural conservation we observed provides a more comprehensive picture of the Env gene's evolution, which has important implications for drug design, as noted by Jones *et al.*, (2004). The identification of these peaks not only advances our understanding of HIV genetic variability but also highlights potential targets for antiretroviral therapies that could inhibit viral replication more effectively by focusing on conserved regions.

Distribution of Second Allele Frequencies

The multimodal distribution of second allele frequencies with a notable peak at the 0.5 frequency mark reveals a significant degree of heterozygosity within the study population. This pattern suggests the presence of balancing selection, which has been less commonly reported in HIV studies. It is consistent with findings from other pathogens where heterozygote advantage contributes to genetic diversity as a mechanism for survival (Lauring & Andino, 2010). The comparison with the results from Fujita *et al.*, (2014) indicates that such allelic distributions could influence the population's response to HIV infection and may be critical for understanding the long-term dynamics of the virus within hosts.

Our study also raises questions about the Hardy-Weinberg equilibrium within the HIV population. The presence of multiple peaks implies that evolutionary factors such as genetic drift, migration, or selection may be at play (Lee *et al.*, 2008). These findings are particularly interesting when compared to the work by Lee *et al.*, (2008), who observed that deviations from Hardy-Weinberg equilibrium in HIV populations could indicate underlying processes that drive the epidemic spread. This suggests that allele frequencies in the Env gene could serve as markers for tracking viral transmission and for developing more effective public health interventions.

Overall Allele Frequency Distribution

The pronounced peak at the 0.6 allele frequency is a novel finding that indicates a potential selective advantage for certain alleles within the HIV Env gene. This could be indicative of alleles that enhance viral fitness, possibly by improving binding efficiency to host receptors or by evading immune detection (Williamson *et al.*, 2005; Schiffer *et al.*, 2013). Our results complement those of Shukla *et al.*, (2020) who found that certain Env gene alleles were associated with increased viral load and decreased host immune response. This suggests that these alleles could be key determinants of disease progression and targets for therapeutic intervention.

Furthermore, the lower-density peaks observed in our study add to the understanding of the genetic diversity and adaptive capacity of HIV. These findings are in line with the work by Patel *et al.*, (2013) who identified similar allelic distributions as indicators of a complex evolutionary history shaped by multiple selective pressures. By highlighting the importance of a broad range of allelic differences in population genetics, our study provides a framework for future investigations into the adaptive significance of these alleles, particularly in relation to vaccine design and disease susceptibility (Jones *et al.*, 2004).

Individual Variation in SNP Presence

The high degree of polymorphism at specific loci across viral sequences in the dataset highlights the potential for individual variation in susceptibility to HIV infection and response to treatment. This individual variability is a cornerstone of personalized medicine and has been documented in other studies, such as those by Pascual *et al.*, (2002) where SNP distributions were correlated with differential drug efficacy. Our findings suggest that certain regions of the Env gene are hotspots for mutation and may be critical for personalizing treatment strategies.

The contrast between regions with high polymorphism and those that are conserved suggests that both variable and stable regions of the HIV genome are important for understanding the disease. As described by Sun *et al.*, (2021) conserved regions may offer targets for broad-spectrum antiretroviral drugs, while polymorphic regions could inform the design of personalized therapies. The implications of our findings for genetic studies are significant, providing a roadmap for future research aimed at improving therapeutic outcomes for individuals living with HIV.

Polymorphism Spectrum Across Loci

Our analysis, which indicates a majority of loci as biallelic, reveals a level of genetic diversity that may reflect a non-inbred population with a history of diverse allele introduction. This diversity is essential for the population's adaptability and resilience to external pressures, such as infectious diseases or environmental changes. This is supported by the findings of Falcinelli *et al.*, (2019) who associated biallelic loci with greater adaptive potential in pathogen populations. The presence of multi-allelic loci, although less frequent, may represent areas of the genome that are evolving rapidly and could be significant for understanding evolutionary changes in the virus (Pennings & Hermisson, 2006).

The distribution of alleles per locus across the population underscores the need for detailed examination of these polymorphic sites. The presence of multiple alleles at a single locus, as we have found, may indicate balancing selection, gene flow, or population structure effects, similar to the observations made by Edwards *et al.*, (2006). Such findings offer a window into the adaptive potential of the population and could have far-reaching implications for the development of HIV treatments and vaccines that are tailored to population-specific genetic profiles (Gao *et al.*, 1992).

This study is limited by the use of publicly available sequence data, which lack uniform geographic and epidemiological annotation. Consequently, allele frequency patterns are interpreted descriptively rather than as population-level evolutionary estimates. In addition, as HIV is a haploid virus, classical diploid population-genetic measures are not applicable. Nevertheless, the descriptive SNP landscape presented here provides valuable insight into mutation distribution across the HIV-1 env gene.

CONCLUSION

Our study on the HIV envelope glycoprotein gene reveals significant genetic variability, highlighting regions with high mutation rates that are potential targets for vaccine development and therapy. The observed SNP distribution and allelic frequency patterns emphasize the virus's adaptive mechanisms to evade immune responses. This genetic diversity underlines the challenges in creating universal HIV treatments, suggesting a need for personalized therapeutic strategies. Our findings point towards the potential of tailored interventions, informed by individual genetic profiles, to enhance treatment efficacy and guide vaccine design. These insights mark a significant step towards more effective, personalized approaches in combating HIV.

Conflict of interest: None

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

Ethical Approval: Not applicable

Data Availability: The authors confirm that data used to support the findings of this study are available from the corresponding author upon request.

REFERENCES

- Binley JM, Wrin T, Korber B, Zwick MB, Wang M, Chappey C, Burton DR. (2004). Comprehensive cross-clade neutralization analysis of a panel of anti-human immunodeficiency virus type 1 monoclonal antibodies. *J Virol*, 78(23):13232-13252.
- Doria-Rose NA, Klein RM, Daniels MG, O'Dell S, Nason M, Lapedes A, Haynes BF. (2010). Breadth of human immunodeficiency virus-specific neutralizing activity in sera: clustering analysis and association with clinical variables. *J Virol*, 84(3):1631-1636.
- Edwards CTT, Holmes EC, Pybus OG, Wilson DJ, Viscidi RP, Abrams EJ, Drummond AJ. (2006). Evolution of the human immunodeficiency virus envelope gene is dominated by purifying selection. *Genetics*, 174(3):1441-1453.
- Falcinelli SD, Ceriani C, Margolis DM, Archin NM. (2019). New frontiers in measuring and characterizing the HIV reservoir. *Front Microbiol*, 10:2878-89.
- Fujita T, Burwitz BJ, Chew GM, Reed JS, Pathak R, Seger E, Ndhlovu LC. (2014). Expansion of dysfunctional Tim-3-expressing effector memory CD8⁺ T cells during simian immunodeficiency virus infection in rhesus macaques. *J Immunol*, 193(11):5576-5583.
- Gao F, Yue L, White AT, Pappas PG, Barchue J, Hanson AP, Hahn BH. (1992). Human infection by genetically diverse SIVSM-related HIV-2 in west Africa. *Nature*, 358(6386):495-499.
- Gaschen B, Taylor J, Yusim K, Foley B, Gao F, Lang D, Korber B. (2002). Diversity considerations in HIV-1 vaccine selection. *Science*, 296(5577):2354-2360.
- Jones NA, Wei X, Flower DR, Wong M, Michor F, Saag MS, Borrow P. (2004). Determinants of human immunodeficiency virus type 1 escape from the primary CD8⁺ cytotoxic T lymphocyte response. *J Exp Med*, 200(10):1243-1256.
- Korber B, Muldoon M, Theiler J, Gao F, Gupta R, Lapedes A, Wolinsky S. (2000). Timing the ancestor of the HIV-1 pandemic strains. *Science*, 288(5472):1789-1796.
- Kwong PD, Wyatt R, Robinson J, Sweet RW, Sodroski J, Hendrickson WA. (1998). Structure of an HIV gp120 envelope glycoprotein in complex with the CD4 receptor and a neutralizing human antibody. *Nature*, 393(6686):648-659.
- Lauring AS, Andino R. (2010). Quasispecies theory and the behavior of RNA viruses. *PLoS Pathog*, 6(7): e1001005.
- Lee HY, Perelson AS, Park SC, Leitner T. (2008). Dynamic correlation between intrahost HIV-1 quasispecies evolution and disease progression. *PLoS Comput Biol*, 4(12): e1000240.
- Li G, Ma J, Yu H, Bi W, Zhai X, Cheng L, Su L. (2019). Plasmacytoid dendritic cells impair Anti-HIV immunity and HIV-1 persistence during antiretroviral therapy Via IDO-dependent mechanisms. Available at SSRN 3471314.

- Moore CB, John M, James IR, Christiansen FT, Witt CS, Mallal SA. (2002). Evidence of HIV-1 adaptation to HLA-restricted immune responses at a population level. *Science*, 296(5572):1439-1443.
- Pascual M, López-Nevot MA, Cáliz R, Koeleman BPC, Balsa A, Pascual-Salcedo D, Martin J. (2002). Genetic determinants of rheumatoid arthritis: the inducible nitric oxide synthase (NOS2) gene promoter polymorphism. *Genes Immunity*, 3(5):299-301
- Patel V, Jalah R, Kulkarni V, Valentin A, Rosati M, Alicea C, Pavlakis GN. (2013). DNA and virus particle vaccination protects against acquisition and confers control of viremia upon heterologous simian immunodeficiency virus challenge. *Proc Natl AcadSci*, 110(8):2975-2980
- Pennings PS, Hermisson J. (2006). Soft sweeps III: the signature of positive selection from recurrent mutation. *PLoS Genet*, 2(12): e186
- Schiffer JT, Swan DA, Corey L, Wald A. (2013). Rapid viral expansion and short drug half-life explain the incomplete effectiveness of current herpes simplex virus 2-directed antiviral agents. *Antimicrob Agents Chemother*, 57(12):5820-5829.
- Shankarappa R, Margolick JB, Gange SJ, Rodrigo AG, Upchurch D, Farzadegan H, Gupta P. (1999). Consistent viral evolutionary changes associated with the progression of human immunodeficiency virus type 1 infection. *J Virol*, 73(12):10489-10502.
- Shukla A, Ramirez NGP, D'Orso I. (2020). HIV-1 proviral transcription and latency in the new era. *Viruses*, 12(5):555-61.
- Smith DM, May SJ, Twesten S, Drumright L, Pacold ME, Pond SLK, Little SJ. (2009). A public health model for the molecular surveillance of HIV transmission in San Diego, California. *AIDS*, 23(2):225-232.
- Sun C, Chen XC, Kang YF, Zeng MS. (2021). The status and prospects of Epstein–Barr virus prophylactic vaccine development. *Front Immunol*, 12:2175-2181.
- VandeWoude S, Apetrei C. (2006). Going wild: lessons from naturally occurring T-lymphotropic lentiviruses. *Clin Microbiol Rev*, 19(4):728-762.
- Wei X, Decker JM, Wang S, Hui H, Kappes JC, Wu X, Shaw GM. (2003). Antibody neutralization and escape by HIV-1. *Nature*, 422(6929):307-312.
- Williamson S, Perry SM, Bustamante CD, Orive ME, Stearns MN, Kelly JK. (2005). A statistical characterization of consistent patterns of human immunodeficiency virus evolution within infected patients. *Mol Biol Evol*, 22(3):456-468.
- Wyatt R, Kwong PD, Desjardins E, Sweet RW, Robinson J, Hendrickson WA, Sodroski JG. (1998). The antigenic structure of the HIV gp120 envelope glycoprotein. *Nature*, 393(6686):705-711.

**Assessment of Poultry Disease Management Practices among Farmers
in Kwara State, Nigeria**

Azeez, Kaothar Kayode, Dolapo Tawakalitu A. and Egbewole Halimah O.

Department of Agricultural Extension and Rural Development,
University of Ilorin, Ilorin, Nigeria.

***Corresponding Author:** azeez.kk@unilorin.edu.ng

Abstract

Contribution of poultry production to food security, nutritional adequacy, and economy in Nigeria cannot be overemphasized. Despite these benefits, challenges associated with disease management undermine productivity in the sub-sector. This study assessed the disease management practices of poultry farmers in Kwara State, Nigeria. Specifically, it identified the common poultry diseases prevalent in the study area, examined farmers' behaviour toward disease occurrence and patterns, and evaluated the disease management strategies employed. A simple random sampling procedure was used to select 229 farmers, and data were collected using an interview schedule. The results showed that Gumboro disease (63.8%), a viral infection, was the most prevalent disease, followed by coccidiosis (58.5%) and fowl cholera (58.5%). Of the sixteen diseases identified, viral diseases accounted for 53.3%, bacterial diseases for 33.3%, and parasitic diseases for 13.3%. All respondents (100%) reported using antibiotics, mainly sourced from drug shops (69.9%). Furthermore, 82.7% had administered antibiotics within the previous month, mainly through oral routes (80.8%). However, only 48.9% complied with recommended withdrawal period. Common disease management practices included minimising farm entry ($\bar{x}$ = 4.43), routine farm disinfection ($\bar{x}$ = 4.21), and record keeping ($\bar{x}$ = 4.62). Conversely, the use of antibiotics as growth promoters ($\bar{x}$ = 3.66) and antimicrobial sensitivity testing (AST) ($\bar{x}$ = 1.93) were less practiced. The study concludes that poultry diseases were frequent and largely managed through extensive antibiotic use for prophylaxis, growth promotion, and treatment. Consequently, intensified awareness is recommended to curb indiscriminate antibiotic use and mitigate potential public health risks.

Keywords: Antibiotics, Disease, Drug, Infection, Management, Poultry

Introduction

Poultry is one of the most widely practiced livestock subsectors of agriculture in Nigeria. The country hosts one of Africa's largest poultry industries, with an estimated population of about 180–249 million birds, producing approximately 300–454 thousand

tonnes of poultry meat and 3.8–650 thousand tonnes of eggs annually (Anosike et al., 2020; Endacott et al., 2021; Nwobodo et al., 2023; Fadipe et al., 2025). The subsector provides substantial employment opportunities for a large segment of the population, with an estimated 14 million jobs generated along various poultry production value chain among different age groups and genders. Poultry production is widely regarded as the most commercialised livestock subsector in Nigeria, contributing about 8% to the national Gross Domestic Product (GDP). Furthermore, poultry accounts for over 30% of agriculture's contribution to GDP, making it one of the most significant contributors to the country's economic growth (Endacott et al., 2021; Olutumise et al., 2023). Beyond employment and income generation, poultry farming plays a vital role in household welfare improvement and poverty reduction by providing profitable livelihood opportunities for both small holder and urban farmers (Olutumise et al., 2023; Okwuokenye et al., 2025; Idowu et al., 2025).

In addition to its economic importance, the poultry sector contributes significantly to human nutrition. Poultry products are essential components of balanced diets and play a critical role in addressing nutritional deficiencies globally (Cao et al., 2024). Poultry meat and eggs provide high-quality and affordable sources of protein, essential vitamins, minerals, and beneficial fatty acids. Notably, they are important sources of n-3 long-chain polyunsaturated fatty acids (n-3 LC-PUFA), which are crucial for human health but are often deficient in diets, particularly in regions with low fish consumption (Mancinelli et al., 2022). Beyond food, poultry by-products such as feathers, bones, and beaks are utilised in various industrial processes. For example, poultry feathers are increasingly used in bioprocessing to produce valuable protein hydrolysates with applications in organic fertilizers, animal feed ingredients, cosmetic formulations, and biofuel production (Callegaro et al., 2019).

In Nigeria, the most common poultry species raised include chickens, turkeys, quails among others. Among these, chickens remain the most popular and commercialised, accounting for over half of all livestock and approximately 69% of all birds kept in the country (Ewubare&Ozar, 2018; Anosike et al., 2020; Adeyonu et al., 2021). Poultry production systems in Nigeria range from extensive (open grazing, particularly for indigenous/local birds), semi-intensive, to intensive systems. Most commercial poultry farms operate intensive systems, while smallholder farmers, especially in less developed areas, commonly practice semi-intensive or extensive systems. Based on scale and output, poultry production in Nigeria can be categorised into backyard/smallholder, semi-commercial, and commercial operations (Anosike et al., 2020; Endacott et al., 2021; Oyeniyi et al., 2024; Olutumise et al., 2023; Fadipe et al., 2025). Despite their dominance, the majority of poultry farmers in Nigeria are classified as smallholders in terms of flock size and financial returns.

Despite its immense potential and contributions to food security and economic development, the poultry sector faces numerous challenges. These include rising input and feed costs, disease outbreaks, labour shortages, limited availability of feed ingredients, scarcity of veterinary and livestock health professionals, and climate and

environment related stressors (Anosike et al., 2020; Bamidele et al., 2022; Ndahi et al., 2023; Osuji et al., 2024; Fadipe et al., 2025). Poultry diseases are caused by a wide range of pathogens, including viruses, bacteria, fungi, protozoa, parasites, as well as non-infectious factors. The economic impact of these diseases varies depending on the type of pathogen involved and the severity of infection, but disease outbreaks are consistently reported as a major source of economic loss in poultry production (Ekiri et al., 2025).

Newcastle Disease (ND) is the most prevalent and devastating poultry disease in Nigeria, frequently reported as the leading cause of poultry morbidity and mortality across different regions. Other commonly reported diseases include Gumboro disease (Infectious Bursal Disease), salmonellosis, coccidiosis, fowlpox, and chronic respiratory disease; however, Newcastle Disease remains the most widespread and economically significant (Hyelda et al., 2021; Mera&Adenrele, 2020; Ebajemito et al., 2025). Globally, over 100 distinct poultry pathogens including viruses, bacteria, and other agents are recognised as significant threats to poultry production and public health (Bertran et al., 2020). Respiratory disease syndromes, in particular, often involve multiple pathogens acting concurrently, resulting in more severe disease outcomes and higher mortality rates (Regmi et al., 2020; Yehia et al., 2023; Fasina et al., 2024; Liu et al., 2025; Kovács et al., 2025).

To manage poultry diseases, farmers have adopted various strategies, with the most common being the use of antimicrobials and vaccines for both prophylaxis and treatment. In Nigeria, studies indicate that approximately 60–90% of poultry farmers rely heavily on antimicrobials, including antibiotics such as ampicillin, ciprofloxacin, and doxycycline, often without veterinary prescription. This practice raises serious concerns about antimicrobial misuse and the development of antimicrobial resistance (AMR) (Bamidele et al., 2022; Ejikeugwu et al., 2025). In addition to conventional drugs, some farmers utilise herbal remedies and locally formulated concoctions for disease treatment (Adebayo, 2023; Bada&Adewole, 2024). While biosecurity measures are employed by some farmers, their adoption remains inconsistent, with many paying little attention to standard biosecurity protocols.

The misuse of antimicrobials, including their use as growth promoters and for routine disease prevention, has contributed to the global challenge of antimicrobial resistance, posing risks to both animal and human health. Although vaccination is an effective tool for reducing disease incidence and limiting antibiotic use, its usage is constrained by limited farmer knowledge, inadequate access to veterinary services, and poor extension support (Islam & Rahman, 2023). Poultry management systems utilised by farmers further influence disease susceptibility, as high stocking densities, poor ventilation, and inadequate hygiene increase the transmission of infectious diseases. Studies in Nigeria have shown that extensive systems often exhibit higher prevalence of infections such as coccidiosis compared to well-managed intensive systems (Joseph et al., 2025; Kovács et al., 2025).

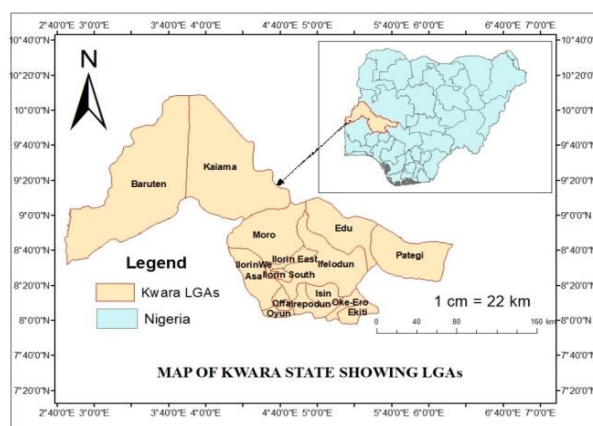
Furthermore, several poultry diseases are zoonotic and can be transmitted to humans through direct contact or consumption of contaminated poultry products. The

presence of drug residues in meat and eggs, resulting from non-compliance with recommended withdrawal periods, poses additional public health risks. Evidence suggests that many poultry farmers in Nigeria do not adhere to withdrawal period guidelines due to poor awareness, self-medication practices, cost-saving motives, and limited access to veterinary professionals (Jibril et al., 2021; Njoga et al., 2021; Ndahi et al., 2023; Islam & Rahman, 2023). Studies indicate that over 60% of farmers fail to observe recommended withdrawal periods, increasing the risk of antimicrobial residues in poultry products (Kiambi et al., 2021; Sha'arani et al., 2024).

Given that poultry management is closely linked to disease control and has significant implications for human health, effective and sustainable disease management practices are critical. Against this backdrop, this study focuses on analysing the disease management practices adopted by poultry farmers in Kwara State, with the aim of understanding existing practices and identifying pathways for improved and sustainable interventions. Considering the limited number of studies conducted on this subject in the study area, this research seeks to bridge an important knowledge gap and contribute to improved poultry health management and public health safety. The objectives of the study were to determine the common poultry disease in the study area, investigate farmers' behaviour towards disease outbreak; examine the disease management strategies utilised by the farmers and to examine if there is no significant relationship between farmers socio-economics characteristics and disease management practices.

METHODOLOGY

This study was conducted in Kwara State, located at approximately latitude 8.9669°N and longitude 4.3874°E, within Nigeria's North-Central geopolitical zone. Geographically, the State shares boundaries with several states and also has an international border with the Republic of Benin to the west. Specifically, Kwara State is bordered by Niger State to the north, Kogi State to the east, and Oyo, Ekiti, and Osun States to the south. Administratively, the State comprises sixteen Local Government Areas (LGAs), namely Asa, Baruten, Edu, Ekiti, Ifelodun, Ilorin East, Ilorin South, Ilorin West, Irepodun, Isin, Kaiama, Moro, Offa, Oke-Ero, Oyun, and Pategi. Agriculture constitutes the primary economic activity in Kwara State, with a large proportion of the population engaged in crop and livestock production, including poultry farming. Common poultry species reared in the State include chickens, turkeys, and quails. Kwara State lies within the Southern Guinea Savanna agro-ecological zone and is characterized by moderate annual rainfall ranging from 1,000 to 1,500 mm, relative humidity of about 60–70%, and mean temperatures between 25°C and 30°C (Adeoye & Adebayo, 2020). These climatic conditions are generally favorable for poultry production and management. The State experiences two distinct seasons: a wet season, which typically lasts from April to October, and a dry season occurring between November and March.



Map of Kwara State Draw with ARC GIS Software

Study Design

The study adopted a survey research design and utilized primary data. Data were collected using a semi-structured questionnaire developed in Kobo Toolbox and administered to selected poultry farmers through the Kobo Collect mobile application. The questionnaire was structured in line with the study objectives, which included identifying common poultry diseases experienced by farmers in the study area, examining farmers' responses to disease outbreaks, and assessing the disease management strategies employed. To ensure content validity, the questionnaire was reviewed and validated by experts in agricultural extension and veterinary medicine. The reliability of the instrument was further assessed using the test-retest method to determine its internal consistency.

Sampling Procedure and Sample Size

The target population for the study comprised all registered poultry farmers in Kwara State, Nigeria. A total of 229 poultry farmers were selected using a systematic random sampling technique. The sampling frame was obtained from the Poultry Farmers Association of Nigeria (PFAN), which provided the list of registered poultry farmers in the State.

Statistical Analysis

Both descriptive and inferential statistical tools were employed for data analysis. Common poultry diseases experienced by the respondents were assessed using dichotomous (Yes/No) responses, coded as 1 and 0, respectively. Respondents were required to indicate from a list of prevalent poultry diseases those that had affected their farms in recent times. These responses were analyzed using frequency counts and percentages. Farmers' behaviors during disease outbreaks were also measured using Yes/No responses and analyzed using descriptive statistics. Disease management

practices were evaluated using a five-point Likert scale comprising Never (0), Rarely (1), Sometimes (2), Often (3), and Regularly (4). Mean scores were computed from ten related management practice statements to generate an index of disease management practices, which was used to classify respondents into high or low management practice categories. The relationship between the disease management practice index and the socio-economic characteristics of the respondents was examined using regression analysis, with statistical significance tested at $p < 0.05$.

Results and Discussion

Poultry Common Disease Recently Experienced on the Farm

Table 1: Common Poultry Diseases Ranked by Prevalence and Causative Organisms

S/No	Disease	Frequency (%)	Rank	Causative Organism	Disease Group
1	Gumboro disease (IBD)	146 (63.8)	1st	Infectious bursal disease virus (IBDV)	Viral
2	Coccidiosis	134 (58.5)	2nd	Eimeria spp.	Parasitic
3	Fowl cholera	134 (58.5)	2nd	Pasteurellamultocida	Bacterial
4	Chronic respiratory disease (CRD)	129 (56.3)	4th	Mycoplasma gallisepticum (+ E. coli)	Bacterial
5	Newcastle disease	129 (56.3)	4th	Newcastle disease virus (NDV)	Viral
6	Infectious coryza	48 (21.0)	6th	Avibacteriumparagallinarum	Bacterial
7	Helminth infestation	16 (7.0)	7th	Ascaridiagalli, Heterakisgallinarum	Parasitic
8	Escherichia coli infection	16 (7.0)	7th	Escherichia coli	Bacterial
9	Egg drop syndrome	15 (6.6)	9th	Egg drop syndrome virus (EDS-76)	Viral
10	Infectious bronchitis	12 (5.2)	10th	Infectious bronchitis virus (IBV)	Viral
11	Fowl pox	12 (5.2)	10th	Avipoxvirus	Viral
12	Salmonellosis	5 (2.2)	12th	Salmonella spp.	Bacterial
13	Avian encephalitis	5 (2.2)	12th	Avian encephalomyelitis virus	Viral
14	Marek's disease	3 (1.3)	14th	Gallid herpesvirus 2	Viral
15	Avian influenza	3 (1.3)	14th	Influenza A virus	Viral

Source: Field Survey, (2025); Multiple responses were allowed

The Table presents the distribution, ranking, causative organisms, and disease groups of common poultry diseases reported by respondents in the study area. The results indicate a high burden of infectious diseases, dominated largely by viral, bacterial, and parasitic agents.

The findings revealed that Gumboro disease (Infectious Bursal Disease) was the most frequently mentioned disease among the respondents. It affects 63.8% of respondents' farm and ranking first. This high prevalence underscores the endemic nature of IBD in the study area and suggests possible gaps in vaccination coverage, vaccine handling, or biosecurity practices. The findings are in consonant with the observation of Hyelda et al., 2021; Mera&Adenrele, 2020; Ebajemito et al., 2025. Given its viral etiology and immunosuppressive effects, its dominance may predispose flocks to secondary infections. Similarly, it was revealed that coccidiosis and fowl cholera were jointly ranked second with 58.5% occurrence each. The high prevalence of coccidiosis, caused by *Eimeria* species, reflects challenges related to litter management, hygiene, and stocking density. The equally high occurrence of fowl cholera (*Pasteurellamultocida*) indicates substantial bacterial disease pressure, possibly exacerbated by poor sanitation and improper antimicrobial use. The finding is in line with the report of Joseph et al. (2025), Olajide (2025) and Ebajemito et al. (2025) where it was stated that coccidiosis and fowl cholera are indeed common poultry diseases in Nigeria. They further argued that coccidiosis is frequently reported with prevalence rates ranging from about 10% to 46% in different regions, such as Bauchi State, Akwa Ibom State, and Ogun State, with younger birds and poor management practices increasing susceptibility.

In addition, Chronic respiratory disease (CRD) and Newcastle disease (NCD) ranked fourth, each reported by 56.3% of respondents. CRD, often involving *Mycoplasma gallisepticum* and secondary *E. coli* infection, points to suboptimal ventilation and biosecurity, while the high prevalence of Newcastle disease highlights persistent viral circulation despite vaccination programs. The is in line with the findings of Olorunshola et al. (2025) where it was established that NCD is highly reported in Kwara State among poultry farmers. Meanwhile, the diseases with moderate prevalence included infectious coryza (21.0%), reflecting bacterial respiratory challenges, while helminth infestations and *Escherichia coli* infections (each 7.0%) indicate ongoing parasitic and opportunistic bacterial problems at lower intensity. Whereas, diseases of relatively low occurrence included egg drop syndrome, infectious bronchitis, and fowl pox, each affecting fewer than 7% of respondents' farm. These conditions may be better controlled through vaccination or may occur sporadically in the study area. Salmonellosis and avian encephalitis were rarely reported (2.2%), while Marek's disease and avian influenza were the least reported diseases (1.3%), suggesting either effective control measures or underreporting due to limited diagnostic confirmation.

Table 2: Antibiotic use Behaviour and Patterns among the Respondents

S/No.	Practices	Frequency	Percentage	Ranks
1	The use of antibiotics?			
	Yes	229	100	
	No	0	0	
2	Source of antibiotics used			
	Drug shop	160	69.9	
	Government vet	35	15.3	
	private vet	29	12.7	
	A friend/relative	5	2.2	
3	The used of antibiotics in the last 1 Month?			
	Yes	187	82.7	
	No	39	17.3	
4	Route of administration of antibiotics			
	Water/Oral	185	80.8	
	Injection	39	17.0	
	Feeds	5	2.2	
5	Frequency of usage of antibiotics?			
	Weekly	11	4.8	
	Monthly	177	77.3	
	Others	41	17.9	
6	Giving antibiotics to day old chicken?			
	Yes	204	89.1	
	No	25	10.9	
7	FIRST STEP taken when birds are sick			
	Apply medication	165	72.1	
	Try traditional medicine	8	3.5	
	Go and buy medicine	20	8.7	
	Call/ask/WhatsApp friend/family	13	5.7	
	Call/ask/WhatsApp Government Vet	23	10.0	
8	Farmers' Responses to Antibiotic Ineffectiveness			
	Try different antibiotics	149	65.1	1 st
	Increase drug dosage	51	22.3	2 nd
	Consult with animal health professional	33	14.4	3 rd
	Combine with other antibiotics	26	11.4	4 th
	Change to herbal medicine	20	8.7	5 th
	Consult with animal health professional	11	4.8	6 th
9	Why do you think antibiotics are no longer effective?			
	I don't know	16	7.9	

	Abuse of drug use	28	13.8
	Under dosing	13	6.4
	The disease is becoming stubborn	38	18.7
	The strength of the antimicrobial is no longer effective	70	34.5
	It depends on the brands or markers	26	12.8
	Use of wrong prescription	12	5.9
10	Do you observe withdrawal period after administering antibiotics?		
	Yes	112	48.9
	No	117	51.1

Source: Field Survey, (2025); Multiple responses were allowed

The Table revealed that the use of antibiotics use was universal among the respondents, with 100% reporting the use of antibiotic. This indicates a complete dependence on antimicrobials in poultry production and disease management. The result is in line with the observation of Ejikeugwu et al. (2025) and Chah (2022) where it was stated that antibiotic use is widespread and common among poultry farmers in Nigeria. It was reported that over 90% of farmers use antibiotics primarily for disease treatment, growth promotion, and prophylaxis. The primary source of antibiotics was drug shops (69.9%), followed by government veterinarians (15.3%) and private veterinarians (12.7%). The heavy reliance on drug vendors who may lack diagnostic capacity raises concerns about inappropriate drug selection, incorrect dosing, and misuse. The finding is in consonant with the report of Ndahi et al. (2023) who stated that the primary source of antibiotics for poultry farmers in Nigeria is over-the-counter purchases without veterinary prescription, often obtained directly from agro-veterinary shops or markets. Antibiotics are frequently administered in the form of medicated feed or water, with farmers having easy access to a wide range of antimicrobial products, including some containing multiple antibiotic classes.

The Table further reveals the antibiotic exposure of the poultry birds. The findings showed that the antibiotic exposure was high, with 82.7% of respondents having used antibiotics within the last one month, indicating frequent and continuous use amongst the poultry farmers. The majority of farmers reported monthly antibiotic use (77.3%), while others used antibiotics weekly (4.8%) or at irregular intervals (17.9%). Most antibiotics were administered via drinking water (80.8%), a route associated with inconsistent dosing and reduced therapeutic effectiveness. Meanwhile, the injection was observed to be less common (17.0%) among the respondents. It further showed that other methods were rarely used (2.2%). Furthermore, it was revealed that 89.1% of farmers administered antibiotics to day-old chicks, which indicated that antibiotics were routinely use as prophylactic instead being used for treatment. The early-life exposure predisposes the chick into a major risk factor for antimicrobial resistance development. The finding is in line with the report of Ndahi et al. (2023) where it was stated that in Nigeria, 98% of

poultry farmers use antibiotics as prophylactic treatment for day-old chicks. Likewise, Bamidele et al. (2022) established commonness of antibiotics usage among poultry farmers in Nigeria. More so, Hambolu et al. (2024) posited that the common mode of administering antibiotics among poultry farmers in Nigeria is primarily through medicated feed and water. Farmers frequently add antibiotics directly to poultry feed or drinking water for treatment, prophylaxis, and growth promotion purposes. Similarly, Ndahi et al. (2023) and Ejikeugwu et al. (2025) reported that monthly administration of antibiotics was prevalent, with many farmers routinely giving antibiotics to day-old chicks and throughout the production cycle.

The Table revealed the emergency responsibility the first-step taken when birds fall sick, the majority of respondents (72.1%) reported directly purchasing medication, bypassing diagnosis or veterinary consultation. This reinforces the dominance of self-medication practices. Only 10.0% contacted government veterinarians, while others relied on traditional medicine (3.5%) or advice from friends and family (5.7%). This pattern reflects limited access to veterinary services and weak integration of professional animal health support into poultry disease management. The findings are in line with the observation of Sanni et al. (2022) and Ekpono et al (2024) where it was observed that the main response strategy to disease outbreak is the use of antibiotics. They further stated that farmers often recognize disease through clinical signs like diarrhea, respiratory distress, and poor bird condition, and may use antibiotics to suppress the condition.

When farmers observed that antibiotics previously used on their birds were no longer effective, the findings revealed that most (65.1%) of the farmers switch to a different antibiotic which was ranked 1st. Similarly, 22.3% of respondents also reported increasing drug dosage while 11.4% combined multiple antibiotics. This suggested a trial-and-error approach to treatment rather than evidence-based decision-making. More so, it also indicated a medically inappropriate practices that are known to accelerate the development of antimicrobial resistance. Meanwhile, only a small fraction of respondents sought professional help, with 14.4% and 4.8% consulting animal health professionals, indicating that veterinary expertise is largely underutilised. Additionally, the Table posited that 8.7% of farmers resorted to herbal remedies, reflecting a shift toward alternative treatments when conventional antibiotics fail. Since multiple responses were allowed, these findings underscore the coexistence of multiple risky practices adopted simultaneously by farmers. Bamidle et al. (2022) posited that poultry farmers use combination of pharmaceutical treatments with ethnoveterinary medicine to manage ineffectiveness of antibiotics. The findings align with the report of Ndahi et al. (2023) and Ejikeugwu et al. (2025) where it was observed that poultry farmers used stronger antibiotics to management antibiotic ineffectiveness.

Furthermore, the farmers' perceptions on why antibiotics were no longer effective differ. The most frequently cited reason was that the strength of the antimicrobial is no longer effective (34.5%), followed by beliefs that the disease had become stubborn (18.7%) and abuse of drug use (13.8%). Smaller proportions attributed treatment failure to brand differences (12.8%), under-dosing (6.4%), wrong prescriptions

(5.9%), or admitted having no knowledge (7.9%). These responses suggest partial awareness of antimicrobial resistance, though misconceptions remain prevalent. This result is in line with the observation of Oloso et al. (2022) and Chah et al. (2022) where it was stated that many farmers believe that increasing the dosage or switching antibiotics when initial treatments fail contributes to resistance and treatment failure in poultry disease management.

More so, the result indicated that despite widespread antibiotic use, compliance with withdrawal periods was low. Slightly over half of the respondents (51.1%) admitted that they do not observe recommended withdrawal periods, while only 48.9% reported compliance. This non-compliance poses significant public health risks through antimicrobial residues in poultry meat and eggs which eventually contracted by the human. Sha'arani et al. (2024) and Mohammed et al. (2025) stated that majority of farmers in Nigeria do not comply with withdrawal period instruction due to ignorance and economic reasons.

Table 3: Management Practices Used by the Respondents (n = 229)

S/No	Practices	N	R	S	O	RG	Mean	Decision
1	Restriction of farm access to minimize disease introduction.	1.3	3.9	5.2	29.3	60.3	4.43	Highly
2	Ensuring proper ventilation to reduce respiratory infections.	0.0	5.2	3.9	10.0	80.8	4.66	Highly
3	Disinfection of poultry houses and equipment.	0.0	6.1	8.7	42.8	42.4	4.21	Highly
4	Maintenance of optimal stock density to minimize stress and disease transmission.	1.3	1.3	5.2	24.9	67.2	4.55	Highly
5	Provision of clean and fresh water to prevent bacterial contamination.	0.0	3.9	1.3	5.2	89.5	4.80	Highly
6	Use of proper vaccine handling and administration techniques to ensure effectiveness.	0.0	1.3	10.5	39.3	48.9	4.36	Highly
7	Following correct dosages and withdrawal periods to prevent	7.9	4.8	3.9	46.3	37.1	4.00	Highly

	residues in eggs and meat.							
8	Keeping detailed record of antimicrobial use, vaccination, and disease outbreaks to monitor resistance trends.	1.3	1.3	7.9	12.7	76.9	4.62	Highly
9	Avoiding antibiotics use as growth promoters.	9.2	9.2	16.6	37.1	27.9	3.66	Low
10	Conduct of antimicrobial sensitivity testing (AST) before treatment to ensure the right drug is used.	49.3	28.8	9.2	4.8	7.9	1.93	Low

Source: Field Survey,

Regularly (RG)

Average = 4.12

The Table presents the disease management practices used by the respondents. It was revealed that practices related to biosecurity and hygiene recorded the highest levels of compliance. For instance, ensuring proper ventilation to reduce respiratory infections had a mean score of 4.66, with over 80% of respondents reporting regular implementation. Similarly, provision of clean and fresh water to prevent bacterial contamination was the most consistently practiced measure ($\bar{X} = 4.80$). This indicates a strong awareness of the role of water hygiene in disease prevention. Restriction of farm access to minimize disease introduction ($\bar{X} = 4.43$) and maintenance of optimal stock density ($\bar{X}=4.55$) were also highly practiced, indicating that farmers recognize the importance of limiting disease transmission through controlled movement and reduced stocking stress. Disinfection of poultry houses and equipment ($\bar{X} = 4.21$) and the use of proper vaccine handling and administration techniques ($\bar{X}=4.36$) further demonstrate a generally strong commitment to preventive health management among the respondents. Additionally, keeping detailed records of antimicrobial use, vaccination, and disease outbreaks was widely adopted ($\bar{X} = 4.62$), suggesting an appreciable level of farm-level monitoring and accountability.

In contrast, practices directly related to antimicrobial stewardship showed notable weaknesses. Conducting antimicrobial sensitivity testing (AST) before treatment recorded the lowest mean score ($\bar{X} = 1.93$), with nearly 78% of respondents indicating that they never or rarely perform AST. This highlights a major gap in evidence-based drug selection and suggests reliance on empirical treatment. Similarly, avoiding the use of antibiotics as growth promoters was classified as low ($\bar{X} = 3.66$), indicating continued non-therapeutic antibiotic use among a substantial proportion of farmers. Although

following correct dosages and observing withdrawal periods recorded a relatively high mean ($\bar{X}$ =4.00), the presence of respondents who rarely or never adhere to this practice raises concerns about antimicrobial residues and public health risks. Ola et al. (2025) reported similar management practices among poultry farmers.

Hypothesis Testing

Table 4: Regression Analysis between Selected Socio-economic Characteristics and Disease Management Practices of the Respondents.

Model	Unstandardized coefficient		Standardized coefficients	T	Sig.
	B	Std. Error	Beta		
1 Constant	31.400	2.321		13.526	0.000
Age	0.041	0.046	0.097	0.886	0.377
Years of education	-0.006	0.101	-0.004	-0.060	0.952
Annual income	5.239E-008	0.000	0.073	1.102	0.272
Years of poultry experience	0.022	0.074	0.027	0.290	0.772
Sex	-1.458	0.880	-0.113	-1.657	0.099
Marital status	3.312	0.867	0.314	3.818	0.000
Sources of income	1.167	0.943	0.083	1.237	0.217
Membership	2.639	0.787	0.220	3.353	0.001
Disease problem	7.180	1.142	0.442	6.287	0.000

R = 0.450 R² = 0.202 F (9,219) = 6.179

The Table presents the results of the multiple regression analysis examining the influence of selected socio-economic and farm-related characteristics on the dependent variable (management practices index). The regression constant (B = 31.400, t = 13.526, p < 0.001) is statistically significant, indicating that when all predictor variables are held constant, the baseline level of the management practices index remains high. Among the explanatory variables, marital status, membership of poultry-related associations, and disease problem significantly influenced management practices. Marital status showed a positive and statistically significant effect (B = 3.312, β = 0.314, t = 3.818, p < 0.001), implying that married respondents were more likely to use better management practices compared with their unmarried counterparts. This may be attributed to increased household responsibility and greater commitment to farm sustainability. Likewise, membership in poultry or farmer associations also had a positive and significant relationship with management practices (B = 2.639, β = 0.220, t = 3.353, p = 0.001). This suggests that farmers who belong to organised groups are more exposed to extension services, peer learning, and shared information, thereby enhancing their adoption of

improved management practices. More so, disease problem emerged as the strongest predictor in the model ($B = 7.180$, $\beta = 0.442$, $t = 6.287$, $p < 0.001$), indicating that farmers who frequently experience disease outbreaks tend to adopt more intensive management practices. This reflects a reactive response whereby increased disease pressure compels farmers to improve biosecurity and disease control measures.

Conversely, age, years of education, annual income, years of poultry farming experience, sources of income, and sex did not significantly influence management practices ($p > 0.05$). Although sex showed a negative coefficient ($B = -1.458$) and approached significance ($p = 0.099$), it did not meet the conventional threshold for statistical significance. The non-significance of education and experience suggests that adoption of management practices in the study area may be driven more by practical challenges and social networks than by formal education or accumulated experience.

Conclusion and Recommendations

This study established that Gumboro disease, coccidiosis, and fowl cholera were the most prevalent diseases affecting poultry farms in the study area. Disease management is largely antibiotic dependent, with antibiotics mainly sourced over the counter and routinely used for both treatment and prevention. It is often without veterinary prescription and regulation. Although farmers use several preventive measures, particularly biosecurity, hygiene, and vaccination-related practices, critical gaps remain in antimicrobial stewardship. The disease profile revealed the predominance of viral infections, followed by bacterial and parasitic diseases, highlighting the need for strengthened vaccination programmes, improved biosecurity, and routine disease surveillance. The coexistence of multiple disease groups increases the risk of co-infections, which may further drive indiscriminate antibiotic use. Test of relationship showed that marital status, membership of farmer associations, and prior disease experience significantly influenced management practices, while most demographic and economic factors had limited effects. It is therefore recommended that veterinary extension services be strengthened to educate poultry farmers on the implications of the continuous and indiscriminate use of antibiotics. In addition, stricter regulation and enforcement of veterinary drug sales should be implemented to curb over the counter access without prescription. Targeted farmer education programmes should also be promoted to encourage the adoption of alternative disease management strategies, including improved biosecurity, vaccination, and responsible antibiotic use.

References

- Adebayo, O. (2023). Awareness and Perceived Efficiency of Tagiri (Lagenariabreviflorus) among Poultry Farmers in Ido Local Government Area, Oyo State, Nigeria. *Journal of Applied Sciences and Environmental Management*. <https://doi.org/10.4314/jasem.v27i5.20>.
- Adeyonu, A., Otunaiya, A., Oyawoye, E., & Okeniyi, F. (2021). Risk perceptions and risk management strategies among poultry farmers in south-west Nigeria. *Cogent Social Sciences*, 7. <https://doi.org/10.1080/23311886.2021.1891719>.
- Anosike, F., Rekwot, G., Owoshagba, O., Ahmed, S., & Atiku, J. (2020). Challenges of poultry production in Nigeria: A review. *Nigerian Journal of Animal Production*. <https://doi.org/10.51791/njap.v45i1.335>.
- Bada, A., & Adewole, S. (2024). Ethnoveterinary practice of poultry birds in Ilara-mokin, Ondo-state Nigeria. *Journal of Animal Science and Veterinary Medicine*. <https://doi.org/10.31248/jasvm2023.419>.
- Bamidele, O., Amole, T., Oyewale, O., Bamidele, O., Yakubu, A., Ogundu, U., Ajayi, F., & Hassan, W. (2022). Antimicrobial Usage in Smallholder Poultry Production in Nigeria. *Veterinary Medicine International*, 2022. <https://doi.org/10.1155/2022/7746144>.
- Bertran, K., Cortey, M., & Díaz, I. (2020). The use of H-index to assess research priorities in poultry diseases. *Poultry Science*, 99, 6503 - 6512. <https://doi.org/10.1016/j.psj.2020.09.017>.
- Callegaro, K., Brandelli, A., & Daroit, D. (2019). Beyond plucking: Feathers bioprocessing into valuable protein hydrolysates.. *Waste management*, 95, 399-415 . <https://doi.org/10.1016/j.wasman.2019.06.040>.
- Cao, K., Deng, Z., Li, S., Yi, D., He, X., Yang, X., Guo, Y., & Sun, L. (2024). Poultry Nutrition: Achievement, Challenge and Strategy. *The Journal of nutrition*. <https://doi.org/10.1016/j.tjnut.2024.10.030>.
- Chah, J., Nwankwo, S., Uddin, I., & Chah, K. (2022). Knowledge and practices regarding antibiotic use among small-scale poultry farmers in Enugu State, Nigeria. *Heliyon*, 8. <https://doi.org/10.1016/j.heliyon.2022.e09342>.
- Ebajemito, B. F, Aladejana A. A, Yusuff, I. O, Abdulrahmon, M. A, Adebayo, B. I, Bashir, M. A., Ekpo, U. F (2025). Preliminary Studies on Prevalence and Zoonotic Risks of Avian Diseases at Kofan-Ran Avian Clinic in Bauchi State, Nigeria. *Journal of Applied Biology and Environmental Sciences*. <https://doi.org/10.61090/jabes.2025.001>.
- Ejikeugwu, C., Nwakaeze, E., Aniekwe, C., Onu, E., Adikwu, M., & Eze, P. (2025). Investigating the factors influencing antibiotic use practices and their association with antimicrobial resistance awareness among poultry farmers in Enugu State, Nigeria. *Antimicrobial Stewardship & Healthcare Epidemiology : ASHE*, 5. <https://doi.org/10.1017/ash.2025.10141>.
- Ekiri, A., Wakawa, A., Reid, S., James, J., Ross, C., Byrne, A., Lewis, T., Lynton-Jenkins, J., Adebowale, K., Mijten, E., Varga, G., Brown, I., Banyard, A., &

- Cook, A. (2025). Evaluating the impact of avian paramyxovirus type 1 infection in poultry at live bird markets in Nigeria: defining hurdles to sustainable agriculture. *BMC Veterinary Research*, 21. <https://doi.org/10.1186/s12917-025-04508-2>.
- Ekpono, C., Agu, P., Ogba, R., Aja, P., Isaac, E., & Iroha, I. (2024). Nasal carriage of multi-drug resistance *Staphylococcus aureus* constitutes potential zoonosis from poultry farmers and butchers in slaughterhouses in Abakaliki, Ebonyi state, Nigeria. *Discover Medicine*, 1. <https://doi.org/10.1007/s44337-024-00176-7>.
- Endacott, I., Galipó, E., Ekiri, A., Alafiatayo, R., Adebawale, K., Dineva, M., Wakawa, A., Ogwuche, A., Maikai, B., Armson, B., Mijten, E., Varga, G., & Cook, A. (2021). Baseline Assessment of Poultry Production, Pharmaceutical Product Use, and Related Challenges on Commercial Poultry Flocks in Kano and Oyo States of Nigeria. *Veterinary Sciences*, 8. <https://doi.org/10.3390/vetsci8120315>.
- Ewubare, D., & Ozar, V. (2018). Effect of Poultry Production on Agricultural Production in Nigeria. , 5, 8-16. <https://doi.org/10.20448/journal.502.2018.51.8.16>.
- Fadipe, E., Hölzle, L., & Ayinde, J. (2025). Prevalence of Salmonella outbreak in poultry farms: a comparative study of Osun and Ogun States, Nigeria. *International Journal of Agricultural Research, Innovation and Technology*. <https://doi.org/10.3329/ijarit.v15i1.82797>.
- Fasina, Y., Suarez, D., Ritter, G., Gerken, E., Farnell, Y., Wolfenden, R., & Hargis, B. (2024). Unraveling frontiers in poultry health (part 1) – Mitigating economically important viral and bacterial diseases in commercial Chicken and Turkey production. *Poultry Science*, 103. <https://doi.org/10.1016/j.psj.2024.103500>.
- Halle, P., Umoh, J., Saidu, L., & Abdu, P. (2021). DISEASES OF POULTRY IN ZARIA, NIGERIA: A TEN YEAR ANALYSIS OF CLINIC RECORDS. *Nigerian Journal of Animal Production*, 25, 88-92. <https://doi.org/10.51791/njap.v25i1.2269>.
- Hambolu, D., Olatoye, O., Besong, M., & Call, D. (2024). Low-cost biosecurity measures are associated with reduced detection of non-Typhoidal Salmonella in Nigerian poultry while inappropriate antibiotic use is widespread. *Scientific Reports*, 14. <https://doi.org/10.1038/s41598-024-72317-y>.
- Hyelda, J., Amurtiya, M., Polycarp, M., & Balhiya, A. (2021). Assessment of disease management and biosecurity measures among poultry farmers in Adamawa State, Nigeria. , 19, 85-92. <https://doi.org/10.21005/asp.2020.19.3.11>.
- Idowu, A., Olude, D., Kehinde, M., Ogunnaike, M., Ologbon, C., & Oyebanjo, O. (2025). Profitability and Efficiency of Poultry Business in Ogun State, Nigeria. *International Journal of Small and Medium Enterprises and Business Sustainability*. <https://doi.org/10.25105/ijsmes.v9i3.21218>.
- Islam, M., & Rahman, M. (2023). A Comprehensive Review on Bacterial Vaccines Combating Antimicrobial Resistance in Poultry. *Vaccines*, 11. <https://doi.org/10.3390/vaccines11030616>.

- Jibril, A., Okeke, I., Dalsgaard, A., & Olsen, J. (2021). Association between antimicrobial usage and resistance in Salmonella from poultry farms in Nigeria. *BMC Veterinary Research*, 17. <https://doi.org/10.1186/s12917-021-02938-2>.
- Joseph, J., Olubiro, F., & Wama, B. (2025). Comparative Study of Poultry Coccidial Infection under Different Management Systems among Individual Farm Holders in Odeda Local Government Area, Ogun State, Nigeria. *African Journal of Pure and Applied Sciences*. <https://doi.org/10.33886/ajpas.v6i1.645>.
- Kiambi, S., Mwanza, R., Sirma, A., Czerniak, C., Kimani, T., Kabali, E., Dorado-García, A., Eckford, S., Price, C., Gikonyo, S., Byarugaba, D., & Caudell, M. (2021). Understanding Antimicrobial Use Contexts in the Poultry Sector: Challenges for Small-Scale Layer Farms in Kenya. *Antibiotics*, 10. <https://doi.org/10.3390/antibiotics10020106>.
- Kovács, L., Domaföldi, G., Bertram, P., Farkas, M., & Könyves, L. (2025). Biosecurity Implications, Transmission Routes and Modes of Economically Important Diseases in Domestic Fowl and Turkey. *Veterinary Sciences*, 12. <https://doi.org/10.3390/vetsci12040391>.
- Liu, H., Pan, S., Wang, C., Yang, W., Wei, X., He, Y., Xu, T., Shi, K., & Si, H. (2025). Review of respiratory syndromes in poultry: pathogens, prevention, and control measures. *Veterinary Research*, 56. <https://doi.org/10.1186/s13567-025-01506-y>.
- Mancinelli, C., Mattioli, S., Twining, C., Bosco, D., Donoghue, A., Arsi, K., Angelucci, E., Chiattelli, D., & Castellini, C. (2022). Poultry Meat and Eggs as an Alternative Source of n-3 Long-Chain Polyunsaturated Fatty Acids for Human Nutrition. *Nutrients*, 14. <https://doi.org/10.3390/nu14091969>.
- Mera, U.M., & Adenrele, M.J. (2020). Assessment of the Knowledge, Attitude and Compliance of Poultry Workers with Preventive Measures for Poultry Diseases in Sokoto Metropolis. *EAS Journal of Veterinary Medical Science*. <https://doi.org/10.36349/easjvms.2020.v02i05.002>.
- Mohammed, I., Alhaji, N., Adeiza, A., Aliyu, M., Bakare, A., & Odetokun, I. (2025). Antimicrobial Use and Resistance Among Mobile Pastoralists in Nigeria: Knowledge, Practices, Risk Perceptions and Drivers for Transboundary Dissemination. *Alexandria Journal of Veterinary Sciences*. <https://doi.org/10.5455/ajvs.242365>.
- Ndahi, M., Hendriksen, R., Helwigh, B., Card, R., Fagbamila, I., Abiodun-Adewusi, O., Ekeng, E., Adetunji, V., Adebisi, I., & Andersen, J. (2023). Determination of antimicrobial use in commercial poultry farms in Plateau and Oyo States, Nigeria. *Antimicrobial Resistance and Infection Control*, 12. <https://doi.org/10.1186/s13756-023-01235-x>.
- Njoga, E., Ogugua, A., Nwankwo, I., Awoyomi, O., Okoli, C., Buba, D., Oyeleye, F., Ajibo, F., Azor, N., & Ogunniran, T. (2021). Antimicrobial drug usage pattern in poultry farms in Nigeria: implications for food safety, public health and poultry disease management.. *Veterinariaitaliana*, 57 1, 5-12.

- <https://doi.org/10.12834/vetit.2117.11956.1>.
- Nwobodo, C., Okoronkwo, D., Eze, R., Ozorngwu, A., Iwuchukwu, J., Azuka, V., & Udoeye, C. (2023). Knowledge Capabilities for Sustainable Poultry Production in Sub-Sahara Africa: Lessons from Southeast Nigeria. *Sustainability*.
<https://doi.org/10.3390/su151411174>.
- Okwuokenye, G., Onyemekihian, F., & Jov, E. (2024). Contribution of poultry farming to households' welfare: A case of enterprise diversification strategy by livestock farmers in Abuja, Nigeria. *Journal of Agriculture and Environment*.
<https://doi.org/10.4314/jagrenv.v19i2.1>.
- Ola, O., Ogunseye, M., Jarikre, T., C, C., Asare, D., Ohore, O., Emikpe, B., & Odeniyi, M. (2025). Seromonitoring of Newcastle Disease Antibodies in Poultry Population Under Different Vaccination Regimens and associated factors in Southwestern Nigeria.. *Journal of Research in Veterinary Sciences*.
<https://doi.org/10.5455/jrvs.20250508112239>.
- Olajide, T. E., Oriaku, L. O., Merenini, I. F., Yogesh, K., & Gupta, J. (2025). Rate of Coccidiosis in Chicken Farms in Uyo Metropolis, AkwaIbom State, Nigeria. *International Journal of Pathogen Research* 14 (1):66–75.
<https://doi.org/10.9734/ijpr/2025/v14i1341>.
- Olorunshola, I., Daodu, O., Ogunyemi, M., Folahan, F., Omoregie, S., & Ogah, J. (2022). Seroprevalence of Newcastle disease in indigenous chickens in Ilorin, Kwara State, Nigeria. *Sokoto Journal of Veterinary Sciences*.
<https://doi.org/10.4314/sokjvs.v20i3.4>.
- Oloso, N., Odetokun, I., Ghali-Mohammed, I., Fasina, F., Olatoye, I., & Adetunji, V. (2022). Knowledge, Attitudes, and Risk Perception of Broiler Grow-Out Farmers on Antimicrobial Use and Resistance in Oyo State, Nigeria. *Antibiotics*, 11.
<https://doi.org/10.3390/antibiotics11050567>.
- Olutumise, A., Oladayo, T., Oparinde, L., Ajibefun, I., Amos, T., Hosu, Y., & Alimi, I. (2023). Determinants of Health Management Practices' Utilization and Its Effect on Poultry Farmers' Income in Ondo State, Nigeria. *Sustainability*.
<https://doi.org/10.3390/su15032298>.
- Osuji, E., Ahamefule, B., Ben-Chendo, G., Osuji, M., Nwose, R., Eleazar, A., Opaluwa, H., Ukoha, I., Nwaiwu, I., Ajibade, Y., Opeyemi, G., Ibeagwa, O., Tim-Ashama, A., Offor, E., Nwachukwu, E., Anyanwu, U., Anyiam, K., & Iwezor-Magnus, D. (2024). Effect of climate variables on poultry production efficacy in Nigeria. *Online Journal of Animal and Feed Research*.
<https://doi.org/10.51227/ojafr.2024.23>.
- Oyeniya, F., Dada, O., Popoola, I., Olowoyo, E., Oyeniya, T., Fadairo, O., & Popoola, L. (2024). A review of intensive contract poultry farming in Nigeria. *Proceedings of the Nigerian Academy of Science*. <https://doi.org/10.57046/ubod4576>.
- Regmi, B., Dhakal, I., Shah, M., & Pande, K. (2020). A Retrospective Study of Poultry Diseases Diagnosed at the Veterinary Laboratory, Pokhara, Nepal. , 4, 398-402.
<https://doi.org/10.26855/ijfsa.2020.12.006>.

- Sanni, A., Onyango, J., Usman, A., Abdulkarim, L., Jonker, A., & Fasina, F. (2022). Risk Factors for Persistent Infection of Non-Typhoidal Salmonella in Poultry Farms, North Central Nigeria. *Antibiotics*, 11.
<https://doi.org/10.3390/antibiotics11081121>.
- Sha'arani, H.M., Aminu, A.I., Aminu, B.M. (2024). Occurrence of antimicrobial residues in broiler chickens from selected farms and markets in Kano Metropolis, Nigeria. *Dutse Journal of Pure and Applied Sciences*.
<https://doi.org/10.4314/dujopas.v10i1a.28>.
- Ukashatu, S., Magaji, A., Najamuddeen, G., & , S. (2012). Survey of poultry diseases among exotic breeds of poultry in Katsina metropolis, Katsina state, Nigeria. , 1, 69-73. <https://doi.org/10.14196/sjz.v1i3.342>.
- Yehia, N., Salem, H., Mahmmoud, Y., Said, D., Samir, M., Mawgod, S., Sorour, H., AbdelRahman, M., Selim, S., Saad, A., El-Saadony, M., El-Meihy, R., El-Hack, M., El-Tarabily, K., & Zanaty, A. (2023). Common viral and bacterial avian respiratory infections: an updated review.. *Poultry science*, 102 5, 102553 .
<https://doi.org/10.1016/j.psj.2023.102553>.

**Antihyperglycemic and Antioxidant Effects of *Ipomoea batatas* L.
Leaves in Streptozotocin-Induced Diabetic Wistar Rats**

Amuzat A.O., Abdullahi F .K., Ndatsu Y., Muhammad H.B. and Sulaiman R. S.
Ibrahim Badamasi Babangida University Lapai, Niger State, Nigeria

Muhammad H.B

Federal University of Lafia, Nasarawa State, Nigeria

Corresponding Author Mail/Phone No: allyhamzah@yahoo.co.uk/0803 8510909

Abstract

Hyperglycemia, a hallmark feature of diabetes mellitus, contributes significantly to metabolic dysfunction and oxidative stress. The growing burden of diabetes, particularly in low- and middle-income countries, has intensified the search for affordable plant-based interventions that may aid glycemic regulation. This study evaluated the antihyperglycemic and antioxidant effects of aqueous and methanolic extracts of *Ipomoea batatas* L. leaves in streptozotocin-induced diabetic Wistar rats. Fresh leaves of *I. batatas* were air-dried, pulverized, and extracted using distilled water and methanol. Acute oral toxicity was assessed using the Lorke method. Diabetes was induced by intraperitoneal administration of streptozotocin (65 mg/kg body weight). Diabetic rats were administered aqueous or methanolic leaf extracts at doses of 100, 200, and 400 mg/kg body weight for 14 days. Fasting blood glucose levels, body weight, and activities of antioxidant enzymes (superoxide dismutase, catalase, glutathione peroxidase, and glutathione reductase) were evaluated. Phytochemical screening revealed the presence of flavonoids, tannins, saponins, alkaloids, phenols, terpenoids, steroids, and cardiac glycosides in both extracts. Treatment with the extracts resulted in a significant ($p < 0.05$) reduction in fasting blood glucose levels, attenuation of diabetes-associated weight loss, and modulation of antioxidant enzyme activities in a dose-dependent manner. The methanolic extract at 400 mg/kg exhibited effects comparable to glibenclamide. These findings suggest that *I. batatas* leaf extracts possess antihyperglycemic activity and antioxidant potential, supporting their traditional use in glycemic regulation.

Keywords: Hyperglycemia; *Ipomoea batatas*; Streptozotocin; Antihyperglycemic activity; Antioxidant enzymes

Introduction

Diabetes mellitus (DM) is a chronic metabolic disorder characterized by persistent hyperglycemia resulting from impaired insulin secretion, insulin action, or both. It is a major global public health concern due to its rising prevalence and association with long-term complications such as cardiovascular disease, nephropathy, neuropathy, and retinopathy (American Diabetes Association, 2021; Saeedi et al., 2019). In sub-Saharan Africa, including Nigeria, diabetes management is often complicated by delayed diagnosis, limited access to healthcare services, and the high cost of conventional pharmacotherapy (BobgaBilla, 2023). Although insulin and oral antihyperglycemic agents are effective in controlling blood glucose, their prolonged use may be associated with adverse effects such as hypoglycemia, weight gain, and gastrointestinal disturbances (Cerf, 2020). These limitations have stimulated increasing interest in medicinal plants as complementary approaches for glycemic control.

Medicinal plants are widely utilized in traditional medicine owing to their accessibility and bioactive phytochemical content. Compounds such as flavonoids, phenolics, alkaloids, and saponins have been shown to modulate glucose metabolism and oxidative stress through mechanisms including enhancement of insulin sensitivity, stimulation of glucose uptake, and attenuation of free radical generation (Majid et al., 2019; Rahman et al., 2021).

Ipomoea batatas L. (sweet potato), a member of the Convolvulaceae family, is extensively cultivated as a food crop. While its tubers are commonly consumed, the leaves are rich in dietary fiber, vitamins, minerals, and polyphenolic compounds (Cartabiano-Leite et al., 2020; Suhendy, 2023). Ethnobotanical surveys document the traditional use of *I. batatas* leaves in the management of diabetes, inflammation, and other ailments. Importantly, several experimental studies have already reported the antihyperglycemic and antioxidant activities of *I. batatas* leaves (Zhao et al., 2007; Rafiu& Luka, 2018; Almoraie, 2019; Akhtar et al., 2018; Arisanti et al., 2023).

However, variations in extraction solvents, dosage regimens, and oxidative stress markers evaluated across studies necessitate further investigation to clarify dose-dependent effects and antioxidant enzyme responses in standardized experimental models. Therefore, the present study aimed to evaluate the antihyperglycemic activity and antioxidant enzyme modulation of aqueous and methanolic extracts of *Ipomoea batatas* leaves in streptozotocin-induced diabetic Wistar rats.

MATERIALS AND METHODS

Chemicals and Reagents

Streptozotocin and Glibenclimide were purchased from KunleAra' Pharmacy in Ibadan and they were of analytical grade. Methanol and distilled water used for the extraction were obtained from the Department of Biochemistry and Biotechnology postgraduate laboratory, Ibrahim Badamasi Babangida University Lapai, Niger State, Nigeria. All other chemicals and reagents used for sample analysis were supplied by Merck (Darmstadt, Germany).

Collection and Identification of Plant Material

Plant Material Preparation

Fresh leaves of *Ipomoea batatas* L. were collected in August 2024 from Lapai Local Government Area, Niger State, Nigeria. The plant was authenticated at the Herbarium of the Department of Biological Sciences, Ibrahim Badamasi Babangida University, Lapai (Voucher No. 432). Leaves were air-dried at room temperature (25–28 °C) for 14 days and pulverized using a mechanical grinder.

Extraction Procedure

Fifty gram (50 g) of powdered leaf material was subjected to cold maceration separately using 200 mL each of distilled water and methanol for 24 hours with intermittent stirring. The resulting extracts were filtered using muslin cloth followed by Whiteman's filter paper (No 1). Aqueous and methanolic extracts were concentrated using a water bath (aqueous extract) and rotary evaporator (methanolic extract). The paste was poured into a beaker and resulting extract was freeze dried and stored in an air-tight container for further use. The extract was reconstituted in distilled water to give the required doses of 100, 200 and 400 mg/kg bw used in this study.

Experimental Animals

Seventy healthy male Wistar rats (181.450 ± 13.43 g) were obtained from Animal holding unit of the Department of Biochemistry, Federal University of Technology Minna, Niger State. Animals were acclimatized for one week under standard laboratory conditions with access to standard feed and water *ad libitum*. All experimental procedures were approved by the Institutional Animal Ethics Committee.

Ethical Approval

Approval for the use of animals was obtained from the Ethical Review Committee of the Department of Biochemistry Ibrahim Badamasi Babangida University Lapai, Niger State, Nigeria. (the ethical clearance statement was verbally obtained from Departmental PG board as we were not aware of the existence of Institution Ethical Committee until now that we were told about committee existence. Therefore, we could not get approval number from the institutional review board before this study was carried out).

Phytochemical Screening

Qualitative screening of the extracts for alkaloids, flavonoids, tannins, saponins, phenols, terpenes, steroids, and cardiac glycosides was carried out through the established protocols described by Balamurugan et al. (2019) based on water and methanol solvents used.

Acute Toxicity Study

Acute oral toxicity was evaluated using the method described by Lorke (1983). Extracts were administered at graded doses up to 5000 mg/kg body weight, and animals were observed first for 24 hours and the observation was later extended to 14 days for signs of toxicity or mortality. The LD₅₀ was estimated accordingly.

Induction of Diabetes

Diabetes was induced by a single intraperitoneal injection of Streptozotocin (65 mg/kg body weight) freshly dissolved in cold citrate buffer (0.1 M, pH 4.5) into the rats. Rats with fasting blood glucose ≥ 200 mg/dL after 72 hours were considered diabetic as described by Solihah et al. (2023).

Experimental Design

Rats were randomly assigned into nine groups (n = 5) and the rats in each group were orally administered the extracts once daily for 14 days. Blood glucose was measured on days 0, 4, 8, 12, and 14.

AE = aqueous extract and ME = methanolic extract

Group 1: Non-diabetic Control (NDC)

Group 2: Diabetic rats orally administered distilled water (Diabetic Control).

Group 3: Diabetic rats orally administered 10mg/kg body weight of standard drug, glibenclamide.

Group 4: Diabetic rats orally administered 100mg/kg body weight of aqueous extract.

Group 5: Diabetic rats orally administered 200mg/kg body weight of aqueous extract.

Group 6: Diabetic rats orally administered 400mg/kg body weight of aqueous extract.

Group 7: Diabetic rats orally administered 100mg/kg body weight of methanolic extract.

Group 8: Diabetic rats orally administered 200mg/kg body weight of methanolic extract.

Group 9: Diabetic rats orally administered 400mg/kg body weight of methanolic extract.

Biochemical Analyses

After two weeks of experimental period, the rats were subjected to a twelve-hour fasting prior to their been euthanized by exposing the animals to an overdose of chloroform in the anesthetic box with the lid on. The heart of each sacrificed rat was pierced and blood drawn into clean sample bottles. A Denley BS400 centrifuge (England) was used at 2556 g to separate the serum from the collected blood samples after been allowed to coagulate for ten minutes. The collected sera were subjected to evaluation of blood glucose level, and estimation of oxidative stress biomarkers.

Statistical Analysis

Data were expressed as mean $\pm$ SD. Statistical analysis was performed using [GraphPad Prism version XX]. One-way ANOVA followed by Tukey's post-hoc test was used, with significance set at $p < 0.05$.

Results and Discussion

Phytochemical Analysis

The aqueous and methanolic extracts of *Ipomoea batatas* (sweet potato) leaves contained numerous important bioactive chemicals, according to qualitative phytochemical screening. Saponins, tannins, flavonoids, and phenols were found to be more present in the methanolic extract than in the aqueous extract. Alkaloids, flavonoids, cardiac glycosides, terpenoids, steroids, and phenols were detected in both extracts, but their proportions were somewhat different as shown in **Table 1**.

Table 1. Qualitative Phytochemical screening of *Ipomoea batatas* leaves extracts

	Water	Methanol
Saponins	+	+++
Tannins	+	+++
Alkaloids	+	+
Flavonoids	+	+++
Cardiac glycoside	+	+
Terpenoids	+	+
Steroids	+	+
Phenols	+	+++

Key: + Present

Toxicology Studies

The results for sub-acute toxicity test for leaf extracts of *I. batatas* is shown in **Table 2**. The leaf extracts of *I. batatas* did not result in any deaths, behavioral abnormalities, and significant body weight changes during the toxicological evaluation. In this study, the administration of the extracts to rats showed no mortality nor any negative behavioral display suggesting that the extracts were well-tolerated, even at the higher dose of 5000 mg/kg body weight.

Table 2. LD₅₀ of *Ipomoea batatas* leaves extracts on Wistar rats

Dosage (mg/kg bw)	No. of animals	Mortality (Aqueous extract)	Mortality (Methanolic extract)
Phase 1			
10	3	Nil	Nil
100	3	Nil	Nil
1000	3	Nil	Nil
Phase 2			
1900	3	Nil	Nil
2500	3	Nil	Nil
5000	3	Nil	Nil

Body weight of wistar rats administered aqueous and methanolic extracts of *Ipomeabatatas* leaves

Table 3 shows the body weight change of the experimental rats over the course of two weeks of experimental period for both the diabetic and non-diabetic groups. A significant ($p > 0.05$) increase in average body weight of rats in normal control group was observed during the experimental period (from 174 ± 5.95 g on day 1 to 193 ± 5.90 g on day 14). In contrast, the average body weight of rats in diabetic control group significantly ($p > 0.05$) decreased over the experimental period (from 159 ± 7.51 g at day 0 to 127 ± 6.03 g at day 14). Glibenclamide (BLG)-treated rats showed a significant ($p > 0.05$) increase in weight (155 ± 6.68 g in day 0 to 174 ± 4.50 g in day 14 as compared to untreated diabetic rats. Rats treated with both aqueous and methanolic extracts showed a dose-dependent increase in their weights after two weeks of treatment with the highest dose (AE-400 and ME-400 mg/kg) resulted in a significant ($p > 0.05$) increase in body weight (208 ± 1.50 g and 210 ± 6.85 g, respectively). Based on this study, administration of methanolic extract of *Ipomoea batatas* Leaves significantly ($p > 0.05$) prevented the weight loss caused by diabetes.

Table 3. Effect of administration of aqueous and methanolic extracts of *Ipomoea batatas* Leaves on body weight of Streptozotocin-induced diabetic wistar rats

Sample	DAY 1 (g)	DAY 4 (g)	DAY 7 (g)	DAY 10 (g)	DAY 14 (g)
Normal Control	174.12 ± 5.95^b	178.23 ± 2.54^c	180.43 ± 8.56^c	190.63 ± 2.80^c	193.33 ± 5.90^d
Diabetic control	159.65 ± 7.51^a	154.88 ± 1.21^a	146.66 ± 1.39^a	137.78 ± 5.40^a	127.78 ± 6.03^a
GLB-5mg/kg bw	155.34 ± 6.68^a	156.67 ± 0.97^a	165.77 ± 1.87^b	172.56 ± 9.11^b	174.77 ± 4.50^b
AE-100mg/kg bw	172.74 ± 8.10^a	178.45 ± 2.13^c	182.45 ± 2.78^c	184.44 ± 1.37^b	187.55 ± 2.00^c
AE-200mg/kg bw	159.15 ± 2.00^a	164.45 ± 2.17^b	167.44 ± 6.03^b	170.45 ± 2.90^b	173.34 ± 3.00^b
AE-400mg/kg bw	171.53 ± 2.82^b	175.33 ± 2.65^c	182.33 ± 2.50^c	195.12 ± 9.77^c	208.89 ± 1.50^d
ME-100mg/kg bw	180.66 ± 1.85^{bc}	183.98 ± 2.65^d	185.23 ± 7.18^c	189.76 ± 2.19^c	197.29 ± 3.00^d
ME-200mg/kg bw	187.74 ± 2.45^c	191.33 ± 6.96^e	194.66 ± 9.19^d	196.56 ± 5.65^c	199.93 ± 4.00^d
ME-400mg/kg bw	175.87 ± 4.98^b	184.56 ± 6.58^d	192.67 ± 2.68^d	200.78 ± 6.51^{dc}	210.76 ± 4.98^e

Values are expressed in mean $\pm$ standard error of mean of triplicates. Values with the same superscript across the row have no significant difference at $p < 0.05$.

Keys: AE-aqueous extract, ME-methanolic extract, GLB – Glibenclimide, bw – body weight.

Glucose level of Streptozotocin-induced diabeticwistar rats administered aqueous and methanolic Extract of *Ipomoea batatas*Leaves.

Table 4 shows the blood glucose levels of Streptozotocin-induced diabetic wistar rats administered methanolic and aqueous extracts of *Ipomoea batatas* leaves The glucose levels in the normal control group ranged from 76.90±0.14 mg/dl before induction to 74.64±0.08 mg/dl on day 14. Following induction, the glucose levels in the diabetic control group increased significantly ($p > 0.05$) to 235.78±2.30 mg/dl, and remained significantly ($p > 0.05$) hyperglycemic for the duration of the experiment. The glibenclamide treatment caused a significant ($p > 0.05$) decrease in glucose level to 80.02±2.33 mg/dl at day 14. Methanolic and aqueous extracts of *Ipomoea batatas*Leaves significantly ($p > 0.05$) reduced glucose levels in a dose-dependent manner. The AE-400 group decreased from 265.18±0.26 to 92.06±0.96 mg/dl, whereas the ME-400 group decreased from 342.40±1.31 to 87.26±1.56 mg/dl. Although both treatments were redeeming, the 400 mg/kg methanolic extract (ME-400) showed a significantly ($p > 0.05$) higher reduction in glucose levels by the 14th day, suggesting a more blood sugar lowering effect in diabetic rats.

Table 4. Glucose level of Streptozotocin-induced diabetic wistar rats administered aqueous and methanolic extracts of *Ipomoea batatas*Leaves.

Sample	Day1 (mg/dl)	Day4 (mg/dl)	Day7(mg/dl)	Day10 (mg/dl)	Day14 (mg/dl)
Normal Control	76.90 ± 0.14 ^b	82.68 ± 1.59 ^a	80.7±1.02 ^a	77.68±0.55 ^a	74.64 ± 0.08 ^a
Diabetic control	78.00 ± 0.27 ^c	235.78 ± 2.30 ^b	237.97±1.85 ^b	239.05±1.20 ^b	240.18 ± 0.9 ⁱ
GLB-5mg/kg bw	82.84 ± 0.78 ^d	255.60 ± 0.25 ^c	197.07±1.68 ^c	139.56±1.95 ^c	80.02 ± 2.33 ^b
AE-100mg/kg bw	74.10 ± 1.23 ^a	278.14 ± 0.70 ^e	234.87±1.28 ^d	199.61±1.52 ^d	164.34 ± 1.86 ^h
AE-200mg/kg bw	85.14 ± 0.43 ^f	315.00 ± 1.61 ^g	266.50±1.74 ^e	196.25±1.80 ^e	126.00 ± 1.86 ^f
AE-400mg/kg bw	76.85 ± 0.48 ^b	265.18 ± 0.26 ^d	207.89±0.61 ^c	141.63±0.92 ^c	92.06 ± 0.96 ^d
ME-100mg/kg bw	77.86 ± 1.27 ^c	289.08 ± 0.56 ^f	235.75±0.72 ^d	190.51±0.93 ^d	145.26 ± 0.98 ^g
ME-200mg/kg bw	90.00 ± 0.91 ^g	314.10 ± 2.60 ^h	236.83±2.05 ^d	168.92±1.90 ^e	113.58 ± 1.76 ^e
ME-400mg/kg bw	83.08 ± 0.95 ^e	342.40 ± 1.31 ⁱ	233.07±1.44 ^d	149.80±1.55 ^c	87.26 ± 1.56 ^c

Values are expressed in mean ± standard error of mean of triplicates. Values with the same superscript down the Column have no significant difference at $p < 0.05$.

Keys: AE-aqueous extract, ME-methanolic extract, GLB – Glibenclimide, bw – body weight, **Day 1**- the day STZ was administered, **Day 4** – 3 days after the administration of STZ, **Day 14**- 14 days of treatment after the diabetes has been confirmed in the experimental rats.

Antioxidants activity of Streptozotocin-induced diabeticwistar rats administered aqueous and methanolic Extract of *Ipomoea batatas*Leave

The antioxidant status was assessed by measuring the activities of catalase, superoxide dismutase (SOD), glutathione peroxidase (GPx), and glutathione reductase (GR), as indicated in **Table 5**. In comparison to the normal control, the diabetic control rats showed a significant ($p > 0.05$) increase in the activities of all antioxidant enzymes, indicating oxidative stress. However, following the aqueous extract treatment, the antioxidant enzyme activity significantly ($p > 0.05$) decreased in a dose-dependent manner. The ME-400 showed lowest activity of catalase (9.58 ± 0.64 U/mL) and Glutathion reductase (GR) (89.34 ± 1.50 U/mL), indicating a significant improvement in oxidative defense. The groups AE-100 and AE-200 showed the greatest Glutathion Peroxidase (GPx) activity (83.20 ± 0.73 and 82.32 ± 1.59 U/mL, respectively). Alyhough, not to the same extent, methanolic extract treatments also increased antioxidant enzyme activities. The AE-400 group showed moderate activities of catalase (13.58 ± 0.71 U/mL) and GR (94.49 ± 0.84 U/mL), whereas GPx and SOD activities were relatively low.

Table 5: Activities of Antioxidant enzymes in Streptozotocin-induced diabeticrats administered aqueous and methanolic Extracts of *Ipomoea batatas*Leave

Sample	Catalase(U/mL)	SOD (U/mL)	Glutathione peroxidase (U/mL)	Glutathione reductase (U/mL)
Normal Control	15.86 ± 0.38^c	27.97 ± 0.78^b	79.32 ± 0.89^{ab}	109.10 ± 1.39^b
Diabetic control	16.03 ± 0.44^c	28.66 ± 0.33^b	88.20 ± 0.24^b	109.66 ± 1.10^b
GLB-5mg/kg bw	12.10 ± 0.57^{ab}	20.98 ± 0.65^a	64.30 ± 1.74^a	89.17 ± 0.04^a
AE-100mg/kg bw	14.06 ± 0.33^b	23.10 ± 1.27^{ab}	83.20 ± 0.73^b	101.24 ± 1.50^b
AE-200mg/kg bw	16.98 ± 0.88^c	24.28 ± 1.47^{ab}	82.32 ± 1.59^b	106.03 ± 1.20^b
AE-400mg/kg bw	13.58 ± 0.71^b	20.75 ± 1.59^a	74.54 ± 1.54^{ab}	94.49 ± 0.84^a
ME-100mg/kg bw	14.56 ± 0.65^b	23.48 ± 1.38^{ab}	73.68 ± 0.87^{ab}	96.41 ± 1.26^{ab}
ME-200mg/kg bw	11.58 ± 0.58^{ab}	22.39 ± 1.55^a	67.14 ± 1.30^a	93.13 ± 1.92^a
ME-400mg/kg bw	9.58 ± 0.64^a	21.59 ± 0.61^a	61.83 ± 0.88^a	89.34 ± 1.50^a

Discussion

Streptozotocin induces diabetes through selective pancreatic β -cell damage, leading to insulin deficiency, hyperglycemia, weight loss, and oxidative stress (Cerf, 2020). In this study, hyperglycemia was established in rats administered 65 mg/kg body weight of streptozotocin.

Presently, almost 80% of the global population depends on the use of medicinal plants for their health needs (Lathaet *al.* 2016). The presenceof phytochemicals that are of health importance in plants may be responsible for their health benefits. In the present study, aqueous and methanolicextracts of *Ipomea. batatas* leaf were found to contain

flavonoids, tannins, saponins, alkaloids, phenols, terpenoids, steroids, and cardiac glycosides. The presence of these bioactive agents that have been reported useful as therapeutic agents may be responsible for the traditional use of extracts of *Ipomea batatas* by the locals. This is in tandem with the findings of Almorai (2019) who reported the presence of alkaloids, flavonoids, glycosides, tannins, saponins and steroids in boiled aqueous extract of *Ipomea batatas* leaf. The variation in the level of some phytochemical constituents of aqueous and methanolic extracts of *Ipomea batatas* in this study could be attributable to the variation in solvent of extraction. Studies have shown that variation in phytochemical constituents of a plant may be due to variation in plant part used, and geographical location where the plant was harvested. This finding agrees with earlier findings which reported that not all plant contain all phytochemicals and that those present varies according to the part of the plant or solvents of extraction (Lawalet al. 2014).

In this study, administration of *I. batatas* leaf extracts to Streptozotocin-induced diabetic rats resulted in a dose-dependent reduction in fasting blood glucose levels of hyperglycemic wistar rats, suggesting improved glycemic regulation. These effects are consistent with previous reports attributing the antihyperglycemic activity of *I. batatas* leaves to their rich flavonoid and phenolic content (Zhao et al., 2007; Rafiu & Luka, 2018; Almorai, 2019). The methanolic extract demonstrated superior efficacy, likely due to enhanced extraction of polyphenolic compounds.

Diabetes-associated weight loss observed in untreated rats was significantly attenuated following extract administration, indicating partial restoration of metabolic balance. Improved weight gain in diabetic rats treated with extracts of *I. batatas* leaf may be due to improved insulin secretion induced by the extracts administration as reflected in the reduction of glucose levels in extracts administered rats in this study. This observation is in tandem with the work of Vague et. al (1986) who reported a positive correlation between serum insulin level and weight gain. Also, the weight gain observed in diabetic rats treated with *I. batatas* leaf extracts may be due to the inhibition of structural protein breakdown usually associated with diabetes thereby preventing wasting, a condition that causes loss of body weight. This may be due to improved glucose absorption as a result of improved insulin secretion by the pancreas. Charlton et. Al (1998) reported that there is usually increase in structural protein catabolism as a means of obtaining energy fuel thereby reducing body weight of a diabetic patient.

Superoxide dismutase (SOD), catalase (CAT) and glutathione peroxidase (GPx) are enzymes that play a significant role in providing antioxidant defences in organisms by destroying the peroxides generated in the body (Kaleem et. al, 2006).. Both CAT and GPx are involved in the elimination of H₂O₂. While SOD acts to dismutate superoxide radical to H₂O₂, GPx acts upon H₂O₂ produced to generate harmless molecule (Kaleem et. al, 2006). The functions of SOD, CAT and GPx are interconnected and reduction in their activities results in the accumulation of peroxides resulting in increased oxidative stress in diabetic rats. Administration of *I. batatas* leaf extracts reduced the activity of these enzymes suggesting that phytochemical components of the extracts might have

donated protons to stabilize the free radicals generated due to STZ administration thereby reducing the need for the activities of the antioxidant enzymes and thus may help to avoid the free radicals generated during diabetes mellitus. This study suggests that diabetic rats exposed to oxidative stress but treated with *I. batatas* leaf extracts can partially reduce the imbalances between the generation of reactive oxygen species (ROS) and the scavenging enzyme activity. In this study, oxidative stress, a central contributor to diabetic complications, was modulated in diabetic rats by the administration of *I. batatas* leaves extracts as evidenced by improved antioxidant enzyme activities. These findings support the antioxidant potential of *I. batatas* leaves and align with existing literature.

Conclusion

This study demonstrates that aqueous and methanolic extracts of *Ipomoea batatas* leaves possess significant antihyperglycemic activity and antioxidant enzyme-modulating effects in streptozotocin-induced diabetic rats. The methanolic extract exhibited comparatively greater efficacy at higher doses. While the findings support the traditional use of *I. batatas* leaves in glycemic regulation, further studies are required to establish long-term safety and elucidate underlying mechanisms.

References

- Adwas, A. A., Elsayed, A., Azab, A. E., & Quwaydir, F. A. (2019). Oxidative stress and antioxidant mechanisms in human body. *J. Appl. Biotechnol. Bioeng*, 6(1), 43-47.
- Akhtar, N., Akram, M., Daniyal, M., & Ahmad, S. (2018). Evaluation of antidiabetic activity of *Ipomoea batatas* L. extract in alloxan-induced diabetic rats. *International journal of immunopathology and pharmacology*, 32, 205873841 Z8814678.
- Almoraie, N. M. (2019). The Role of *Ipomoea Batatas* Leaves Extract on the Treatment of Diabetes Induced by Streptozotocin. *Pharmacophore*, 10(3-2019), 14-20.
- American Diabetes Association. (2021). 2. Classification and diagnosis of diabetes: standards of medical care in diabetes—2021. *Diabetes care*, 44(Supplement_1), S15-S33.
- Arisanti, C. I. S., Wirasuta, I. M. A. G., Musfiroh, I., Ikram, E. H. K., & Muchtaridi, M. (2023). *Mechanism of Anti-Diabetic Activity from Sweet Potato (Ipomoea batatas): A Systematic Review*. *Foods* 2023, 12, 2810.
- Balamurugan, V., Fatima, S., & Velurajan, S. (2019). A guide to phytochemical analysis. *International Journal of Advance Research and Innovative Ideas in Education*, 5(1), 236-245.
- BobgaBilla, J. K. (2023). *Challenges and opportunities in managing Type 2 Diabetes Mellitus in Sub-Saharan Africa: the cases of Nigeria and South Africa* (Doctoral dissertation, Hochschule für Angewandte Wissenschaften Hamburg).
- Cartabiano-Leite, C. E., Porcu, O. M., & de Casas, A. F. (2020). Sweet potato (*Ipomoea batatas* L. Lam) nutritional potential and social relevance: a review. *history*, 11(6), 23-40.

- Cerf, M. E. (2020). Beta cell physiological dynamics and dysfunctional transitions in response to islet inflammation in obesity and diabetes. *Metabolites*, 10(11), 452.
- Charlton, M. & Nair, K.S., (1998). Protein metabolism in insulin-dependent diabetes mellitus. *The Journal of nutrition*, 128(2), 323S-327S.
- Galicía-García, U., Benito-Vicente, A., Jebari, S., Larrea-Sebal, A., Siddiqi, H., Uribe, K. B., & Martín, C. (2020). Pathophysiology of type 2 diabetes mellitus. *International journal of molecular sciences*, 21(17), 6275.
- Kaleem, M., Asif, M., Ahmed, Q. U., & Bano, B. (2006). Antidiabetic and antioxidant activity of *Annona squamosa* extract in streptozotocin-induced diabetic rats. *Singapore medical journal*, 47(8), 670.
- Lawal, A. K., Rotter, T., Kinsman, L., Sari, N., Harrison, L., Jeffery, C., ... & Flynn, R. (2014). Lean management in health care: definition, concepts, methodology and effects reported (systematic review protocol). *Systematic reviews*, 3(1), 103.
- Magtalas, M. C., Balbin, P. T., Cruz, E. C., Clemente, R. F., Buan, A. K. G., Garcia, J. P., ... & Tantengco, O. A. G. (2023). Ethnomedicinal plants used for the prevention and treatment of anemia in the Philippines: a systematic review. *Tropical Medicine and Health*, 51(1), 27.
- Majid, M., Ijaz, F., Baig, MW., Nasir, B., Khan, MR., Haq, IU. (2019) Scientific validation of ethnomedicinal use of *Ipomoea batatas*L. Lam. as aphrodisiac and gonadoprotective agent against bisphenol A induced testicular toxicity in male Sprague Dawley rats. *BioMed Research International* 2019: 1–21.
- Majid, M., Ijaz, F., Baig, MW., Nasir, B., Khan, MR., Haq, IU. (2019) Scientific validation of ethnomedicinal use of *Ipomoea batatas*L. Lam. as aphrodisiac and gonadoprotective agent against bisphenol A induced testicular toxicity in male Sprague Dawley rats. *BioMed Research International* 2019: 1–21.
- Naomi, R., Bahari, H., Yazid, M. D., Othman, F., Zakaria, Z. A., & Hussain, M. K. (2021). Potential effects of sweet potato (*Ipomoea batatas*) in hyperglycemia and dyslipidemia—a systematic review in diabetic retinopathy context. *International journal of molecular sciences*, 22(19), 10816.
- Naomi, R., Bahari, H., Yazid, M. D., Othman, F., Zakaria, Z. A., & Hussain, M. K. (2021). Potential effects of sweet potato (*Ipomoea batatas*) in hyperglycemia and dyslipidemia—a systematic review in diabetic retinopathy context. *International journal of molecular sciences*, 22(19), 10816.
- Rafiu, A. A., & Luka, C. (2018). Evaluation of the antidiabetic property of aqueous extract of *Ipomoea batatas* leaf on hyperglycemia, hyperlipidemia, blood electrolytes, and enzymatic antioxidants of streptozotocin-induced diabetic rats. *J. Res. Diabetes Metab*, 4(1), 022-026.
- Rahman, M. S., Hossain, K. S., Das, S., Kundu, S., Adegoke, E. O., Rahman, M. A., & Pang, M. G. (2021). Role of insulin in health and disease: an update. *International journal of molecular sciences*, 22(12), 6403.
- Saeedi, P., Petersohn, I., Salpea, P., Malanda, B., Karuranga, S., Unwin, N., & IDF Diabetes Atlas Committee. (2019). Global and regional diabetes prevalence

- estimates for 2019 and projections for 2030 and 2045: Results from the International Diabetes Federation Diabetes Atlas. *Diabetes research and clinical practice*, 157, 107843.
- Suhendy, H., Fidrianny, I., & Insanu, M. (2023). Phytochemical compounds and pharmacological activities of *Ipomoea batatas* L.: An updated review. *Pharmacia*, 70, 1283-1294.
- Vague, P., Juhan-Vague, I., Aillaud, M.F., Badier, C., Viard, R., Alessi, M.C. & Collen, D., (1986). Correlation between blood fibrinolytic activity, plasminogen activator inhibitor level, plasma insulin level, and relative body weight in normal and obese subjects. *Metabolism*, 35(3), 250-253.
- Zhao, R., Li, Q., Long, L., Li, J., Yang, R., & Gao, D. (2007). Antidiabetic activity of flavone from *Ipomoea Batatas* leaf in non-insulin dependent diabetic rats. *International Journal of Food Science and Technology*, 42(1), 80-85.

Note On Extension of Rellich-type Inequality

Y. O. Anthonio and K. Rauf

Department of Mathematics,
Lagos State University of Science and Technology, Ikorodu.

Corresponding Author E-mail Addresses: anthonio.yo@lasustech.edu.ng and
krauf@unilorin.edu.ng.

Abstract

This paper examine Hardy type inequalities within the context of equalities that directly yield new Hardy type inequalities by eliminating the remainder term. Additionally, we characterize the class of functions that make the remainder term vanish. The focus is on utilizing orthogonality properties in general Hilbert space, which offers a straightforward understanding of Hardy type inequalities and the absence of nontrivial extremizers.

2010 AMS Subject Classification: 22E30, 35H20, 46E35, and 47J10.

Keywords: Hardy inequality, Rellich inequality, uncertainty principle, Bessel s inequality, horizontal Laplacian.

Introduction

Rellich inequality, also known as Rellich-Kondrachov compactness theorem, is a fundamental result in functional analysis and the theory of partial differential equations. It provides conditions under which certain embedding operators are compact. This theorem is named after the mathematicians Franz Rellich and Vladimir Iosifovich Kondrachov.

The statement of the Rellich-Kondrachov Theorem in its simplest form is:

Let (Ω) be a bounded domain in (R^j) with a smooth boundary. Then the embedding of the Sobolev space $(H^1(\Omega))$ into $(L^2(\Omega))$ is compact. That is, any bounded sequence in $(H^1(\Omega))$ has a subsequence that converges in $(L^2(\Omega))$. The Rellich-Kondrachov theorem has several important implications. It guarantees that Sobolev spaces can be compactly embedded into certain (L^p) spaces, which is crucial for solving partial differential equations as it ensures the existence of solutions under specific conditions. It aids in the analysis of weak convergence in Sobolev spaces, which is vital for studying the behavior of functions and their approximations. The theorem is instrumental in the regularity theory of elliptic and parabolic partial differential equations, providing a foundation for proving the existence and uniqueness of solutions, Rellich (1969). Let (Ω) be a bounded open

subset of (R^j) with a Lipschitz boundary. The theorem states that: If p and q are such that $(1 \leq q < p < \infty)$, then the embedding $(W^{1,p}(\Omega) \hookrightarrow L^q(\Omega))$ is compact. Hence, $W^{1,p}(\Omega) \subset L^q(\Omega)$ compactly, if $q < p$

The proof of the Rellich-Kondrachov theorem involves several steps as follows, using the fact that (Ω) can be covered by a finite number of small regions. Applying Sobolev inequalities to these regions to control the functions in (H^1) . Employing a diagonalization argument to extract convergent subsequences. The Rellich-Kondrachov theorem is a powerful tool in analysis, particularly in the study of Sobolev spaces and partial differential equations. Its ability to guarantee the compactness of embeddings is crucial for proving many fundamental results in these areas. Indeed, G. H. Hardy's contributions, particularly his work on inequalities Hardy *et. al.* (1952) and most importantly on Hardy's inequality, have had a lasting impact on various branches of mathematics and physics. The applications you mentioned highlight the versatility and significance of his findings in diverse areas such as mathematical analysis, differential equations, and quantum mechanics. Hardy's work continues to be influential and celebrated in the academic community.

The statement is as follows: If numbers $a, r > 0$, function $\zeta(\chi) \geq 0$ and $\int_a^b \zeta^r(\chi) d\chi \leq \infty$ is integrable and convergent, then

$$\int_a^b \left(1 + \frac{1-\chi}{\chi}\right) \left(\int_0^\chi \zeta(\beta) d\beta\right)^r d\chi \leq \frac{r^r}{(r-1)^r} \int_a^b \zeta^r(\chi) d\chi \quad (1.1)$$

where $\frac{r^r}{(r-1)^r}$ is the possible constant.

Friedrich Rellich and Werner Heisenberg were two eminent figures whose work has significantly influenced various domains such as mathematical analysis, the theory of partial differential equations, physics, and quantum mechanics. Their contributions, particularly in the context of Hardy-type, Hardy-Rellich, and uncertainty principle inequalities, have found profound applications across these fields.

Friedrich Rellich was a German mathematician renowned for his work in mathematical analysis and partial differential equations. His contributions to the spectral theory of differential operators laid a foundational framework for modern mathematical physics. One of his notable achievements was the Rellich-Kondrachov Compactness Theorem, which has critical implications in functional analysis and partial differential equations. Rellich's exploration of Hardy-type inequalities has been particularly impactful. Hardy inequalities, named after G. H. Hardy, are integral inequalities that provide bounds for integrals of functions and their derivatives. Rellich extended these inequalities, resulting in what are now known as Hardy-Rellich inequalities. These inequalities offer deeper insights into the behavior of solutions to differential equations, especially in quantum mechanics and the study of wave equations, see Hardy *et. al.* (1952).

Werner Heisenberg, a German theoretical physicist, is best known for formulating the Heisenberg Uncertainty Principle, a fundamental concept in quantum mechanics. This principle states that the position and momentum of a particle cannot both

be precisely measured at the same time. The mathematical formulation of this principle involves inequalities that are closely related to the Hardy and Hardy-Rellich inequalities.

Heisenberg's work extended beyond the uncertainty principle. He played a crucial role in the development of matrix mechanics, one of the first formulations of quantum mechanics. His contributions have had lasting implications in both theoretical and applied physics, influencing the development of technologies such as semiconductors and quantum computing.

The Hardy-type, Hardy-Rellich, and uncertainty principle inequalities have a broad range of applications. They are pivotal in understanding the properties of functions and their integrals, providing essential tools for mathematicians working in various branches of analysis.

In partial differential equations, these inequalities are used to establish the existence and uniqueness of solutions, as well as to study the qualitative behavior of these solutions Rozanova (1976).

In physics, particularly in quantum mechanics, these inequalities are instrumental in describing the behavior of quantum systems, providing bounds that are crucial for understanding phenomena at the quantum level.

Owing to their profound usefulness, these inequalities have undergone extensive extensions and refinements. The interest in these inequalities is reflected in numerous books and monographs, such as references [Yoshida (1966), Hilger (1988), Opic and Kufner(1990), Ruzhansky and Suragan (2019)] and articles [Godunova and Levin (1969), Beesack (1979), Hilger(1997), Brezis and Vazquez (1997), D'Ambrosio (2005), Devyver (2014), Rauf and Anthonio (2017), Anthonio and Rauf (2021)], where their applications and extensions are discussed in detail.

One significant recent development is the class of interpolation inequalities known as Caffarelli-Kohn-Nirenberg (CKN) inequalities, particularly on the Heisenberg group. The Heisenberg group, a fundamental structure in quantum mechanics, provides a natural setting for exploring these inequalities.

Caffarelli-Kohn-Nirenberg inequalities generalize classical Sobolev inequalities and have found numerous applications in mathematical physics. They provide a framework for deriving various forms of Hardy, Hardy-Rellich, and uncertainty principle type inequalities. These derivations not only deepen the understanding of the underlying mathematical structures but also enhance the ability to apply these inequalities in solving complex physical problems.

The legacies of Friedrich Rellich and Werner Heisenberg continue to inspire and guide researchers across mathematics and physics. The inequalities that bear their influence are Hardy-type, Hardy-Rellich, and uncertainty principle inequalities, they remain vital tools in both theoretical and applied contexts. The results provide a study platform for ongoing discoveries and advancements in science.

The following are the proof of the main results:

Corollary 1.1:

Let Y be a scalar product space. The following fundamental statements are equivalent on scalar product $(\cdot, \cdot)$.

$$\left\| \frac{\zeta(\chi) - \zeta_j(\chi)}{|\chi|^{\frac{j+2}{2}-1} \log \frac{A}{|\chi|}} \right\|^2 = -2k \operatorname{Re} \left(\frac{\zeta(\chi) - \zeta_j(\chi)}{|\chi|^{\frac{j+2}{2}-1} \log \frac{A}{|\chi|}} \middle| \frac{\partial_q \zeta}{|\chi|^{\frac{j-4}{2}+3}} \right) < \infty \quad (1.2)$$

and

$$\left\| \frac{\zeta(\chi) - \zeta_j(\chi)}{|\chi|^{\frac{j+2}{2}-1} \log \frac{A}{|\chi|}} \right\|^2 = 4k^2 \left\| \frac{\partial_q \zeta(\chi)}{|\chi|^{\frac{n-4}{2}+3}} \right\|^2 - \left\| \frac{\zeta(\chi) - \zeta_j(\chi)}{|\chi|^{\frac{j+2}{2}-1} \log \frac{A}{|\chi|}} + 2k \frac{\partial_q \zeta(\chi)}{|\chi|^{\frac{j-4}{2}+3}} \right\|^2 < \infty \quad (1.3)$$

where $k > 0$ is a constant, $\frac{\zeta(\chi) - \zeta_j(\chi)}{|\chi|^{\frac{j-1}{2}+1} \log \frac{A}{|\chi|}}, \frac{\partial_q \zeta(\chi)}{|\chi|^{\frac{j-4}{2}+1}} \in Y$

Proof: The standard equivalent equality.

$$\operatorname{Re} \left(\frac{\zeta(\chi) - \zeta_j(\chi)}{|\chi|^{\frac{j+2}{2}-1} \log \frac{A}{|\chi|}} \middle| \frac{\partial_q \zeta}{|\chi|^{\frac{j-4}{2}+3}} + 2k \frac{\partial_q \zeta}{|\chi|^{\frac{j-4}{2}+3}} \right) = 0 \quad (1.4)$$

The standard proof of Hardy inequality is bases on the inequality

$$\left\| \frac{\zeta(\chi) - \zeta_j(\chi)}{|\chi|^{\frac{j+2}{2}-1} \log \frac{A}{|\chi|}} \right\|^2 \leq 2k \left\| \frac{\zeta(\chi) - \zeta_n(\chi)}{|\chi|^{\frac{j+2}{2}-1} \log \frac{A}{|j|}} \right\| \left\| \frac{\partial_q \zeta(\chi)}{|j|^{\frac{j-4}{2}+3}} \right\| \quad (1.5)$$

then apply Cauchy-Schwarz inequality to (1.2). Hence the proof of the Corollary 1.1. One dimensional Hardy-type equalities mentioned as follows.

Theorem 1.1: Let $k \in \mathbb{C}$, $\zeta, \chi^{1-q} |\zeta(\chi)|^2 \in (0, \infty)$, and j is equal one and q is positive.

The following equalities hold:

$$\begin{aligned} & \left(\frac{q}{2} \right)^2 \int_0^\infty \chi^{1-q} \left| \frac{1}{\chi} \int_0^\chi \zeta(\alpha) d\alpha \right|^2 d\chi \\ &= \int_0^\infty \chi^{1-q} |\zeta(\chi)|^2 d\chi + \int_0^\infty \chi^{1-q} \frac{q |\zeta(\chi)|}{\chi} \left| \int_0^\chi \zeta(\alpha) d\alpha \right| d\chi - \int_0^\infty \chi^{1-q} \frac{q^2}{4\chi^2} \left| \int_0^\chi \zeta(\alpha) d\alpha \right|^2 d\chi - \int_0^\infty \chi^{1-q} |\zeta(\chi)|^2 d\chi \quad (1.6) \\ &= \int_0^\infty \chi^{1-q} |\zeta(\chi)|^2 d\chi - \int_0^\infty \chi \left(\chi^{-\frac{q}{2}} \int_0^\chi \zeta(\alpha) d\alpha \right)^2 d\chi \end{aligned}$$

$$\int_0^\chi \zeta(\alpha) d\alpha = k \chi^{\frac{q}{2}} \quad \text{Equation (1.6) disappears, if } k \neq 0 \quad \text{It the same equation with,}$$

$$\begin{aligned} & \left(\frac{q}{2} \right)^2 \int_0^\infty \chi^{1-q} \left| \frac{1}{\chi} \int_0^\chi \zeta(\alpha) d\alpha \right|^2 d\chi = \infty \quad \text{if } k = 0 \quad \text{then} \\ & \int_0^\infty \chi^{1-q} \left| \frac{1}{\chi} \int_0^\chi \zeta(\alpha) d\alpha \right|^2 d\chi = |k|^2 \chi^{-1} \notin (0, \infty) \quad (1.7) \end{aligned}$$

Proof: Taking Corollary 1.1 and apply integration by parts, with some assertion

$$k = \frac{1}{q}, v = -\zeta \quad u, = \frac{1}{\chi} \int_0^\chi \zeta(\alpha) d\alpha \quad \text{then}$$

$$\begin{aligned} & \left(\frac{q}{2} \right)^2 \int_0^\infty \chi^{1-q} \left| \frac{1}{\chi} \int_0^\chi \zeta(\alpha) d\alpha \right|^2 d\chi \\ &= \left(\frac{q}{2} \right)^2 \int_0^\infty \chi^{-1-q} \left| \frac{1}{\chi} \int_0^\chi \zeta(\alpha) d\alpha \right|^2 d\chi \\ &= \frac{2}{q} \operatorname{Re} \int_0^\infty \chi^{-q} \overline{\zeta(\chi)} \int_0^\chi \zeta(\alpha) dy \\ &= \frac{2}{q} \operatorname{Re} \int_0^\infty \chi^{1-q} \left(\frac{1}{\chi} \int_0^\chi \zeta(\alpha) d\alpha \right) \overline{\zeta(\chi)} d\chi \quad (1.8) \end{aligned}$$

This concludes the demonstration of the theorem.

Similarly,

Theorem 1.2:

Let $\zeta, \chi^{1+q} |\zeta(\chi)|^2 \in (0, \infty)$, $k \in \mathbb{C}$ and j is equal one and a is positive

$$\begin{aligned} & \left(\frac{q}{2} \right)^2 \int_0^\infty \chi^{1+q} \left| \frac{1}{\chi} \int_0^\chi \zeta(y) dy \right|^2 d\chi \\ &= \int_0^\infty \chi^{1+q} |\zeta(\chi)|^2 d\chi + \int_0^\infty \chi^{1-q} \frac{q |\zeta(\chi)|}{\chi} \left| \int_0^\chi \zeta(\alpha) d\alpha \right| d\chi - \int_0^\infty \chi^{1+q} \frac{q^2}{4\chi^2} \left| \int_0^\chi \zeta(\alpha) d\alpha \right|^2 d\chi - \int_0^\infty \chi^{1+q} |\zeta(\chi)|^2 k\chi \\ &= \int_0^\infty \chi^{1+q} |\zeta(\chi)|^2 d\chi - \int_0^\infty \chi \left(\int_0^\chi \zeta(\alpha) d\alpha \right)^2 d\chi \end{aligned} \quad (1.9)$$

Equation (1.9) disappears, if setting $\int_0^\chi \zeta(\alpha) d\alpha = k\chi^{-\frac{q}{2}}$ and

$\left(\frac{q}{2} \right)^2 \int_0^\infty \chi^{1+q} \left| \frac{1}{\chi} \int_0^\chi \zeta(\alpha) d\alpha \right|^2 d\chi = \infty$, if $k = 0$ then

$$\int_0^\infty \chi^{1+q} \left| \frac{1}{\chi} \int_0^\chi \zeta(\alpha) d\alpha \right|^2 d\chi = |k|^2 \chi^{-1} \notin (0, \infty) \quad (1.10)$$

Proof: Taking Corollary 1.1 and apply integration by parts, with some assertion

$$k = \frac{1}{q}, v = -\zeta, u = \frac{1}{\chi} \int_0^\chi \zeta(\alpha) d\alpha \quad \text{then}$$

$$\begin{aligned} & \left(\frac{q}{2} \right)^2 \int_0^\infty \chi^{1+q} \left| \frac{1}{\chi} \int_0^\chi \zeta(\alpha) d\alpha \right|^2 d\chi \\ &= \left(\frac{q}{2} \right)^2 \int_0^\infty \chi^{1+q} \left| \frac{1}{\chi} \int_0^\chi \zeta(\alpha) d\alpha \right|^2 d\chi \\ &= \frac{2}{q} \operatorname{Re} \int_0^\infty \chi^q \overline{\zeta(\chi)} \int_0^\chi \zeta(\alpha) d\alpha \\ &= \frac{2}{q} \operatorname{Re} \int_0^\infty \chi^{1+q} \left(\frac{1}{\chi} \int_0^\chi \zeta(\alpha) d\alpha \right) \overline{\zeta(\chi)} d\chi \end{aligned} \quad (1.11)$$

This proves the theorem.

The next is proof of Hardy type inequalities with logarithms in the critical weighted Sobolev spaces.

Theorem 1.3:

Taking j to be greater or equal to two then equalities.

$$\begin{aligned}
 & \left\| \frac{1}{4} \frac{\zeta - \zeta_A}{|\chi|^{\frac{j-2}{2}+1} \log \frac{A}{|\chi|}} \right\|^2 \\
 &= \left\| \frac{1}{|\chi|^{\frac{j-4}{2}+1}} \partial_q \zeta(\chi) \right\|^2 - \left\| \frac{\zeta - \zeta_A}{2|\chi| \log \frac{A}{|\chi|}} \right\|^2 - 2 \left\| \frac{1}{|\chi|^{\frac{j-4}{2}+1}} \partial_q \zeta(\chi) \right\| \left\| \frac{\zeta - \zeta_A}{2|\chi| \log \frac{A}{|\chi|}} \right\| - \left\| \frac{1}{|\chi|^{\frac{j-4}{2}+1}} \partial_q \zeta(\chi) \right\|^2 \\
 &= -2 \left\| \frac{1}{|\chi|^{\frac{n-4}{2}+1}} \partial_q \zeta(\chi) \right\| \left\| \frac{\zeta - \zeta_A}{2|\chi| \log \frac{A}{|\chi|}} \right\| = \left\| \frac{1}{|\chi|^{\frac{j-4}{2}+1}} \partial_q \zeta(\chi) \right\|^2 - \left\| \frac{\log \frac{A}{|\chi|^{\frac{1}{2}}}}{|\chi|^{\frac{j-4}{2}+1}} \partial_q \left(\frac{\zeta - \zeta_A}{2|\chi| \log \frac{A}{|\chi|^{\frac{1}{2}}}} \right) \right\|^2 \quad (1.12)
 \end{aligned}$$

Let a function $\Phi: S^{j-1} \rightarrow \mathbb{C}$,

$$\frac{1}{4} \left\| \frac{\zeta - \zeta_A}{|\chi|^{\frac{j-2}{2}+1} \log \frac{A}{|\chi|}} \right\|^2 < \infty$$

which makes $\int_{S^{j-1}} |\Phi(\omega)|^2 d\sigma(\omega) = 0$. unless If

$$\frac{|\zeta(\chi) - \zeta_A(\chi)|^2}{\left| \log \frac{A}{|\chi|} \right|} = \left| \Phi\left(\frac{\chi}{|\chi|}\right) \right|^2$$

that is

$$|\zeta(\chi) - \zeta_A(\chi)| = \left| \log \frac{A}{|\chi|} \right|^{\frac{1}{2}} \Phi\left(\frac{\chi}{|\chi|}\right) \in L^j$$

where

$$\zeta_A(\chi) = \zeta\left(A \frac{\chi}{|\chi|}\right) \quad \text{and}$$

the right hand side of (1.12) vanishes, if

$$\zeta(\chi) - \zeta_R(\chi) = \left| \log \frac{A}{|\chi|} \right|^{\frac{1}{2}} \Phi\left(\frac{\chi}{|\chi|}\right).$$

Proof: Let $A \in R^j$ be less than zero then,

$$\begin{aligned}
 \int_{|\chi| < A^j} \frac{|\zeta(\chi) - \zeta_A(\chi)|^2}{|\chi|^j \left| \log \frac{A}{|\chi|} \right|^2} d\chi &\leq \frac{1}{\log \frac{A}{|\chi|^j}} \int_{A^j} \frac{|\zeta(x) - \zeta_A(\chi)|^2}{|\chi|^j} d\chi \\
 &= \int_0^A a^{-1} \left(\log \frac{A}{a} \right)^{-2} \int_{S^{j-1}} |\zeta(a\omega) - \zeta(A\omega)|^2 d\sigma(\omega) \zeta(a\omega) da \\
 &= -2\text{Re} \int_0^{A^j} \left(\log \frac{A}{a} \right)^{-1} \int_{S^{j-1}} |\zeta(a\omega) - \zeta(A\omega)| \omega \overline{\nabla \zeta(a\omega)} d\sigma(\omega) \zeta(a\omega) da \\
 &= -2\text{Re} \int_{|\chi| < A^j} \frac{|\zeta(\chi) - \zeta_A(\chi)|}{|\chi|^{\frac{j-2}{2}+1}} \frac{\partial_a \zeta(\chi)}{\left| \log \frac{A}{|\chi|} \right|} \frac{1}{|\chi|^{\frac{j-4}{2}+1}} < \infty d\chi \tag{1.13}
 \end{aligned}$$

In polar coordinates (q, ϑ) , employ integration by parts when handling radial functions as shown in (1.14) and Corollary 1.1. This implies:

$$\begin{aligned}
 \left| \log \frac{A}{q} \right| &= \int_t^A \frac{d\beta}{\beta} \geq \frac{\frac{A}{q} - 1}{\frac{A}{q}} = \frac{A - q}{A} = \frac{|q - A|}{A} \geq 0, \\
 &\text{and} \\
 |\zeta(a\omega) - \zeta(A\omega)|^2 &\leq \|\nabla\|_\infty^2 |A - q|^2 < \infty \tag{1.14}
 \end{aligned}$$

and hence, the following

$$\left\| \frac{\zeta(\chi) - \zeta_j(\chi)}{|\chi|^{\frac{j+2}{2}-1} \log \frac{R}{|\chi|}} \right\|^2 = 4k^2 \text{Re} \left\| \frac{\partial_q \zeta(\chi)}{|\chi|^{\frac{j-4}{2}+2}} \right\|^2 - 4 \left\| \frac{\zeta(\chi) - \zeta_j(\chi)}{|\chi|^{\frac{j+2}{2}-1} \log \frac{A}{|\chi|}} + \frac{1}{2} k \frac{\partial_q \zeta(\chi)}{|\chi|^{\frac{j-4}{2}+2}} \right\|^2 < \infty. \tag{1.15}$$

Next proof is when $A^j \in R^j$ is greater than zero then, it yields

$$\int_{|\chi| > A^j} \frac{|\zeta(\chi) - \zeta_A(\chi)|^2}{|\chi|^n \left| \log \frac{R}{|\chi|} \right|^2} d\chi \leq \frac{1}{\log \frac{A}{|\chi|^j}} \int_{A^j} \frac{|\zeta(\chi) - \zeta_A(\chi)|^2}{|\chi|^j} d\chi \leq \infty \quad (1.16)$$

$$\begin{aligned} &= \int_{A^j}^{\infty} \left(q \log \frac{A}{|q|} \right)^{-2} \int_{S^{j-1}} |\zeta(q\omega) - \zeta(A\omega)|^2 d\sigma(\omega) \zeta(q\omega) dq \\ &= 2 \operatorname{Re} \int_{A^j}^{\infty} \left(q \log \frac{A}{|q|} \right)^{-2} \int_{S^{j-1}} |\zeta(q\omega) - \zeta(A\omega)| \omega \cdot \nabla \zeta(q\omega) d\sigma(\omega) \zeta(q\omega) dq \leq \infty \\ &= 2 \operatorname{Re} \int_{|\chi| > A^j} \frac{|\zeta(\chi) - \zeta_A(\chi)|}{|\chi|^{\frac{j-2}{2}+1} \left| \log \frac{A}{|\chi|} \right|} \frac{\partial_q \zeta(\chi)}{|\chi|^{\frac{j-4}{2}+1}} d\chi \leq \infty \end{aligned} \quad (1.17)$$

$$\left| \log \frac{A}{q} \right| = \int_{\beta}^q \frac{d\beta}{\beta} \geq \frac{\frac{q}{A} - 1}{\frac{q}{A}} = \frac{q - A}{q} = \frac{|A - q|}{q}$$

Then,

$$\left\| \frac{\zeta(\chi) - \zeta_j(\chi)}{|\chi|^{\frac{j+2}{2}-1} \log \frac{A}{|\chi|}} \right\|^2 = 4k^2 \operatorname{Re} \left\| \frac{\partial_q \zeta(\chi)}{|\chi|^{\frac{j-4}{2}+2}} \right\|^2 - 4 \left\| \frac{\zeta(\chi) - \zeta_j(\chi)}{|\chi|^{\frac{j+2}{2}-1} \log \frac{A}{|\chi|}} + \frac{1}{2} k \frac{\partial_q \zeta(\chi)}{|\chi|^{\frac{j-4}{2}+2}} \right\|^2 < \infty \quad (1.18)$$

Adding (1.16), (1.19), proof of Theorem 1.1 and $\partial_q \zeta(\chi)$ completes the proof of the theorem.

Theorem 1.4:

Let j be greater than or equal to three. Then the equalities hold if $\zeta(\chi) \in R^j$.

$$\begin{aligned} (j-2)^2 2^{-2} \|\zeta(\chi) |\chi|^{-1}\|^2 &= \|\partial_q \zeta(\chi)\|^2 - \|\partial_q \zeta(\chi) + (j-2)2^{-1} |\chi|^{-1} \zeta(\chi)\|^2 \\ &= \|\partial_q \zeta(\chi)\|^2 - \left\| |\chi|^{-\frac{n-6}{2}+2} \partial_q \left(|\chi|^{\frac{j-6}{2}+2} \zeta(\chi) \right) \right\|^2 < \infty \end{aligned} \quad (1.19)$$

The second term in the right hand side of (1.19) vanishes if and if is of the form

$$\zeta(\chi) = \frac{|\chi|^{\frac{j}{2}}}{|\chi|} \Phi(\chi |\chi|^{-1}) < \infty \quad (1.20)$$

Suppose a function $\Phi: S^{j-1} \rightarrow \mathbb{C}$ that renders left hand side of (1.17) infinite unless

$$\int_{S^{j-1}} |\Phi(\omega)|^2 d\sigma(\omega) = 0$$

$$|\zeta(\chi) \chi|^2 = \Phi(|\chi| |\chi|^{-1})^2 |\chi|^{-j} < \infty \quad (1.21)$$

It is noted that in (1.20), a function in (1.17) implies the existence of a nontrivial extremizer. The associated integral diverges at both the origin and infinity. The methodologies for the proofs differ, with some relying on direct calculations involving the quotient and the optimizer of a Hardy inequality.

Additionally, Theorem 1.4 will be established through an orthogonal argument within a Hilbert space framework, especially utilizing an equality.

$$(j-2)^2 2^{-2} \|\zeta(\chi) |\chi|^{-1}\|^2 = \|\nabla \zeta(\chi)\|^2 \|\nabla \zeta(\chi) + (j-2) 2^{-1} \chi |\chi|^{-2} \zeta(\chi)\|^2 < \infty \quad (1.22)$$

The radial symmetry is shared, but they differ for non-radial functions. However, the Dirichlet integral is decompose into radial and spherical components.

Proof: The polar coordinates (q, ω) , (1.4) and (1.20) gives

$$\begin{aligned} \int_j |\zeta(\chi)|^2 |\chi|^{-2} d\chi &= \int_0^\infty q^{j-3} \int_{S^{j-1}} |\zeta(q\omega)|^2 d\sigma(\omega) dq \\ &= -2(j-2)^{-1} \operatorname{Re} \int_0^\infty q^{j-2} \int_{S^{j-1}} \zeta(q\omega) \nabla \zeta(q\omega) d\sigma(\omega) dq \\ &= -2(j-2)^{-1} \operatorname{Re} \int_j \zeta(\chi) |\chi|^{-1} \partial_q \zeta(\chi) d\chi < \infty \end{aligned} \quad (1.23)$$

Integration by parts in the radial variable was carried out in the proof of Theorem 1. Using Corollary 1.1 with $\frac{1}{j-2}$, $\frac{\zeta(\chi)}{|\chi|}$, and $\partial_q \zeta(\chi)$ in the Hilbert space $L^2(R^j)$, equation (1.20) is obtained. A direct calculation then led to the derivation of equation on the right hand side of (1.8) from the left hand side of (1.7). The remainder terms vanish if and only if $\partial_q (|\chi|^{\frac{j-6}{2}+2} \zeta)$ equals 0, indicating that $|\chi|^{\frac{j-6}{2}+2} \zeta(\chi)$ is a function on the sphere. This completes the proof of Theorem.

Terms of Vanishing Condition of Remainder

In the realm of mathematics, inequality serves as a powerful tool, offering insights into the relationships between quantities. Embracing inequality means

acknowledging the diversity and richness of mathematical structures, where differences exist and contribute to the complexity of the subject. In particular, when examining inequalities, understanding the equality case is crucial. This occurs when the inequality becomes an equation, often indicating a point of balance or extremum. Characterizing the equality case involves identifying conditions under which the inequality holds with equality.

In many cases, this is tied to the vanishing condition of the remainder. For instance, in the context of polynomial division, equality occurs when the remainder becomes zero, indicating that the divisor perfectly divides the dividend. This concept extends to various mathematical contexts, providing deeper insights into the nature of inequalities and their equality cases. In this section, the characterization of equality cases in terms of vanishing conditions of remainders in the Relish inequality is discussed.

Theorem 2.1: Taking j to be greater or equal to five then

$$\begin{aligned}
 & j^2(j-4)^2 4^{-2} \left\| |x|^{-2} \zeta(x) \right\|^2 \\
 &= \left\| \partial_q^2 \zeta(x) + j |x|^{-1} \partial_a \zeta(x) - |x|^{-1} \partial_q \zeta(x) \right\|^2 \\
 &- \left\| \partial_q^2 \zeta(x) + j |x|^{-1} \partial_q \zeta(x) - |x|^{-1} \partial_a \zeta(x) + 2^{-2} j^2 |x|^{-2} \zeta(x) - j |x|^{-2} \zeta(x) \right\|^2 \\
 &+ 2j \left\| |x|^{-1} \partial_q \zeta(x) + \zeta(x) 2^{-1} n |x|^{-2} - 2 |x|^{-2} \zeta(x) \right\|^2 - 2^{-1} j^2 \left\| |x|^{-1} \partial_q \zeta(x) + \zeta(x) 2^{-1} j |x|^{-2} - 2 |x|^{-2} \zeta(x) \right\|^2 \\
 &= \left\| |x|^{\frac{2-2j}{2}} \partial_q \left(|x|^{\frac{2j-2}{2}} \partial_q \zeta(x) \right) \right\|^2 - \left\| |x|^{\frac{2-2j}{2}} \partial_q \left(|x|^{-1} \partial_q \left(|x|^{\frac{3j}{6}} \zeta(x) \right) \right) \right\|^2 \\
 &+ 2j \left\| |x|^{\frac{2-2j}{2}} \partial_a \left(|x|^{-1} \partial_a \left(|x|^{\frac{2j-4}{2}} \zeta(x) \right) \right) \right\|^2 - 2^{-1} j^2 \left\| |x|^{\frac{2-2j}{2}} \partial_q \left(|x|^{-1} \partial_q \left(|x|^{\frac{2n-4}{2}} \zeta(x) \right) \right) \right\|^2 \\
 &= \left\| |x|^{\frac{2-2j}{2}} \partial_q \left(|x|^{\frac{2j-2}{2}} \partial_q \zeta(x) \right) \right\|^2 - \left\| |x|^{\frac{(j+2)}{2}} \partial_q \left(|x|^3 \partial_q \left(|x|^{\frac{j-4}{2}} \zeta(x) \right) \right) \right\|^2 \\
 &+ 2j \left\| |x|^{\frac{2-2j}{2}} \partial_q \left(\partial_q \left(|x|^{\frac{2j-4}{2}} \zeta(x) \right) \right) \right\|^2 - 2^{-1} j^2 \left\| |x|^{\frac{2-2j}{2}} \partial_q \left(\partial_q \left(|x|^{\frac{2j-4}{2}} \zeta(x) \right) \right) \right\|^2 < \infty \quad (2.1)
 \end{aligned}$$

This statement holds true for $\in H^2(R^j)$. Furthermore, there is no $\in H^2(R^j)$ that satisfies

$$\begin{aligned}
 & n^2(j-4)^2 4^{-2} \left\| |x|^{-2} \zeta(x) \right\|^2 \\
 &= \left\| \partial_q^2 \zeta(x) + j |x|^{-1} \partial_a^2 \zeta(x) - |x|^{-1} \partial_q^2 \zeta(x) \right\|^2 \\
 &= \left\| |x|^{\frac{2-2j}{2}} \partial_q \left(|x|^{\frac{2j-2}{2}} \zeta(x) \right) \right\|^2 < \infty \quad (2.2)
 \end{aligned}$$

and

$$j^2(j-4)^2 4^{-2} \left\| |\chi|^{-2} \zeta(\chi) \right\|^2 = \left\| \nabla \zeta(\chi) \right\|^2 < \infty, \quad \text{putting} \quad \zeta(\chi) = 0 \quad (2.3)$$

Proof: With

$$\begin{aligned} & \int_j |\zeta(\chi)^2 \chi^{-1}| d\chi \\ &= \frac{2}{(j-3)(j-4)} \left(\left\| |\chi|^{-1} \partial_q \zeta(\chi) \right\|^2 + \operatorname{Re} \int_j |\zeta(\chi) \chi^{-2}| \overline{\partial_q^2 \zeta(\chi)} d\chi \right) \end{aligned} \quad (2.4)$$

The norm on the right hand sides of (2.4) can be written as follows

$$\begin{aligned} & \left\| |\chi|^{-1} \partial_q \zeta(\chi) \right\|^2 \\ &= \left\| \partial_q |\chi|^{-1} \zeta(\chi) + |\chi|^{-2} \zeta(\chi) \right\|^2 \\ &= \left\| \partial_q |\chi|^{-1} \zeta(\chi) \right\|^2 + 2 \operatorname{Re} \left(\partial_q (|\zeta(\chi)| \chi^{-2}) \overline{|\zeta(\chi)| \chi^{-2}} \right) + \left\| |\zeta(\chi)| \chi^{-2} \right\|^2 \end{aligned} \quad (2.5)$$

putting $\zeta(\chi) = \zeta(\chi) |\chi|^{-1}$ in (2.5) yields

$$\left\| |\chi|^{-1} \zeta(\chi) \right\|^2 = (j-2)^2 2^{-1} \left\| |\chi|^{-2} \zeta(\chi) \right\|^2 + \left\| |\chi|^{\frac{2-j}{2}} \partial_q (|\chi|^{\frac{j-4}{2}} \zeta(\chi)) \right\|^2 \quad (2.6)$$

which implies

$$2 \operatorname{Re} \left(\partial_q (|\zeta(\chi)| \chi^{-2}) \overline{|\zeta(\chi)| \chi^{-2}} \right) = -(j-2) \left\| |\chi|^{-2} \zeta(\chi) \right\|^2 \quad (2.7)$$

combining (1.26), (1.27) and (1.28) become

$$\left\| |\chi|^{-2} \partial_q \zeta(\chi) \right\|^2 = (j-2)^{-2} 2^{-2} \left\| |\chi|^{-2} \zeta(\chi) \right\|^2 + \left\| |\chi|^{\frac{2-j}{2}} \partial_q (|\chi|^{\frac{j-4}{2}} \zeta(\chi)) \right\|^2 \quad (2.8)$$

The right side of latter inequality yields

$$\begin{aligned} & \operatorname{Re} \int_j \zeta(\chi) |\chi|^{-2} \overline{\partial_q^2 \zeta(\chi)} d\chi \\ &= \operatorname{Re} \int_j \zeta(\chi) |\chi|^{-2} \overline{\partial_q^2 \zeta(\chi)} d\chi + \frac{j}{|\chi|} \operatorname{Re} \int_j \zeta(\chi) |\chi|^{-1} \overline{\partial_q^2 \zeta(\chi)} d\chi - \frac{1}{|\chi|} \operatorname{Re} \int_j \zeta(\chi) |\chi|^{-1} \overline{\partial_q^2 \zeta(\chi)} d\chi \\ &+ \operatorname{Re} \int_j \zeta(\chi) |\chi|^{-3} \overline{\partial_q^2 \zeta(\chi)} d\chi + j \operatorname{Re} \int_j \zeta(\chi) |\chi|^{-3} \overline{\partial_q^2 \zeta(\chi)} d\chi \end{aligned} \quad (2.9)$$

Last two integrals give

$$\begin{aligned}
 & \operatorname{Re} \int_j \zeta(\chi) |\chi|^{-3} \overline{\partial_q \zeta(\chi)} d\chi \\
 &= \frac{1}{2} \operatorname{Re} \int_j \zeta(\chi)^2 \partial_q (|\chi|^{-3}) d\chi \\
 &= \frac{1}{2} \operatorname{Re} \int_n \chi |\chi|^{-4} \nabla (|\zeta(\chi)|^2) \\
 &= 2 \left\| |\chi|^{-2} \zeta(\chi) \right\|^2 - 2^{-1} j \left\| |\chi|^{-2} \zeta(\chi) \right\|^2 \quad (2.10)
 \end{aligned}$$

From (2.1), (2.4), (2.6) and (2.7) that

$$\begin{aligned}
 & j(j-4)4^{-1} \left\| |\chi|^{-2} \zeta(\chi) \right\|^2 \\
 &= -\operatorname{Re} \int_j \zeta(\chi) |\chi|^{-2} \overline{\partial_a^2 \zeta(\chi)} d\chi + \frac{j}{|\chi|} \operatorname{Re} \int_j \zeta(\chi) |\chi|^{-1} \overline{\partial_q^2 \zeta(\chi)} d\chi - \left\| |\chi|^{\frac{2-j}{2}} \partial_a (|\chi|^{\frac{j-4}{2}} \zeta(\chi)) \right\|^2 < \infty \quad (2.11)
 \end{aligned}$$

Let us assume $\zeta \in H^2(R^j)$ satisfies (2.2). Then, by (2.3), it follows that $\partial_q (|\chi|^{\frac{j-4}{2}} \zeta(\chi)) = 0$, which is equivalent to the existence of $\Phi: S^{j-1} \rightarrow \mathbb{C}$ almost everywhere. In this case, $\frac{\zeta(\chi)}{|\chi|^2} \in L^1(R^j)$ where the last condition $\Phi(\chi) \equiv 0$ which in turn implies $\zeta(\chi) \equiv 0$ if and only if $\Phi(\chi) \equiv 0$, which implies $\zeta(\chi) \equiv 0$. If $\zeta \in H^2(R^j)$ satisfies (1.5), then the problem is reduced to case (2.2), and It is only sufficient to prove (1.5). Therefore, the proof of Corollary 1.1 completes the proof of the Theorem 2.1.

Relation between Bessel's and Relish-type Inequality

Bessel's inequality is a fundamental result in the context of inner product spaces. It provides an upper bound on the sum of the squares of the coefficients when a vector is expressed as a combination of an orthonormal set. Given a vector (χ) in a Hilbert space (H) and an orthonormal sequence $(\{e_k\}_{k=1}^n) \in (H)$, Bessel's inequality states that:

$$\sum_{i=1}^n |\langle \chi, e_k \rangle|^2 \leq \|\chi\|^2$$

Here, $\langle \chi, e_k \rangle$ denotes the inner product of (χ) and e_k , and $(|\chi|)$ is the norm of (χ) . Bessel's inequality essentially says that the projection of a vector (χ) onto the span of the orthonormal sequence $(\{e_k\})$ does not capture more "energy" (as measured by the sum of the squares of the coefficients) than the original vector (χ) itself. In the context of Fourier series, where signals are decomposed into orthogonal basis functions (e.g., sines and cosines), Bessel's inequality guarantees that the energy of the partial sums of the series does not exceed the energy of the signal. Bessel's inequality is crucial in the theory of approximations. It ensures that any finite approximation of a function (using an

orthonormal basis) provides a bounded error, which is essential for convergence analysis. In quantum mechanics, state vectors in Hilbert spaces can be expressed in terms of orthonormal eigenstates of an observable. Bessel's inequality provides a bound on the probabilities of measuring these eigenstates. The proof of Bessel's inequality leverages the Pythagorean theorem generalized to Hilbert spaces. By considering the orthogonal projection of (χ) onto the subspace spanned by $(\{e_k\})$, one can show that the sum of the squares of the inner products $(|\langle \chi, e_k \rangle|^2)$ is less than or equal to the norm of (χ) squared. In essence, Bessel's inequality is a cornerstone in understanding how vectors can be decomposed in terms of orthonormal bases, ensuring that such decompositions respect the intrinsic geometry of the space.

Definition:

Suppose Y is a linear space over the real or complex number field K .

A mapping $(.,.): Y \times Y \rightarrow K$ is said to be positive Hermitian form if the following holds:

$$(i) \quad \left(\alpha \frac{\zeta(\chi) - \zeta_j(\chi)}{|\chi|^{\frac{j+2}{2}-1} \log \frac{R}{|\chi|}} + \beta \frac{\partial_q \zeta}{|\chi|^{\frac{j-4}{2}+3}}, 0 \right) = \alpha \left(\frac{\zeta(\chi) - \zeta_j(\chi)}{|\chi|^{\frac{j+2}{2}-1} \log \frac{R}{|\chi|}}, 0 \right) + \beta \left(\frac{\partial_q \zeta}{|\chi|^{\frac{j-4}{2}+3}}, 0 \right),$$

for all $\frac{\zeta(\chi) - \zeta_j(\chi)}{|\chi|^{\frac{j+2}{2}-1} \log \frac{R}{|\chi|}}, \frac{\partial_q \zeta}{|\chi|^{\frac{j-4}{2}+3}} \in Y$. and $\alpha, \beta \in K$.

$$(ii) \quad \left(\frac{\zeta(\chi) - \zeta_j(\chi)}{|\chi|^{\frac{j+2}{2}-1} \log \frac{R}{|\chi|}}, \frac{\partial_q \zeta}{|\chi|^{\frac{j-4}{2}+3}} \right) = \left(\frac{\partial_q \zeta}{|\chi|^{\frac{j-4}{2}+3}}, \frac{\zeta(\chi) - \zeta_j(\chi)}{|\chi|^{\frac{j+2}{2}-1} \log \frac{R}{|\chi|}} \right),$$

$$\frac{\zeta(\chi) - \zeta_j(\chi)}{|\chi|^{\frac{j+2}{2}-1} \log \frac{R}{|\chi|}}, \frac{\partial_q \zeta}{|\chi|^{\frac{n-4}{2}+3}} \in Y.$$

for all

$$(iii) \quad \left(\frac{\zeta(\chi) - \zeta_j(\chi)}{|\chi|^{\frac{j+2}{2}-1} \log \frac{R}{|\chi|}}, \frac{\zeta(\chi) - \zeta_j(\chi)}{|\chi|^{\frac{j+2}{2}-1} \log \frac{R}{|\chi|}} \right) \geq 0,$$

$$\frac{\zeta(\chi) - \zeta_j(\chi)}{|\chi|^{\frac{j+2}{2}-1} \log \frac{R}{|\chi|}}, \quad \frac{\partial_q \zeta}{|\chi|^{\frac{j-4}{2}+3}} \in Y.$$

Considering the fact that

$$\left\| \frac{\zeta(\chi) - \zeta_j(\chi)}{|\chi|^{\frac{j+2}{2}-1} \log \frac{R}{|\chi|}} \right\| = \left(\frac{\zeta(\chi) - \zeta_j(\chi)}{|\chi|^{\frac{n+2}{2}-1} \log \frac{R}{|\chi|}}, \frac{\zeta(\chi) - \zeta_j(\chi)}{|\chi|^{\frac{n+2}{2}-1} \log \frac{R}{|\chi|}} \right)^{\frac{1}{2}} < \infty, \quad \frac{\zeta(\chi) - \zeta_j(\chi)}{|\chi|^{\frac{j+2}{2}-1} \log \frac{R}{|\chi|}} \in Y. \quad (3.1)$$

represents the semi-norm associated to this form and $(e_i, e_j)_{i \in I}$ is orthonormal family of vectors in Y , which implies $(e_i, e_j) = \delta_{ij}$ (i, j) then there exists the following inequality [4].

$$\left\| \frac{\zeta(\chi) - \zeta_j(\chi)}{|\chi|^{\frac{n+2}{2}-1} \log \frac{R}{|\chi|}} \right\|^2 \geq \sum_{i \in I} \left(\frac{\zeta(\chi) - \zeta_j(\chi)}{|\chi|^{\frac{j+2}{2}-1} \log \frac{R}{|\chi|}}, e_i \right)^2, \quad \text{for all } \frac{\zeta(\chi) - \zeta_j(\chi)}{|\chi|^{\frac{j+2}{2}-1} \log \frac{R}{|\chi|}} \in Y \quad (3.2)$$

which is known as Bessel's Inequality. Every finite H of interval I yields

$$\begin{aligned} 0 &\leq \left\| \frac{\zeta(\chi) - \zeta_j(\chi)}{|\chi|^{\frac{j+2}{2}-1} \log \frac{R}{|\chi|}} - \sum_{i \in I} \left(\frac{\zeta(\chi) - \zeta_j(\chi)}{|\chi|^{\frac{j+2}{2}-1} \log \frac{R}{|\chi|}}, e_i \right) e_i \right\|^2 \\ &= \left(\frac{\zeta(\chi) - \zeta_j(\chi)}{|\chi|^{\frac{j+2}{2}-1} \log \frac{R}{|\chi|}} - \sum_{i \in H} \left(\frac{\zeta(\chi) - \zeta_j(\chi)}{|\chi|^{\frac{j+2}{2}-1} \log \frac{R}{|\chi|}}, e_i \right) e_i, - \frac{\zeta(\chi) - \zeta_j(\chi)}{|\chi|^{\frac{j+2}{2}-1} \log \frac{R}{|\chi|}} - \sum_{j \in H} \left(\frac{\zeta(\chi) - \zeta_j(\chi)}{|\chi|^{\frac{j+2}{2}-1} \log \frac{R}{|\chi|}}, e_j \right) e_j \right) \\ &= \left\| \frac{\zeta(\chi) - \zeta_j(\chi)}{|\chi|^{\frac{j+2}{2}-1} \log \frac{R}{|\chi|}} \right\|^2 - \sum_{i \in H} \left(\frac{\zeta(\chi) - \zeta_j(\chi)}{|\chi|^{\frac{j+2}{2}-1} \log \frac{R}{|\chi|}}, e_i \right)^2 - \sum_{j \in H} \left(\frac{\zeta(\chi) - \zeta_j(\chi)}{|\chi|^{\frac{j+2}{2}-1} \log \frac{R}{|\chi|}}, e_j \right)^2 \\ &\quad + \sum_{i, j \in H} \left(\frac{\zeta(\chi) - \zeta_j(\chi)}{|\chi|^{\frac{j+2}{2}-1} \log \frac{R}{|\chi|}}, e_i \right) \left(\frac{\zeta(\chi) - \zeta_j(\chi)}{|\chi|^{\frac{j+2}{2}-1} \log \frac{R}{|\chi|}}, e_j \right) \delta_{i, j} \\ &= \left\| \frac{\zeta(\chi) - \zeta_j(\chi)}{|\chi|^{\frac{j+2}{2}-1} \log \frac{R}{|\chi|}} \right\|^2 - \sum_{i \in H} \left(\frac{\zeta(\chi) - \zeta_j(\chi)}{|\chi|^{\frac{j+2}{2}-1} \log \frac{R}{|\chi|}}, e_i \right)^2 \end{aligned} \quad (3.3)$$

$$\frac{\zeta(\chi) - \zeta_j(\chi)}{|\chi|^{\frac{j+2}{2}-1} \log \frac{R}{|\chi|}} \in Y$$

for all which shows an improvement in the assertion.

The following Corollary is pivot to the proof of Theorem 3.1.

Corollary 3.1 :

Let Y be a linear space endowed with a positive hermitian form $(.,.)$ and $(g_i)_{k=\overline{1,n}}$ be an orthonormal family in $(Y; (.,.))$. Then,

$$\begin{aligned} & \left\| \frac{\zeta(\chi) - \zeta_j(\chi)}{|\chi|^{\frac{j+2}{2}-1} \log \frac{R}{|\chi|}} \right\|^2 - \sum_{i=1}^N \left| \left(\frac{\zeta(\chi) - \zeta_j(\chi)}{|\chi|^{\frac{j+2}{2}-1} \log \frac{R}{|\chi|}}, g_i \right) \right|^2 \\ & \leq \left\| \frac{\zeta(\chi) - \zeta_j(\chi)}{|\chi|^{\frac{j+2}{2}-1} \log \frac{R}{|\chi|}} - \sum_{j=1}^N \lambda_j g_j \right\|^2 \end{aligned}$$

(3.4)

$$\text{for all } \lambda_i \in N \text{ and } \frac{\zeta(\chi) - \zeta_j(\chi)}{|\chi|^{\frac{j+2}{2}-1} \log \frac{R}{|\chi|}} \in Y$$

Proof: Adopting Mathematical induction, for $j = 1$

$$\left\| \frac{\zeta(\chi) - \zeta_j(\chi)}{|\chi|^{\frac{j+2}{2}-1} \log \frac{R}{|\chi|}} \right\|^2 - \left| \left(\frac{\zeta(\chi) - \zeta_j(\chi)}{|\chi|^{\frac{j+2}{2}-1} \log \frac{R}{|\chi|}}, g_1 \right) \right|^2 \leq \left\| \frac{\zeta(\chi) - \zeta_j(\chi)}{|\chi|^{\frac{j+2}{2}-1} \log \frac{R}{|\chi|}} - \lambda_1 g_1 \right\|^2 \quad (3.5)$$

which is equivalent with

$$0 \leq |\lambda_1|^2 - 2 \operatorname{Re} \left(\frac{\zeta(\chi) - \zeta_n(\chi)}{|\chi|^{\frac{j+2}{2}-1} \log \frac{R}{|\chi|}}, \lambda_1 g_1 \right) + \left| \left(\frac{\zeta(\chi) - \zeta_j(\chi)}{|\chi|^{\frac{j+2}{2}-1} \log \frac{R}{|\chi|}}, g_1 \right) \right|^2 \quad (3.6)$$

$$2\operatorname{Re}\left(\frac{\zeta(\chi)-\zeta_j(\chi)}{|\chi|^{\frac{n+2}{2}-1}\log\frac{R}{|\chi|}}, \lambda_1 g_1\right) \leq \left(\frac{\zeta(\chi)-\zeta_j(\chi)}{|\chi|^{\frac{j+2}{2}-1}\log\frac{R}{|\chi|}}, \lambda_1 g_1\right),$$

since , then

one has

$$0 \leq |\lambda_1|^2 - 2\operatorname{Re}\left(\frac{\zeta(\chi)-\zeta_j(\chi)}{|\chi|^{\frac{j+2}{2}-1}\log\frac{R}{|\chi|}}, \lambda_1 g_1\right) + \left|\left(\frac{\zeta(\chi)-\zeta_j(\chi)}{|\chi|^{\frac{j+2}{2}-1}\log\frac{R}{|\chi|}}, g_1\right)\right|^2, \quad (3.7)$$

$$\begin{aligned} & |\lambda_1|^2 - 2\operatorname{Re}\left(\frac{\zeta(x)-\zeta_n(x)}{|x|^{\frac{n+2}{2}-1}\log\frac{R}{|x|}}, \lambda_1 g_1\right) + \left|\left(\frac{\zeta(x)-\zeta_n(x)}{|x|^{\frac{n+2}{2}-1}\log\frac{R}{|x|}}, g_1\right)\right|^2 \\ & \leq |\lambda_1|^2 - 2|\lambda_1|\left|\left(\frac{\zeta(x)-\zeta_n(x)}{|x|^{\frac{n+2}{2}-1}\log\frac{R}{|x|}}, g_1\right)\right| + \left|\left(\frac{\zeta(x)-\zeta_n(x)}{|x|^{\frac{n+2}{2}-1}\log\frac{R}{|x|}}, g_1\right)\right|^2 \\ & \leq \left(|\lambda_1| - \left|\left(\frac{\zeta(x)-\zeta_n(x)}{|x|^{\frac{n+2}{2}-1}\log\frac{R}{|x|}}, g_1\right)\right|\right)^2 \end{aligned} \quad (3.8)$$

which is true for $n = 1$.

Assuming $n - 1$ in (3.4), then

$$\begin{aligned}
 & \left\| \frac{\zeta(x) - \zeta_n(x)}{|x|^{\frac{n+2}{2}-1} \log \frac{R}{|x|}} - \sum_{i=1}^{n-1} \left(\frac{\zeta(x) - \zeta_n(x)}{|x|^{\frac{n+2}{2}-1} \log \frac{R}{|x|}}, \lambda_i g_i \right) \right\|^2 = \left\| \left(\frac{\zeta(x) - \zeta_n(x)}{|x|^{\frac{n+2}{2}-1} \log \frac{R}{|x|}}, \lambda_n g_n \right) - \sum_{i=1}^{n-1} \lambda_n g_n \right\|^2 \\
 & \geq \left\| \left(\frac{\zeta(x) - \zeta_n(x)}{|x|^{\frac{n+2}{2}-1} \log \frac{R}{|x|}}, \lambda_n g_n \right) - \sum_{i=1}^{n-1} \left(\frac{\zeta(x) - \zeta_n(x)}{|x|^{\frac{n+2}{2}-1} \log \frac{R}{|x|}}, \lambda_n g_n, g_i \right) \right\|^2 \\
 & = \left\| \left(\frac{\zeta(x) - \zeta_n(x)}{|x|^{\frac{n+2}{2}-1} \log \frac{R}{|x|}}, \lambda_n g_n \right) - \sum_{i=1}^{n-1} \left(\frac{\zeta(x) - \zeta_n(x)}{|x|^{\frac{n+2}{2}-1} \log \frac{R}{|x|}}, g_n \right) \right\|^2 \\
 & \geq \left\| \frac{\zeta(x) - \zeta_n(x)}{|x|^{\frac{n+2}{2}-1} \log \frac{R}{|x|}} - \left(\frac{\zeta(x) - \zeta_n(x)}{|x|^{\frac{n+2}{2}-1} \log \frac{R}{|x|}}, g_n \right) - \sum_{i=1}^{n-1} \left(\frac{\zeta(x) - \zeta_n(x)}{|x|^{\frac{n+2}{2}-1} \log \frac{R}{|x|}}, g_i \right) \right\|^2 \\
 & = \left\| \frac{\zeta(x) - \zeta_n(x)}{|x|^{\frac{n+2}{2}-1} \log \frac{R}{|x|}} - \sum_{i=1}^n \left(\frac{\zeta(x) - \zeta_n(x)}{|x|^{\frac{n+2}{2}-1} \log \frac{R}{|x|}}, g_i \right) \right\|^2 \tag{3.9}
 \end{aligned}$$

for all $\lambda_i \in N$, $\frac{\zeta(x) - \zeta_n(x)}{|x|^{\frac{n+2}{2}-1} \log \frac{R}{|x|}} \in Y$ and $i = 1, 2, \dots, n$. This completes the proof of the Corollary 3.1.

Theorem 3.1

Let Y be a linear space and $(\cdot, \cdot)_1, (\cdot, \cdot)_2$ be two Hermitian forms on Y such that

$$\left| \frac{\zeta(x) - \zeta_n(x)}{|x|^{\frac{n+2}{2}-1} \log \frac{R}{|x|}} \right|_2 \geq \left| \frac{\zeta(x) - \zeta_n(x)}{|x|^{\frac{n+2}{2}-1} \log \frac{R}{|x|}} \right|_1, \quad \frac{\zeta(x) - \zeta_n(x)}{|x|^{\frac{n+2}{2}-1} \log \frac{R}{|x|}} \in Y$$

for all x . Assume that $(e_i)_{i \in I}$ is an orthonormal family in $(Y; (\cdot, \cdot)_1)$ and $(\zeta_i)_{i \in J}$ is an orthonormal family in $(Y; (\cdot, \cdot)_2)$ such that any $i \in J$ there a finite $K \subset J$ so that

$$e_i = \sum_{j \in K} \alpha_j f_j, \quad \alpha_j \in (i \in K) \tag{3.10}$$

then one has the inequality

$$\begin{aligned}
 & \left\| \frac{\zeta(x) - \zeta_n(x)}{|x|^{\frac{n+2}{2}-1} \log \frac{R}{|x|}} \right\|_2^2 - \sum_{i \in I} \left\| \frac{\zeta(x) - \zeta_n(x)}{|x|^{\frac{n+2}{2}-1} \log \frac{R}{|x|}}, e_i \right\|_2^2 \\
 & \geq \left\| \frac{\zeta(x) - \zeta_n(x)}{|x|^{\frac{n+2}{2}-1} \log \frac{R}{|x|}} \right\|_1^2 - \sum_{j \in I} \left\| \frac{\zeta(x) - \zeta_n(x)}{|x|^{\frac{n+2}{2}-1} \log \frac{R}{|x|}}, \zeta_j \right\|_1^2 \geq 0
 \end{aligned} \tag{3.11}$$

for all

$$\frac{\zeta(x) - \zeta_n(x)}{|x|^{\frac{n+2}{2}-1} \log \frac{R}{|x|}} \in Y$$

Proof: Let H be a finite part of I . Since $\|\cdot\|_2, \|\cdot\|_1$, then

$$\begin{aligned}
 & \left\| \frac{\zeta(x) - \zeta_n(x)}{|x|^{\frac{n+2}{2}-1} \log \frac{R}{|x|}} \right\|_2^2 - \sum_{i \in H} \left\| \frac{\zeta(x) - \zeta_n(x)}{|x|^{\frac{n+2}{2}-1} \log \frac{R}{|x|}}, e_i \right\|_2^2 = \left\| \frac{\zeta(x) - \zeta_n(x)}{|x|^{\frac{n+2}{2}-1} \log \frac{R}{|x|}} - \sum_{i \in H} \frac{\zeta(x) - \zeta_n(x)}{|x|^{\frac{n+2}{2}-1} \log \frac{R}{|x|}}, e_i \right\|_2^2 \\
 & \geq \left\| \frac{\zeta(x) - \zeta_n(x)}{|x|^{\frac{n+2}{2}-1} \log \frac{R}{|x|}} - \sum_{i \in H} \frac{\zeta(x) - \zeta_n(x)}{|x|^{\frac{n+2}{2}-1} \log \frac{R}{|x|}}, e_i \right\|_2^2, \quad \frac{\zeta(x) - \zeta_n(x)}{|x|^{\frac{n+2}{2}-1} \log \frac{R}{|x|}} \in Y
 \end{aligned} \tag{3.12}$$

From (3.10) and for any $i \in H$ there exists a finite $K \subset$ with

$$e_i = \sum_{j \in K} (e_i, \zeta_j)_1 \zeta_j, \tag{3.13}$$

hence

$$\begin{aligned}
 & \left\| \frac{\zeta(\chi) - \zeta_j(\chi)}{|\chi|^{\frac{j+2}{2}-1} \log \frac{R}{|\chi|}} - \sum_{i \in H} \left(\frac{\zeta(\chi) - \zeta_j(\chi)}{|\chi|^{\frac{j+2}{2}-1} \log \frac{R}{|\chi|}}, e_i \right)_2 e_i \right\|_1^2 \\
 &= \left\| \frac{\zeta(\chi) - \zeta_j(\chi)}{|\chi|^{\frac{n+2}{2}-1} \log \frac{R}{|\chi|}} - \sum_{i \in H} \left(\frac{\zeta(\chi) - \zeta_j(\chi)}{|\chi|^{\frac{j+2}{2}-1} \log \frac{R}{|\chi|}}, e_i \right)_2 \sum_{j \in K} (e_i, \zeta_j)_1 \zeta_j \right\|_1^2 \\
 &= \left\| \frac{\zeta(\chi) - \zeta_j(\chi)}{|\chi|^{\frac{j+2}{2}-1} \log \frac{R}{|\chi|}} - \sum_{j \in K} \left(\sum_{i \in H} \left(\frac{\zeta(\chi) - \zeta_j(\chi)}{|\chi|^{\frac{j+2}{2}-1} \log \frac{R}{|\chi|}}, e_i \right)_2 e_i, \zeta_j \right)_1 \zeta_j \right\|_1^2 \quad (3.14)
 \end{aligned}$$

Applying Corollary 3.1 for $(\cdot, \cdot) = (\cdot, \cdot), (g_k)_{k=\overline{1, j}} = (\zeta_j)_{j \in K}$. Henceforth

$$\left\| \frac{\zeta(\chi) - \zeta_j(\chi)}{|\chi|^{\frac{j+2}{2}-1} \log \frac{R}{|\chi|}} - \sum_{j \in K} \lambda_j \zeta_j \right\|_1^2 \geq \left\| \frac{\zeta(\chi) - \zeta_j(\chi)}{|\chi|^{\frac{j+2}{2}-1} \log \frac{R}{|\chi|}} - \sum_{j \in K} \left(\frac{\zeta(\chi) - \zeta_j(\chi)}{|\chi|^{\frac{j+2}{2}-1} \log \frac{R}{|\chi|}}, \zeta_j \right)_1 \zeta_j \right\|_1^2 \quad (3.15)$$

where

$$\lambda_j = \left(\sum_{j \in H} \left(\frac{\zeta(\chi) - \zeta_j(\chi)}{|\chi|^{\frac{j+2}{2}-1} \log \frac{R}{|\chi|}}, e_i \right)_2 e_i, \zeta_j \right)_1 \in (j \in K)$$

Furthermore,

$$\begin{aligned}
 & \left\| \frac{\zeta(\chi) - \zeta_j(\chi)}{|\chi|^{\frac{j+2}{2}-1} \log \frac{R}{|\chi|}} - \sum_{j \in H} \left(\frac{\zeta(\chi) - \zeta_j(\chi)}{|\chi|^{\frac{n+2}{2}-1} \log \frac{R}{|\chi|}}, e_j \right)_2 e_j \right\|_2^2 \\
 & \geq \left\| \frac{\zeta(\chi) - \zeta_j(\chi)}{|\chi|^{\frac{j+2}{2}-1} \log \frac{R}{|\chi|}} - \sum_{j \in K} \left(\frac{\zeta(\chi) - \zeta_j(\chi)}{|\chi|^{\frac{j+2}{2}-1} \log \frac{R}{|\chi|}}, \zeta_j \right)_1 \zeta_j \right\|_1^2 \\
 &= \left\| \frac{\zeta(\chi) - \zeta_j(\chi)}{|\chi|^{\frac{j+2}{2}-1} \log \frac{R}{|\chi|}} - \sum_{j \in J} \left(\frac{\zeta(\chi) - \zeta_\chi(\chi)}{|\chi|^{\frac{j+2}{2}-1} \log \frac{R}{|\chi|}}, \zeta_j \right)_1 \zeta_j \right\|_1^2 \quad (3.16)
 \end{aligned}$$

H finite part of I , from (3.11) the result follows.

Applications of Theorem 3.1 are as follows:

(a) Let $(Y; (.,.))$ be an inner space and $(e_i)_{i \in I}$ an orthonormal family in Y .

$$\left\| \Phi \frac{\zeta(\chi) - \zeta_j(\chi)}{|\chi|^{\frac{j+2}{2}-1} \log \frac{R}{|\chi|}} \right\| \leq \left\| \frac{\zeta(\chi) - \zeta_j(\chi)}{|\chi|^{\frac{j+2}{2}-1} \log \frac{R}{|\chi|}} \right\|$$

Assume that $\Phi : Y \rightarrow Y$ is a linear operator such that and

$$\frac{\zeta(\chi) - \zeta_j(\chi)}{|\chi|^{\frac{j+2}{2}-1} \log \frac{R}{|\chi|}} \in Y \quad \text{and} \quad (\Phi e_i, \Phi e_j) = \delta_{ij}, \text{ for all } i, j \in I. \text{ Then one has the inequality:}$$

$$\begin{aligned} & \left\| \frac{\zeta(\chi) - \zeta_j(\chi)}{|\chi|^{\frac{j+2}{2}-1} \log \frac{R}{|j|}} \right\|^2 - \sum_{i \in I} \left(\frac{\zeta(\chi) - \zeta_n(x)}{|\chi|^{\frac{n+2}{2}-1} \log \frac{R}{|x|}}, e_j \right)^2 \\ & \geq \left\| \Phi \frac{\zeta(\chi) - \zeta_j(\chi)}{|\chi|^{\frac{j+2}{2}-1} \log \frac{R}{|\chi|}} \right\|_2^2 - \sum_{i \in I} \left(\Phi \frac{\zeta(\chi) - \zeta_j(\chi)}{|\chi|^{\frac{j+2}{2}-1} \log \frac{R}{|\chi|}}, \Phi e_i \right)^2 \geq 0 \end{aligned} \quad (3.17)$$

for all $\frac{\zeta(\chi) - \zeta_j(\chi)}{|\chi|^{\frac{j+2}{2}-1} \log \frac{R}{|\chi|}} \in Y$. The proof follows by Hermitian form:

$$\left(\frac{\zeta(\chi) - \zeta_j(\chi)}{|\chi|^{\frac{n+2}{2}-1} \log \frac{R}{|\chi|}}, \frac{\partial_q \zeta}{|\chi|^{\frac{j-4}{2}+3}} \right)_2 = \left(\frac{\zeta(\chi) - \zeta_j(\chi)}{|\chi|^{\frac{j+2}{2}-1} \log \frac{R}{|\chi|}}, \frac{\partial_q \zeta}{|\chi|^{\frac{j-4}{2}+3}} \right)$$

and

$$\left(\frac{\zeta(\chi) - \zeta_j(\chi)}{|\chi|^{\frac{j+2}{2}-1} \log \frac{R}{|\chi|}}, \frac{\partial_q \zeta}{|\chi|^{\frac{j-4}{2}+3}} \right)_1 = \left(\Phi \frac{\zeta(\chi) - \zeta_j(\chi)}{|\chi|^{\frac{j+2}{2}-1} \log \frac{R}{|\chi|}}, \Phi \frac{\partial_q \zeta}{|\chi|^{\frac{j-4}{2}+3}} \right),$$

for all $\frac{\zeta(\chi) - \zeta_j(\chi)}{|\chi|^{\frac{j+2}{2}-1} \log \frac{R}{|\chi|}}, \frac{\partial_q \zeta}{|\chi|^{\frac{j-4}{2}+3}} \in Y$ for the family $(\zeta_i)_{i \in I} = (e_i)_{i \in I}$.

(b) Let $\Phi: Y \rightarrow Y$ such that

$$\left\| \Phi \frac{\zeta(\chi) - \zeta_j(\chi)}{|\chi|^{\frac{j+2}{2}-1} \log \frac{R}{|\chi|}} \right\| \leq \left\| \frac{\zeta(\chi) - \zeta_j(\chi)}{|\chi|^{\frac{j+2}{2}-1} \log \frac{R}{|\chi|}} \right\|,$$

and

$$\begin{aligned} & \left\| \frac{\zeta(\chi) - \zeta_j(\chi)}{|\chi|^{\frac{j+2}{2}-1} \log \frac{R}{|\chi|}} \right\|^2 - \sum_{i \in I} \left(\frac{\zeta(\chi) - \zeta_j(\chi)}{|\chi|^{\frac{j+2}{2}-1} \log \frac{R}{|\chi|}}, e_j \right)^2 \\ & \leq \left\| \Phi \frac{\zeta(\chi) - \zeta_j(\chi)}{|\chi|^{\frac{j+2}{2}-1} \log \frac{R}{|\chi|}} \right\|_2^2 - \sum_{i \in I} \left(\Phi \frac{\zeta(\chi) - \zeta_j(\chi)}{|\chi|^{\frac{j+2}{2}-1} \log \frac{R}{|\chi|}}, \Phi e_i \right)^2 \geq 0 \end{aligned} \quad (3.18)$$

with the previous assumption and for all $\frac{\zeta(\chi) - \zeta_j(\chi)}{|\chi|^{\frac{j+2}{2}-1} \log \frac{R}{|\chi|}} \in Y$, and

(c) Let $\Phi: Y \rightarrow Y$ such that Φ is a symmetric positive definite operator

$$\left(\Phi \frac{\zeta(\chi) - \zeta_j(\chi)}{|\chi|^{\frac{j+2}{2}-1} \log \frac{R}{|\chi|}}, \frac{\zeta(\chi) - \zeta_j(\chi)}{|\chi|^{\frac{j+2}{2}-1} \log \frac{R}{|\chi|}} \right) \geq \left\| \frac{\zeta(\chi) - \zeta_j(\chi)}{|\chi|^{\frac{j+2}{2}-1} \log \frac{R}{|\chi|}} \right\|^2.$$

if $(e_i)_{i \in I}$ is an orthonormal family in Y such that $(\Phi e_i, \Phi e_j) = \delta_{ij}$, for all $i, j \in I$, then one has the inequality:

$$\begin{aligned} 0 & \leq \left\| \frac{\zeta(\chi) - \zeta_j(\chi)}{|\chi|^{\frac{j+2}{2}-1} \log \frac{R}{|\chi|}} \right\|^2 - \sum_{i \in I} \left(\frac{\zeta(\chi) - \zeta_j(\chi)}{|\chi|^{\frac{j+2}{2}-1} \log \frac{R}{|\chi|}}, e_j \right)^2 \\ & \leq \left(\Phi \frac{\zeta(\chi) - \zeta_j(\chi)}{|\chi|^{\frac{j+2}{2}-1} \log \frac{R}{|\chi|}}, \frac{\zeta(\chi) - \zeta_j(\chi)}{|\chi|^{\frac{j+2}{2}-1} \log \frac{R}{|\chi|}} \right) - \sum_{i \in I} \left(\Phi \frac{\zeta(\chi) - \zeta_j(\chi)}{|\chi|^{\frac{j+2}{2}-1} \log \frac{R}{|\chi|}}, \Phi e_i \right)^2 \end{aligned} \quad (3.19)$$

for all $\frac{\zeta(\chi) - \zeta_j(\chi)}{|\chi|^{\frac{j+2}{2}-1} \log \frac{R}{|\chi|}} \in Y$. The proof follows from inequalities (a), (b) and (c) for the choices

$$\left(\frac{\zeta(\chi) - \zeta_j(\chi)}{|\chi|^{\frac{j+2}{2}-1} \log \frac{R}{|\chi|}}, \frac{\partial_q \zeta}{|\chi|^{\frac{j-4}{2}+3}} \right)_1 = \left(\phi \frac{\zeta(\chi) - \zeta_j(\chi)}{|\chi|^{\frac{j+2}{2}-1} \log \frac{R}{|\chi|}}, \frac{\partial_q \zeta}{|\chi|^{\frac{j-4}{2}+3}} \right)$$

and

$$\left(\frac{\zeta(\chi) - \zeta_n(x)}{|\chi|^{\frac{j+2}{2}-1} \log \frac{R}{|\chi|}}, \frac{\partial_q \zeta}{|\chi|^{\frac{j-4}{2}+3}} \right)_2 = \left(\frac{\zeta(\chi) - \zeta_j(\chi)}{|\chi|^{\frac{j+2}{2}-1} \log \frac{R}{|\chi|}}, \frac{\partial_q \zeta}{|\chi|^{\frac{j-4}{2}+3}} \right)$$

for all $\frac{\zeta(\chi) - \zeta_n(x)}{|\chi|^{\frac{j+2}{2}-1} \log \frac{R}{|\chi|}}, \frac{\partial_q \zeta}{|\chi|^{\frac{j-4}{2}+3}} \in Y$.

Summary

In this paper, Hardy type inequalities through the lens of equalities is delved into, presenting equalities that inherently yield Hardy type inequalities by eliminating the remainder term. The significant contributions include in the present paper is:

Identifying equalities that simplify the derivation of Hardy type inequalities by removing the remainder term. This approach streamlines the understanding and application of these inequalities in various contexts. By characterizing the class of functions for which the remainder term vanishes, it provide a deeper insight into the structure and properties of these functions. This characterization is crucial for identifying functions that achieve equality in Hardy type inequalities. Utilizing orthogonality properties in a general Hilbert space, hence a straightforward interpretation of Hardy type inequalities was offered. This perspective also clarifies the absence of nontrivial extremizers, highlighting the uniqueness of solutions within this framework. Finally, the relationship between Rellich and Bessel inequalities is achieved. Both inequalities, though arising in different contexts, offer essential bounds that contribute to the understanding of functional analysis. The Rellich inequality, extending into higher-order derivatives, complements the Bessel inequality's foundational role in Hilbert space theory.

By elucidating these relationships and contributions, a comprehensive understanding of Hardy type inequalities and their connections to other fundamental inequalities is provided.

Conclusion

The main findings of the paper emphasized the novel contributions and their significance in the broader context of mathematical analysis.

Recommendation

This study lays the groundwork for future research, particularly in extending these concepts to more complex spaces and exploring their implications in solving partial differential equations and other mathematical problems.

References

- Antonio Y. and Rauf K. (2021). Hardy-type Inequalities for Convex Functions. *International Journal of Mathematics and Computer Science*. 16 (2021), 263-271.
- Beesack P. R. (1979). Elementary Proofs of Some Opial-type Integral Inequalities. *J. Analyse Math.*; 36, 1-14.
- Brezis H. and Vazquez J. L. (1997). Blow-up solutions of some nonlinear elliptic problems, *Rev. Mat. Univ. Comp. Madrid*. 10, 443–469.
- D'Ambrosio L. (2005). Hardy-type inequalities related to degenerate elliptic differential operators. *Ann. Scuola Norm. Sup. Pisa Cl. Sci.* 5(4), 451–486.
- Devyver B. (2014). A spectral result for Hardy inequalities. *J. Math. Pures. Appl.*, 102, 813–853.
- Godunova E. K. and Levin V. I. (1969). Někotoryh integralnyh neravenstvah, soderzashih proizvodnye (Russian). *Izv. vuzov, Matem.* 91, 20-24. .
- Hardy G. H., Littlewood J. E. and Polya G. (1952). *Inequalities*. Cambridge Univ. Press, 2nd ed.
- Hilger S. (1988). *Ein Maketten kalkl mitanwendung auf zentrums mannigfaltigkeiten*. (Ph.D. thesis, Universitt Wrzburg).
- Hilger S. (1997). Differential and difference calculus unified! *Proceedings of the Second World Congress of Nonlinear Analysts, Part 5 (Athens, 1996)*. *Nonlinear Anal.* 5, 2683-2694.
- Opic B. and Kufner A. (1990). *Hardy-type inequalities*, Pitman Res. Notes Math Ser. 219.
- Rauf K. and Antonio Y. O. (2017). Results on an Integral Inequality of the Opial-type. *Glo. J. of Pure and Appl. Sci.* 23, 151-156.
- Rellich F. (1969). *Perturbation theory of eigenvalue problems*. Gordon and Breach, New York.
- Rozanova G. I. (1976). Integral inequalities with derivatives and with arbitrary convex functions, (Russian) *Moskov. Gos. Ped. Inst. Voen Zap.* 460, 58-65.
- Ruzhansky M. and Suragan D. (2019). Hardy inequalities on homogeneous groups. *Progress in Math.* 327, Birkhäuser, 588.
- Yoshida K. (1966). *Functional Analysis*. Springer-Verlag, Berlin, 1966

**Supply Chain Management and Optimization in Transport Logistics;
A Case Study of Unilorin Table Water**

**Ayinla Ally Yeketi, Muhammad Ameenah Shittu, Olorode Adekunle Fawaz and
Ugbeh Emmanuel Chukwuemeke**

Department of Mathematics, University of Ilorin, Nigeria

Corresponding Author E-mail Addresses: ayinla.ay@unilorin.edu.ng

Abstract

This study examines a transportation problem arising from the weekly distribution of Unilorin Table Water from three warehouses (A=500 packs, B=200 packs, C=300 packs) to five demand locations—Campus (100), Tanke (200), Basin (50), Pipe-line (500), and Fate (150). Using the cost matrix provided in Table 3.1, initial feasible transportation plans are constructed with the Northwest Corner Method, the Least Cost Method, and Vogel's Approximation Method. The resulting total transportation costs are 750,000 for the Northwest Corner Method and 730,000 for both the Least Cost and Vogel's Approximation methods. These results show that the latter two approaches produce lower-cost initial feasible solutions for the case data. The paper outlines the steps needed to verify optimality using the Modified Distribution (MODI) method.

Keywords: Optimization, Transportation Problem, Northwest Corner Method, Least Cost Method, Vogel Approximation Method, MODI Method.

Introduction

Optimization refers to the process of determining the conditions that yield the maximum or minimum value of a function. It is an important tool in the science of decision and in the analysis of physical systems where identifying the objectives and qualitative measure of performance of the given system is under study. The objectives could be profit, time or combination of qualities that can be represented by a single number called variables or unknown. Transportation problems on the other hand involve the analysis of optimal transportation routes and the efficient movement of products from multiple sources of production to various marketplaces, with the objective of minimizing transportation costs. Big companies with multiple production houses and extensive customer bases critically analyze transportation problems to enhance operational efficiency. The supply and demand pattern is the constraint and the transportation cost is the objective function.

Supply chain management is a decision making process that steers numerous activities in order to generate added values for all stakeholders. Just like Pan and Lin (2021) presented a solution to address the urgent storage positioning problem and ensure the safety of goods in transit within the logistics supply chain process, based on a thorough study of wireless sensor networks and radio frequency identification (RFID) technology. Zijm al., (2019) were able to show that purchasing function within a firm plays a crucial role in managing the firm's relationship with suppliers and ensuring the availability of necessary goods and services. As industrial firms allocate a significant portion of their revenue towards supplies, effective purchasing has become a key factor in achieving success. These activities are typically organized within an annual purchasing cycle. In addition to ensuring timely and reliable supply, the goals of purchasing also include achieving cost efficiency and contributing to innovation while enhancing the firm's strategic position. It is important to note as emphasised by Benotmane et al., (2017) that in today's increasingly competitive business environment, effective logistics chain management has been essential for maximizing profits and minimizing costs, including manufacturing expenses such as transaction, transport, and storage. Since all supply efforts come with their inherent problems, the work of Sitek and Wikarek (2012) from the perspective of uni-modal logistics provider highlighted the problem of supply chain optimization. Their work adopted a mathematical model of multilevel cost optimization in the form of MILP (Mixed Integer Linear Programming). In that particular research, the cost of production, transport, distribution and environmental protection were adopted as environmental criteria, timing, volume, capacity and mode of transportation were taken into account. It is worth mentioning that Supply chain management involves efficiently routing and scheduling inventory to ensure timely delivery and meet end-user needs through effective communication across all supply chain links Tyagi and Agarwal (2014). Given the current economic globalization, financial difficulties within the supply chain can pose a significant crisis for enterprises operating in this network. To address this challenge and enhance the core competitiveness of international trading enterprises (ITE), it is crucial to alleviate their transportation pressure Xie and Chen (2022).

According to Jayarathnaet al., (2021) there are several methods are available for modeling sustainable supply chain and logistics (SSCL) issues. Multi-objective optimization (MOO) is widely applied in SSCL modeling. However, the selection of an appropriate optimization technique and solution method remains a significant concern, as model performance depends heavily on the decision variables chosen during model development. Hence, the performance of three distinct approaches to transportation problem solving—the northwest corner method, the least cost method, and the Vogel's approximation is the main goal of this study. By so doing, researchers can be guided on what method to adopt when faced with similar problems.

The research is divided into 5 main sections comprising of this introduction, Linear Programming Model, Methodology, Discussion of Results and Conclusion.

Linear Programming Model

Linear Programming Model Formulation

Linear programming problem can be referred to as the optimization method which deals with functions of variables known as the objective function. It is subjected to a set of inequalities which are known as the constant.

It is a special type of mathematical program that is used to describe the characteristics of the optimal solution of optimization problem by means of mathematical relation, and is mostly referred to as a revolutionary development that allows us to make optimal decisions in complex situations.

To represent the many elements of a linear programming model and their meanings for the overall issue of resource allocation to activities, the following symbols are frequently used:

Z = value of overall measure of performance

x_j = level of activity j (for $j = 1, 2, \dots, n$)

c_j = increase in Z that would result from each unit increase in level of activity j

b_i = Amount of resources i that is available for allocation to activities (for $i = 1, 2, \dots, n$)

a_{ij} = Amount of resource i consumed by each unit of activity j

The problem is posed by the model in term of making decision on the level of activities. So $x_1, x_2, \dots, x_n$ are called the decision variables and the values of c_j, b_i, a_{ij} are called the parameters.

Standard Form of the Linear Programming Model

The model selects values for $x_1, x_2, \dots, x_n$ so as to maximize

$$Z = c_1x_1 + c_2x_2 + \dots + c_nx_n,$$

and the standard form of the model is:

$$a_{11}x_1 + a_{12}x_2 + \dots + a_{1n}x_n \leq b_1$$

$$a_{21}x_1 + a_{22}x_2 + \dots + a_{2n}x_n \leq b_2$$

$$a_{m1}x_1 + a_{m2}x_2 + \dots + a_{mn}x_n \leq b_n$$

The function being maximized, $c_1x_1 + c_2x_2 + \dots + c_nx_n$ is the objective function. The constraints are being referred to as the limitations, and the first constraints are called the functional constraint, and are non-negative if the restriction is $x_1 \geq 0$.

Assignment Problem

An assignment problem is a specific form of transportation problem characterized by an equal number of destinations and resources, with the objective of minimizing total cost or maximizing total profit in allocation. Resources such as labor and machinery often exhibit varying levels of efficiency across different activities, which leads to the formulation of the assignment problem. The assignment problem seeks to

determine the optimal allocation of resources to tasks. When there are n persons and n jobs, and each job must be assigned to exactly one person, the problem is considered balanced if the number of persons equals the number of jobs. In this context, the assignment matrix is balanced when the number of rows equals the number of columns, or equivalently, when the number of facilities matches the number of jobs. Conversely, the problem is unbalanced if the number of persons differs from the number of jobs, resulting in an unequal number of rows and columns or a mismatch between facilities and available jobs. An assignment problem can be represented in the form of a matrix representation of real numbers (cost matrix) in the Table 2.1 below. An assignment problem is a special case of transportation problem.

Table 2.1: Assignment Problem Representation

Resources	J_1	J_2	...	J_n	supply
W_1	C_{11}	C_{12}	...	C_{1n}	1
W_2	C_{21}	C_{22}	...	C_{2n}	1
W_3	C_{31}	C_{32}	...	C_{3n}	1
...	...	...	...	...	...
W_N	C_{n1}	C_{n2}	...	C_{nn}	1

Transportation Problem Algorithm

The algorithm for solving a transportation problem involves the following steps:

- Formulate the problem and arrange data in a matrix. The objective is to minimize the total transportation cost with constraints on supply at sources and demand at destinations.
- Obtain an initial feasible solution using one of the three methods which are North West corner method, least cost method and Vogel's approximation method. An initial feasible solution must satisfy the following conditions:
 - The solution must satisfy supply and demand constraints
 - The number of positive allocations must be equal to $m + n - 1$ where m is the number of rows and n is the number of columns.
- Test the initial solution for optimality using the modified distribution method. If optimal stop, if not find an improved solution.
- Update and repeat the solution until the solution is optimal.

Methods of Solving Transportation Problem

North West Corner Method

- Start at the upper left (north-west) corner of the transportation table and allocate the maximum possible amount.
- Repeat until all supply and demand requirements are met

Least Cost Method

- i. Identify the cell with the smallest cost and allocate the minimum between the demand and supply to it.
- ii. Identify the next smallest least cost and also do the allocation as in step i.
- iii. Repeat step i with the reduced transportation table until all demand and supply constraints are satisfied.

Vogel's Approximation Method

- i. Find the difference (penalty) between the smallest and next smallest costs in each row (column) and write them in brackets against the corresponding row (column).
- ii. Identify the row or column with largest penalty. If a tie occurs, break the tie arbitrarily. Choose the cell with smallest cost in that selected row or column and allocate the minimum to it, cross out the satisfied row or column.
- iii. Again compute the column and row penalties for the reduced transportation table.
- iv. Repeat the procedures above until all the rim requirements are satisfied.

Methodology

Transportation Problem Definition

A transportation problem is a type of linear programming problem where items are transported from a set of supply locations to a set of demand locations. The primary goal is to minimize the cost of distributing these items while maximizing profit. The main structure of the transportation problem consists of various shipping routes connecting supply centers to demand centers. The objective is to meet the demand for goods or services at each destination using the available supply at each source, while minimizing transportation cost and time. Transportation problems can be classified as either balanced, where total supply equals total demand, or unbalanced, where total supply and demand are not equal.

Case Data Definition

Unilorin water is a water supply system that produces, treats, and distributes water to the campus and other neighboring communities. Unilorin water produces bottled water of different sizes, which is the basic product it sells from the factory. The factory has warehouses A, B and C. The weekly supply (in packs) in each warehouse is 500, 200 and 300 respectively. The products are to be transported to five main demand locations which are; Campus, Tanke, Basin, Pipe-line and Fate requiring; 100, 200, 50, 500 and 150 packs respectively. The total transportation cost the unilorin water factory incurs weekly is calculated using the following methods to establish the initial feasible solution.

- i. North West corner method
- ii. Least cost method
- iii. Vogel's approximation method

Initial Feasible Solution Methods

To solve the above given problem, it is required to first construct a table and input all the given values into the table. The demand locations which are; Campus, Tanke, Basin, Pipe-line, and Fate are respectively abbreviated as C, T, B, P, F in the table. The table therefore is

Table 3.1: Demand and Supply Table With Their Associated Costs

To \ Fro	C	T	B	P	F	Supply
A	1000	500	600	1000	900	500
B	1000	300	500	800	900	200
C	1000	1200	900	1200	200	300
Demand	100	200	50	500	150	1000

Where the values in the cell represents the cost per transportation from each supply location to each delivery destinations.

The total number of supply constraint = 3

The total number of demand constraint = 5

Northwest Corner Method (NCM)

The minimum amount between the demand and the supply is to be allocated to the cell (transportation cost) in the upper left-hand (North West corner) of the given table which is cell AC which is 100 in this case.

Table 3.2: NCM Allocation 1

To \ Fro	C	T	B	P	F	Supply
A	<u>100</u> 1000	500	600	1000	900	400 500
B	1000	300	500	800	900	200
C	1000	1200	900	1200	200	300
Demand	100	200	50	500	150	1000

Allocate the minimum value 200 to the cell AT which satisfy the entire demand in T and reduces the supply to 200.

Table 3.3: NCM Allocation 2

To \ Fro	C	T	B	P	F	Supply
A	<u>100</u> 1000	<u>200</u> 500	600	1000	900	200 400 500
B	1000	300	500	800	900	200
C	1000	1200	900	1200	200	300
Demand	100	200	50	500	150	1000

Allocate the minimum value 50 to the cell AB which satisfy the entire demand in B and reduces the supply to 150.

Table 3.4: NCM Allocation 3

To \ Fro	C	T	B	P	F	Supply
A	<u>100</u> 1000	<u>200</u> 500	<u>50</u> 600	1000	900	150 200 400 500
B	1000	300	500	800	900	200
C	1000	1200	900	1200	200	300
Demand	100	200	50	500	150	1000

Allocate the minimum value 150 to the cell AP which satisfies the supply in A and reduces the demand to 350.

Table 3.5: NCM Allocation 4

To \ Fro	C	T	B	P	F	Supply
A	<u>100</u> 1000	<u>200</u> 500	<u>50</u> 600	<u>150</u> 1000	900	150 200 400 500
B	1000	300	500	800	900	200
C	1000	1200	900	1200	200	300
Demand	100	200	50	350 500	150	1000

Allocate the minimum value 200 to cell BP which satisfy the entire supply and reduces the demand to 150.

Table 3.6: NCM Allocation 5

To \ Fro	C	T	B	P	F	Supply
A	<u>100</u> 1000	<u>200</u> 500	<u>50</u> 600	<u>150</u> 1000	900	150 200 400 500
B	1000	300	500	<u>200</u> 800	900	200
C	1000	1200	900	1200	200	300
Demand	100	200	50	150 350 500	150	1000

Allocate the minimum value 150 to cell CP which satisfy the entire demand in P and reduces the supply to 150.

Table 3.7: NCM Allocation 6

To \ Fro	C	T	B	P	F	Supply
A	<u>100</u> 1000	<u>200</u> 500	<u>50</u> 600	<u>150</u> 1000	900	150 200 400 500
B	1000	300	500	<u>200</u> 800	900	200
C	1000	<u>1200</u>	900	<u>150</u> 1200	200	150 300
Demand	100	200	50	150 350 500	150	1000

Allocate the minimum value 150 to cell CF which satisfy the entire supply and demand in both cell C and F.

Table 3.8: NCM Allocation 7

To \ Fro	C	T	B	P	F	Supply
A	<u>100</u> 1000	<u>200</u> 500	<u>50</u> 600	<u>150</u> 1000	900	150 200 400 500
B	1000	300	500	<u>200</u> 800	900	200
C	1000	<u>1200</u>	900	<u>150</u> 1200	<u>150</u> 200	150 300
Demand	100	200	50	150 350 500	150	1000

The total transportation cost = $(100 \times 1000) + (200 \times 500) + (50 \times 600) + (150 \times 1000) + (200 \times 800) + (150 \times 1200) + (150 \times 200) = 100,000 + 100,000 + 30,000 + 150,000 + 160,000 + 180,000 + 30,000$.

The total transportation cost = 750,000.

Least Cost Method (LCM)

From Table 3.1, the least transportation cost is 200 in CF, then allocate the minimum 150 to the cell which satisfy the entire demand in F and reduces the supply to 150.

Table 3.9: LCM Allocation 1

To \ Fro	C	T	B	P	F	Supply
A	1000	500	600	1000	900	500
B	1000	300	500	800	900	200
C	1000	1200	900	1200	<u>150</u> 200	150 300
Demand	100	200	50	500	150	1000

The next least transportation cost is 300 in cell BT, then allocate the minimum value 200 to the cell which satisfy the entire demand and supply in both cell B and T.

Table 3.10: LCM Allocation 2

To \ Fro	C	T	B	P	F	Supply
A	1000	500	600	1000	900	500
B	1000	<u>200</u> 300	500	800	900	200
C	1000	1200	900	1200	<u>150</u> 200	150 300
Demand	100	200	50	500	150	1000

The next least transportation cost is 600 in cell AB, then allocate the minimum value 50 to the cell which satisfy the entire demand in B and reduces the supply to 450.

Table 3.10: LCM Allocation 3

To \ Fro	C	T	B	P	F	Supply
A	1000	500	<u>50</u> 600	1000	900	450 500
B	1000	<u>200</u> 300	500	800	900	200
C	1000	1200	900	1200	<u>150</u> 200	150 300
Demand	100	200	50	500	150	1000

The next least transportation cost is 1000 in cell CC, then allocate the minimum value 100 to the cell which satisfy the entire demand in C and reduces the supply to 50.

Table 3.11: LCM Allocation 4

To \ Fro	C	T	B	P	F	Supply
A	1000	500	<u>50</u> 600	1000	900	450 500
B	1000	<u>200</u> 300	500	800	900	200
C	<u>100</u> 1000	1200	900	1200	<u>150</u> 200	50 150 300
Demand	100	200	50	500	150	1000

The next least transportation cost is 1000 in cell AP, then allocate the minimum value 450 to the cell which satisfy the entire supply in A and reduce the demand to 50.

Table 3.12: LCM Allocation 5

To \ Fro	C	T	B	P	F	Supply
A	1000	500	<u>50</u> 600	<u>450</u> 1000	900	450 500
B	1000	<u>200</u> 300	500	800	900	200
C	<u>100</u> 1000	1200	900	1200	<u>150</u> 200	50 150 300
Demand	100	200	50	50 500	150	1000

The next least transportation cost is 1200 in cell CP, then allocate the minimum value 50 to the cell which satisfy the entire demand and supply in both cell C and P.

Table 3.13: LCM Allocation 6

To \ Fro	C	T	B	P	F	Supply
A	1000	500	500 600	450 1000	900	450 500
B	1000	200 300	500	800	900	200
C	<u>100</u> 1000	1200	900	<u>50</u> 1200	<u>150</u> 200	50 150300
Demand	100	200	50	50 500	150	1000

The total transportation cost = $(50 \times 600) + (450 \times 1000) + (200 \times 300) + (100 \times 1000) + (50 \times 1200) + (150 \times 200)$
 $= 30,000 + 450,000 + 60,000 + 100,000 + 60,000 + 30,000.$
 The total transportation cost = 730,000.

Vogel's Approximation Method (VAM)

When using the Vogel's approximation method to solve a transportation problem, the introduction of some values known as penalties is required. A penalty can be referred to as an extra cost added to a particular route or assignment in a transportation problem, to show that it is less efficient than other option. It can also be gotten by subtracting the least cost in the row/column from the next least cost in the row/column. To solve the problem under consideration, it is essential to add the row and column penalties to the given table by subtracting the least cost in the row/column from the next least cost in the same row/column. RP and CP represent the row and column penalties respectively.

The gotten values on the row penalty are; 0, 200, 100, 200, 700 and 100, 200, 100 on the column penalty. Next is to allocate the minimum value 150 to the least transportation cost 200 in cell CF which is the column with the highest penalty.

Table 3.14: VAM Allocation 1

To \ Fro	C	T	B	P	F	Supply	CP1
A	1000	500	600	1000	900	450 500	100
B	1000	300	500	800	900	200	200
C	1000	1200	900	1200	<u>150</u> 200	150 300	100
Demand	100	200	50	500	150	1000	-
RP1	0	200	100	200	700	-	-

Next is to add the second row and column penalty to the table by subtracting the least cost in the row/column from the next least cost in the same row/column. The gotten

values on the row penalty are; 0, 200, 100, 200, 0 and 100, 200, 100 on the column penalty. Next is to also allocate the minimum value 200 to the least transportation cost 300 in cell BT which is the column/row with the highest penalty.

Table 3.15: VAM Allocation 2

To \ Fro	C	T	B	P	F	Supply	CP1	CP2
A	1000	500	600	1000	900	500	100	100
B	1000	<u>200</u> 300	500	800	900	200	200	200
C	1000	1200	900	1200	<u>150</u> 200	150 300	100	100
Demand	100	200	50	500	150	1000	-	-
RP1	0	200	100	200	700	-	-	-
RP2	0	200	100	200	0	-	-	-

Next is to add the third row and column penalty to the table by subtracting the least cost in the row/column from the next least cost in the same row/column. The gotten values on the row penalty are; 0, 0, 300, 200, 0 and 400, 0, 300 on the column penalty. Next is to also allocate the minimum value 50 to the least transportation cost 600 in cell AB which is the row with the highest penalty and satisfy the entire demand in B and reduces the supply to 450.

Table 3.16: VAM Allocation 3

To \ Fro	C	T	B	P	F	Supply	CP1	CP2	CP3
A	1000	500	<u>50</u> 600	1000	900	450 500	100	100	400
B	1000	<u>200</u> 300	500	800	900	200	200	200	0
C	1000	1200	900	1200	<u>150</u> 200	150 300	100	100	300
Demand	100	200	50	500	150	1000	-	-	-
RP1	0	200	100	200	700	-	-	-	-
RP2	0	200	100	200	0	-	-	-	-
RP3	0	0	300	200	0	-	-	-	-

Next is to add the fourth row and column penalty to the table by subtracting the least cost in the row/column from the next least cost in the same row/column. The gotten value is 0, 0, 0, 200, 0 on the row penalty and 0, 0, 200 on the column penalty. Next is to also allocate the minimum value 100 to the least transportation cost 1000 in cell CC which is the row with the highest penalty and satisfy the entire demand in C and reduces the supply to 50.

Table 3.17: VAM Allocation 4

To/Fro	C	T	B	P	F	Supply	CP1	CP2	CP3	CP4
A	1000	500	50 600	1000	900	450 500	100	100	400	0
B	1000	200 300	500	800	900	200	200	200	0	0
C	100 1000	1200	900	1200	150 200	50 150 300	100	100	300	200
Demand	100	200	50	500	150	1000	-	-	-	-
RP1	0	200	100	200	700	-	-	-	-	-
RP2	0	200	100	200	0	-	-	-	-	-
RP3	0	0	300	200	0	-	-	-	-	-
RP4	0	0	0	200	0	-	-	-	-	-

Next is to add the last row and column penalty of the table by subtracting the least cost in the row/column from the next least cost in the same row/column. The gotten value is 0, 0, 0, 200, 0 on the row penalty and 0, 0, 0 on the column penalty. Next is to also allocate the minimum value 450 to the least transportation cost 1000 in cell AP which is the column with the highest penalty and satisfy the entire supply in A and reduces the demand to 50. Also since it is impossible to have any other penalty, then the last minimum value 50 is allocated to the cell CA which satisfies the entire supply and demand in both cells C and A.

Table 3.18: VAM Allocation 5

To/Fro	C	T	B	P	F	Supply	CP1	CP2	CP3	CP4	CP5
A	1000	500	50 600	450 1000	900	450 500	100	100	400	0	0
B	1000	200 300	500	800	900	200	200	200	0	0	0
C	100 1000	1200	900	50 1200	150 200	50 150 300	100	100	300	200	0
Demand	100	200	50	50 500	150	1000	-	-	-	-	-
RP1	0	200	100	200	700	-	-	-	-	-	-
RP2	0	200	100	200	0	-	-	-	-	-	-
RP3	0	0	300	200	0	-	-	-	-	-	-
RP3	0	0	0	200	0	-	-	-	-	-	-

The total transportation cost = $(100 \times 1000) + (200 \times 300) + (50 \times 600) + (450 \times 1000) + (50 \times 1200) + (150 \times 200)$
 $= 100,000 + 60,000 + 30,000 + 450,000 + 60,000 + 40,000.$

The total transportation cost = 730, 000.

It can therefore be concluded from the above solution that the Vogel's Approximation method is the most efficient method to use for the transportation of table water to various communities in Ilorin. Despite the fact that both Vogel's approximation method and the least cost method give the same output, the penalty system adopted by the Vogel's approximation ensures the allocation of resources to the most effective option.

Discussion of Results

From section 3 above, the different methods adopted; NWM, LCM and VAM have been used to find the cost of transporting Unilorin table water from different warehouses to different locations within the Ilorin metropolis. The outcome of each method used is discussed below.

Northwest Corner Allocation

The northwest corner method, being the first adopted method gives the step by step approach to delivering the product to different locations. This method, involving movement from the top-left corner of the table to the bottom-right of the same table, which is in the north-western direction seems simplest of them all. The total cost of the transportation using this method is 750,000 naira.

Least Cost Method

The least cost method is another efficient method in determining an initial feasible solution for the transportation problem. The name “Least Cost” is adopted because the allocations are done based on the least cost required to transport the desired goods to the respective destinations. This method produces 730,000 naira for the cost of transporting Unilorin table water to the defined demand locations.

Vogel’s Approximation Method

Vogel’s approximation method named after William Vogel is the third method used in determining the initial feasible solution of the transportation problem. This method which imposes penalties helps in guiding the allocation process is mostly preferred due to the fact that the initial feasible solution. The initial feasible cost through this method is also gotten to be 730,000 naira.

MODI Optimality Test Method

From the least cost and Vogel’s approximation methods above, the detailed step by step approach of establishing the initial cost of transporting the Unilorin table water from different warehouses to different destinations. The total cost of transportation is gotten to be 730,000 naira, being the initial feasible solution of the transportation problem, it is important to check whether this value is the optimum cost using the modified distribution (MODI) method, otherwise known as u-v method. With this method as discussed in Satapathy et al., (2024), Askerbeyli (2020) and Rinadari&Sihotang (2025), the least cost to transport Unilorin table water from the defined warehouses to the various destinations in the most efficient manner shall be determined. Let u_i and v_j be i th row and j th column respectively, and also, m and n be the total numbers of rows and columns respectively. If $m+n-1$ equals the number of allocated cells, then the transportation problem is said to be non-degenerate. If otherwise, the case is of degeneracy. Considering Table 3.19 below, the total number of rows m is 3 while the total number of column, n is 5. A simple check for degeneracy, $m+n-1 = 3+5-1=7$. From Tabl4.1 below, it is obvious that the number of allocated cells is 6, which is less than the value 7 gotten. Hence, it is a case of degeneracy.

Table 4.1: MODI Allocation Table 1

To \ Fro	C	T	B	P	F	Supply	u_i
A	1000	500	50 600	450 1000	900	450 500	u_1
B	1000	200 300	500	800	900	200	u_2
C	100 1000	1200	900	50 1200	150 200	50 150 300	u_3
Demand	100	200	50	50 500	150	1000	
v_j	v_1	v_2	v_3	v_4	v_5		

To solve this problem, a small number ϵ shall be allocated to an unoccupied cell in a manner that would not result to a loop. Hence, ϵ is allocated to the cell AT as seen in Table 4.2 below.

Table 4.2: MODI Allocation Table 2

To \ Fro	C	T	B	P	F	Supply	u_i
A	1000	500 ϵ	50 600	450 1000	900	450 500	u_1
B	1000	200 300	500	800	900	200	u_2
C	100 1000	1200	900	50 1200	150 200	50 150 300	u_3
Demand	100	200	50	50 500	150	1000	
v_j	v_1	v_2	v_3	v_4	v_5		

The values of u_i and v_j are calculated using the formula

$$c_{ij} = u_i + v_j,$$

where c_{ij} is the cost in the cell row i , column j of all occupied cells. Also, the opportunity cost, which guides on the optimality of the solution is calculated using

$$\Delta_{ij} = c_{ij} - (u_i + v_j),$$

where Δ_{ij} is the cost in the cell row i , column j of all unoccupied cells. If all the $\Delta_{ij} \geq 0$, the gotten solution is optimal, while not if otherwise. From Table 4.2, the occupied cells are; $c_{12}, c_{13}, c_{14}, c_{22}, c_{31}, c_{34}$ and c_{35} . Hence, if $u_1 = 0$, then

$$c_{12} = u_1 + v_2 \Rightarrow v_2 = c_{12} - u_1 = 500 - 0 \Rightarrow v_2 = 500$$

$$c_{13} = u_1 + v_3 \Rightarrow v_3 = c_{13} - u_1 = 600 - 0 \Rightarrow v_3 = 600$$

$$c_{14} = u_1 + v_4 \Rightarrow v_4 = c_{14} - u_1 = 1000 - 0 \Rightarrow v_4 = 1000$$

$$c_{22} = u_2 + v_2 \Rightarrow u_2 = c_{22} - v_2 = 300 - 500 \Rightarrow u_2 = -200$$

$$c_{34} = u_3 + v_4 \Rightarrow u_3 = c_{34} - v_4 = 1200 - 1000 \Rightarrow u_3 = 200$$

$$c_{31} = u_3 + v_1 \Rightarrow v_1 = c_{31} - u_3 = 1000 - 200 \Rightarrow v_1 = 800$$

$$c_{35} = u_3 + v_5 \Rightarrow v_5 = c_{35} - u_3 = 200 - 200 \Rightarrow v_5 = 0$$

Table 4.3: MODI Allocation Table 3

To \ Fro	C	T	B	P	F	Supply	u_i
A	1000	500 £	50 600	450 1000	900	450 500	0
B	1000	200 300	500	800	900	200	-200
C	100 1000	1200	900	50 1200	150 200	50 150 300	200
Demand	100	200	50	50 500	150	1000	
v_j	800	500	600	1000	0		

From the above, the opportunity cost Δ_{ij} is thus calculated for the unoccupied cells as established below;

$$\Delta_{11} = c_{11} - (u_1 + v_1) = 1000 - (0 + 800) = 200 \geq 0$$

$$\Delta_{15} = c_{15} - (u_1 + v_5) = 900 - (0 + 0) = 900 \geq 0$$

$$\Delta_{21} = c_{21} - (u_2 + v_1) = 1000 - (-200 + 800) = 400 \geq 0$$

$$\Delta_{23} = c_{23} - (u_2 + v_3) = 500 - (-200 + 600) = 100 \geq 0$$

$$\Delta_{24} = c_{24} - (u_2 + v_4) = 800 - (-200 + 1000) = 0 \geq 0$$

$$\Delta_{25} = c_{25} - (u_2 + v_5) = 900 - (-200 + 0) = 1100 \geq 0$$

$$\Delta_{32} = c_{32} - (u_3 + v_2) = 1200 - (200 + 500) = 500 \geq 0$$

$$\Delta_{33} = c_{33} - (u_3 + v_3) = 900 - (200 + 600) = 100 \geq 0$$

Since all the gotten Δ_{ij} 's are non-negative, then the basic initial feasible cost 730,000 naira is optimal. Hence, no further reduction may be made in the transportation cost.

Interpretation of the Results

The transportation costs of the delivery of Unilorin table water from warehouses A,B and C to different demand locations is being solved using the northwest corner method, least cost method and Vogel's approximation method. The northwest corner method indicates that the best approach would be allocating 100 packs of the table water, which is the total demand at the Campus and subsequently consider what demand can be attended to at the Tanke. The total demand of the Tanke, 200 was also attended to as the supply limit of 500 from factory A was yet to be accomplished. This leaves warehouse A with a balance of 200. The total demand at Basin is just 50, which is allocated from the 200 balance. Going to Pipeline, the demand is 500, which implies that the remaining 150 from warehouse A alone shall not be enough. By this method, that 150 is allocated and the deficit and made up from supplies from the next warehouse B. Since warehouse B has only 200 packs, their total supply shall be made to Pipeline and the deficit of 150 shall be augmented from the warehouse C. This augmentation leaves warehouse C with just 150

packs remaining, which tallies with the total demand at Fate. This indicates the transportation problem is the balanced type.

The least cost approximation approach which is dependent on the smallest transportation cost considers the smallest cost from the table. 200 is the least of all the transportation cost, hence allocation starts with it. The total demand of Fate got fulfilled with that and reduces the supply from warehouse C to 150. The next observed least cost is 300, hence allocation of the 200 demand from Tanke gets sorted and as well takes the total supply from the warehouse B. The next least cost is 600, which easily solves the demand of Basin, as the total demand is 50. With that, the supply capacity of warehouse A gets reduced to 450. The next least cost is 1000, which takes care of the demand at the Campus. That allocation done fully from the balance of 150 from the warehouse C, at that further reduces the supply capacity of warehouse C from 150 to 50. The next least cost is 1000, being the cost of transportation from warehouse A to Pipeline. The remaining total supply from warehouse A is 450, hence the demand at Pipeline reduces to 50 as its total demand is 500. The next and final least cost is 1200, being the cost of transportation from warehouse C to Pipeline. The balance of supply from warehouse C is 50, hence it is allocated to the Pipeline to complete its demand.

The last method considered is the Vogel's approximation method. The method mimics the least cost method with an extra layer of efficiency, called the penalty. The penalty simply shows the column/row with the highest potential saving, as least cost may not be indicating potential cost savings at times. Hence, the least costs with the highest penalty is always considered when using Vogel's approximation method. This penalty has always give it an edge over other methods in the determination of initial feasible solutions. For the problem under consideration, the rows/columns with the highest penalties coincide with the least costs as found while using the least cost method. Hence, the transportation cost found using both methods are equal. With the MODI method, it was established that this cost, 730,000 is the optimal cost of transporting the Unilorin table water from warehouses A, B and C to Campus, Tanke, Basin, Pipeline and Fate.

Practical Implication for Unilorin Table Water Distribution

From the above results, it is obvious the best transportation option for the distribution of Unilorin table water with the optimal cost is the consideration of the least cost of supply from the warehouses A, B and C with regards to each demand destinations; Campus, Tanke, Basin, Pipeline and Fate. This is done along establishing the penalty attached to each supply. At all times, it is always advisable to calculate these penalties before determining the supply route. This penalty always indicate the greatest potential savings.

Conclusion

This research work considers transportation problem, wherein the delivery of Unilorin table water to five different locations; Campus, Tanke, Basin, Pipe-line and Fate is the case study. Unilorin table water a subsidiary of Unilorin holdings is an integral part

of the holdings that has direct impact on the masses, as water is generally considered basic amenity. The distribution of this table water to the desired location as and when due is definitely of utmost importance. This problem is solved using three main methods of solving transportation problem, namely the; North West corner method, least cost method and Vogel's approximation method. The objective of this work to satisfy the required quantity of table water at each aforementioned destinations with the availability of quantity of this table water at each supply venue at the minimum transportation cost and time.

The study on "Supply Chain Management and Optimization in Transport Logistics; A Case Study of Unilorin Table Water" has provided valuable insights into the complexities and challenges of managing an efficient supply chain in the water production industry. By examining the specific practices and strategies employed by Unilorin Table Water, this research has identified key areas for optimization that can enhance operational efficiency, reduce costs, and improve service delivery. The findings from this case study highlights the importance of leveraging technology and innovative logistics solutions to streamline supply chain processes.

The problem of the distribution of the of Unilorin table water using the adopted methods of solving logistic problem; North West Corner Method, Least Cost Method, and Vogel's Approximation Method is solved. The optimal cost of transportation is found to be 730,000 naira, which is the cost found using the least cost and Vogel's approximation methods. This was found after the initial cost was found to be 750,000 naira while using the North West corner method. The 730,000 naira cost was established to be optimal using the MODI method. Even though the least cost and Vogel's approximation method return the same cost of transportation, it is observed that the Vogel's approximation method is best in the delivery of Unilorin table water to these destinations due to the fact that it does not only consider the least cost of transportation in its allocation process but rather the cost differences known as penalties before the allocations, which is calculated by establishing the difference between the least and the second least costs.

This research not only contributes to the academic understanding of supply chain management but also offers practical recommendations that can be implemented by Unilorin Table Water and similar companies to achieve better performance and competitiveness.

Declaration of Interest: None.

References

Askerbeyli, R. (2020). Study of transportation problem of iron and steel industry in Turkey based on linear programming, VAM and MODI methods. Communications Faculty of Sciences University of Ankara Series A2-A3 *Physical Sciences and Engineering*, 62(1), 79-99.

- Benotmane, Z., Belalem, G., & Neki, A. K. (2017). A cloud computing model for optimization of transport logistics process. *Transport and telecommunication*, 18(3), 194–206.
- Jayarathna, C. P., Dawes, L., & Yigitcanlar, T. (2021). Multiobjective optimization for sustainable supply chain and logistics. *Sustainability*, 13(13617), 1–32.
- Pan, C., & Lin, M. (2021). Optimization of intelligent logistic supply chain management system based on wireless sensor network and RFID technology. *Journal of Sensors*, 2021(8111909), 1–11.
- Riandari, F., & Sihotang, H. T. (2025). Distribution cost optimization: Comparison of NWC, MODI, and Stepping Stone methods in transportation problems. *International Journal of Basic and Applied Science*, 14(2), 85-96.
- Satapathy, E., Das D., & Mohapatra R. (2024). A Study of The Modified Distribution Method In Modern Business. *International Journal of Business and Management Invention*, 13(8), 41-47.
- Sitek, P., & Wikarek, J. (2012). Cost optimization of supply chain with multimodal transport. *Proceedings of Federated Conference on Computer Science and Information Systems*, 7(1000), 1111–1118.
- Tyagi, P., & Agarwal, G. (2014). Supply chain integration and logistic management among BRICS countries. *A Journal of Engineering Research*, 3(5), 284–0936.
- Xie, J., & Chen, C. (2022). Supply chain and logistics optimization management for international trading enterprises using IOT-based economic logistics model. *Operations Management Research*, 15(1), 711–724.
- Zijm, H., Klumpp, M., Regattieri, A., & Heragu, S. (2019). Operations, logistics, and supply chain management: Key domain of supply chain. *Springer Nature Switzerland* (pp. 45–72).

Chemotaxonomic Insights from FTIR Spectral Analysis of Leaves of *Amaranthus* Species

Moses Dele Ake and Abdullahi Alanamu AbdulRahaman

Department of Plant Biology, Faculty of Life Sciences,
University of Ilorin, Ilorin, Nigeria

Corresponding Author: mosesdeleake@yahoo.com; +2348033854530

Abstract

Fourier Transform Infrared (FTIR) spectroscopy was applied to elucidate the biochemical and chemotaxonomic signatures of leaves from six *Amaranthus* taxa (*A. blitum*, *A. caudatus*, *A. spinosus* Green and Red forms, *A. hybridus*, and *A. viridis*). Spectral data obtained within the 4000–650 cm⁻¹ region revealed a conserved biochemical framework dominated by hydroxyl, aliphatic, amide, aromatic, and carbohydrate functional groups, alongside marked interspecific and intraspecific variations attributable to differences in secondary metabolism and structural biopolymers. *Amaranthusblitum* displayed the most intense and broad hydroxyl stretching bands together with dual aromatic out-of-plane bending vibrations, reflecting a higher abundance of hydrogen-bonded polysaccharides and phenolic compounds. In contrast, *A. viridis* lacked detectable hydroxyl stretching vibrations, indicating comparatively low phenolic or hydroxyl-rich constituents and underscoring its chemical divergence. The green and red forms of *A. spinosus* were distinguished by pronounced $\delta(\text{CH}_3)$ vibrations and systematic shifts in amide and aromatic bands, suggesting variations in lignin architecture, cuticular waxes, and protein composition. *Amaranthushybridus* was characterized by a dominant amide I band, indicative of relatively higher protein or carbonyl content but reduced aromatic conjugation. Collectively, these findings highlight the sensitivity of FTIR spectroscopy in resolving subtle biochemical differences among closely related taxa and demonstrate its theoretical relevance for plant chemotaxonomy, as well as its practical utility in nutritional assessment, functional food selection, and biodiversity characterization of *Amaranthus* leaves.

Keywords: *Amaranthus*; leaves; FTIR spectroscopy; chemotaxonomy; biochemical profiling; phenolics; proteins; carbohydrates.

INTRODUCTION

The genus *Amaranthus* L. (family Amaranthaceae) comprises approximately 60–75 species of annual or short-lived perennial herbs with a cosmopolitan distribution, occurring predominantly in tropical and subtropical regions (Iamonico & Sánchez-del-

Pino, 2022; Waselkov *et al.*, 2023). Members of the genus include cultivated grain amaranths, leafy vegetables, ornamentals, and several aggressive weeds. Africa represents one of the major centers of diversity and utilization of *Amaranthus*, where an estimated 25–30 species occur either as indigenous taxa or naturalized introductions (Sogbohossou *et al.*, 2022; Achigan-Dako *et al.*, 2024). In Nigeria, between 8 and 12 species have been documented, including commonly cultivated leafy vegetables such as *A. cruentus*, *A. hybridus*, *A. viridis*, *A. spinosus*, and *A. dubius*, alongside weedy and semi-domesticated forms (Olorode *et al.*, 2022; Akinyemi *et al.*, 2024).

Amaranthus species are of considerable nutritional, economic, and food-security importance in sub-Saharan Africa. Their leaves are widely consumed as vegetables and are valued for their high contents of quality proteins, essential amino acids, dietary fiber, vitamins (A, C, and folates), and minerals such as iron, calcium, magnesium, and zinc (Sarker *et al.*, 2022; Maseko *et al.*, 2023). The affordability, short growth cycle, and adaptability of *Amaranthus* to diverse agroecological conditions make it particularly important for urban and peri-urban agriculture and climate-resilient food systems (Chivenge *et al.*, 2022; FAO, 2024). In Nigeria, *Amaranthus* vegetables contribute significantly to household nutrition and income generation, especially among smallholder farmers and women (Aderibigbe *et al.*, 2023).

Beyond their dietary value, several *Amaranthus* species possess documented ethnomedicinal properties. Leaf extracts are traditionally used in the management of anemia, inflammation, diabetes, gastrointestinal disorders, and wound healing, activities that have been linked to their rich phytochemical composition, including phenolics, flavonoids, betalains, and bioactive lipids (Afolayan *et al.*, 2022; Jiménez-Aguilar *et al.*, 2024). These multifunctional attributes further underscore the importance of accurate species identification and classification within the genus.

Despite its importance, the taxonomy of *Amaranthus* remains problematic. Species delimitation is complicated by extensive morphological plasticity influenced by environmental conditions, overlapping vegetative and reproductive traits, frequent hybridization, and phenotypic convergence between cultivated and weedy taxa (Iamonico, 2023; Waselkov *et al.*, 2023). In West Africa, including Nigeria, local landraces and intermediate forms often blur species boundaries, leading to misidentification and inconsistent nomenclature in floristic, nutritional, and pharmacological studies (Akinyemi *et al.*, 2024). These challenges highlight the need for integrative taxonomic approaches that combine classical morphology with anatomical, molecular, and chemical evidence.

Chemotaxonomy, the use of chemical constituents as taxonomic characters, has gained renewed relevance in resolving such complex plant groups. Secondary metabolites such as phenolics, flavonoids, alkaloids, lipids, and carbohydrates play critical roles in plant adaptation and defense and often exhibit taxon-specific patterns useful for species discrimination (Wink, 2022; Zengin *et al.*, 2023). Advances in analytical techniques have further enhanced the applicability of chemotaxonomic tools in systematic studies.

Fourier Transform Infrared (FTIR) spectroscopy has emerged as a rapid, non-destructive, and cost-effective technique for profiling functional groups in plant biomolecules. FTIR spectra reflect the vibrational frequencies of chemical bonds, allowing the detection of major biochemical classes such as proteins, carbohydrates, lipids, phenolics, and nucleic acids (Mekonnen&Wolde, 2023; Pasieczna-Patkowska *et al.*, 2025). Recent studies have demonstrated the effectiveness of FTIR in plant systematics for distinguishing closely related species, assessing biochemical diversity, and supporting evolutionary and taxonomic interpretations (Shoaib *et al.*, 2022; Verma *et al.*, 2023; Wang *et al.*, 2024).

Although FTIR has been applied to *Amaranthus* for nutritional and compositional analyses, comprehensive chemotaxonomic evaluations of leaf tissues across multiple species remain limited, particularly for African taxa. Leaves are metabolically active organs and major sites of secondary metabolite accumulation, making them ideal for FTIR-based comparative studies aimed at species delimitation and biochemical characterization.

Therefore, the present study employs FTIR spectroscopy to analyze the leaf tissues of selected *Amaranthus* species, with the objectives of identifying characteristic functional group profiles, elucidating interspecific biochemical differences, and assessing the potential of FTIR-derived chemical signatures as reliable chemotaxonomic markers for resolving taxonomic ambiguities within the genus.

MATERIALS AND METHODS

Plant Materials and Seed Source

Seeds of *Amaranthus* species (*A. hybridus* L., *A. viridis* L., *A. caudatus* L., *A. blitum* L., and two morphologically distinct variants of *A. spinosus* L. (red: reddish petiole, stem, and fruit; green: greenish stem, petiole, and leaves) (Table 1; Fig. 1) used in this study were sourced from controlled cultivation carried out during the 2023 growing season at the experimental garden of the Department of Plant Biology, University of Ilorin (8°29'N, 4°40'E), Nigeria. The cultivated populations were established from morphologically identified source materials and grown in spatially separated plots to minimize unintended cross-pollination. Mature seeds were collected from tagged, healthy plants, air-dried, and stored under dry conditions at ambient temperature.

Species identity was verified using standard morphological descriptors, and representative voucher specimens, with assigned voucher numbers, were prepared and deposited at the University of Ilorin Herbarium (UILH) (Table 1). These measures ensured the genetic integrity, traceability, and reproducibility of the plant materials used in the chemotaxonomic and biochemical analyses.

Table 1: Nigerian species of *Amaranthus*

S/N	Species	Common Names	Yoruba Name	Hausa Name	Igbo Name	Voucher number
1	<i>Amaranthushybridus</i> L.	Smooth Pigweed	EfoTete	Alayyahu	Inine	UILH/003/1853/2006
2	<i>Amaranthusviridis</i> L.	Green Amaranth, Slender Amaranth	EfoTete Pupa	Alayyahu	InineAku	UILH/002/1852/2006
3	<i>Amaranthuscaudatus</i> L.	Purple Amaranth (grain/leaf type)	EfoTeteElewe Pupa	AlayyahuJannja	InineOjii	UILH/006/1856/2026
4	<i>Amaranthusblitum</i> L.	Purple Amaranth, Guernsey Pigweed	EfoTeteOyinbo	AlayyahuBature	InineMbuba	UILH/004/1854/2026
5	<i>Amaranthusspinusus</i> L. (Red)	Spiny Amaranth (Red variant)	EfoEwuroTete Pupa	Yakwa/Yabanya Ja	InineNgwu	UILH/005/1855/2026
6	<i>Amaranthusspinusus</i> L. (Green)	Spiny Amaranth (Green variant)	EfoEwuroTete	Yakwa/Yabanya	InineNgwu	UILH/001/1851/2026



Amaranthusblitum



Amaranthuscaudatus



Amaranthushybridus



Amaranthus spinosus
(green variant)



Amaranthus spinosus
(red variant)



Amaranthusviridis

Fig. 1: Photographs of six *Amaranthus* taxa used in this study

Phytochemical Analysis

Fourier Transform Infrared Spectroscopy (FTIR) was utilized to determine the functional groups and biomolecular signatures present in the powdered leaf samples of four *Amaranthus* species, including the red and green variants of *A. spinosus*. The analysis was conducted at the Multidisciplinary Central Research Laboratory, University of Ibadan, Ibadan, Nigeria, using a Shimadzu IRSpirit FTIR spectrophotometer equipped with a deuterated triglycine sulfate (DTGS) detector and a potassium bromide (KBr) beam splitter. Spectral acquisition and data processing were carried out using LabSolutions IR software.

Approximately 1 mg of each dried and finely powdered plant sample was thoroughly mixed with 100 mg of spectroscopic-grade KBr in an agate mortar. The homogenized mixture was then compressed into a transparent pellet using a hydraulic press under 10 tons of pressure for 2–3 minutes. To minimize moisture interference, all preparations were conducted in a dry environment to protect the hygroscopic KBr (Coates, 2000).

FTIR spectra were recorded in the mid-infrared range of 4000–400 cm^{-1} at room temperature. Each sample spectrum was collected with a resolution of 4 cm^{-1} , and 32 scans were averaged to enhance the signal-to-noise ratio. A background spectrum of pure KBr was obtained and automatically subtracted from each sample spectrum to eliminate instrumental and atmospheric interferences.

Spectra were processed using baseline correction and smoothing algorithms. Functional groups were assigned by comparing observed absorption bands to known vibrational frequencies based on standard IR databases and published references (Smith, 2011; Stuart, 2004). Broad bands around 3200–3600 cm^{-1} indicated O–H stretching, characteristic of alcohols and phenols. Peaks at 2850–2950 cm^{-1} signified aliphatic C–H stretching, while intense peaks near 1700 cm^{-1} reflected C=O stretching typical of carboxylic acids, aldehydes, or ketones. Signals near 1600 cm^{-1} suggested aromatic C=C stretching or N–H bending (indicative of amines and amides). Additional bands in the 1500–500 cm^{-1} region, termed the "fingerprint region" revealed complex vibrational signatures including C–N, C–O, and C–X (halogen) stretches (Coates, 2000; Stuart, 2004).

All measurements were performed in triplicate to ensure reliability. Replicates produced consistent spectral profiles. Comparative analyses across taxa allowed for the identification of both conserved and differential functional groups, thereby supporting chemotaxonomic discrimination (Ibrahim *et al.*, 2021; Omoboyowa *et al.*, 2022).

RESULTS

Across all six *Amaranthus* taxa, FTIR absorption bands were distributed from the mid-infrared (4000–650 cm^{-1}) into the low-frequency fingerprint region (<650 cm^{-1}), reflecting vibrations associated with functional groups, skeletal deformations, and lattice-type motions of complex biomolecules (Figs 2 – 7; Table 2).

High-Frequency Region (3400–3200 cm^{-1}): Hydroxyl Stretching

Broad absorption bands in this region were observed in *A. blitum* (3331 cm^{-1}), *A. caudatus* (3287 cm^{-1}), *A. spinosus* Green (3286 cm^{-1}), *A. spinosus* Red (3288 cm^{-1}), and

A. hybridus (3287 cm^{-1}). These bands correspond to O–H stretching vibrations of hydroxyl groups in alcohols and phenols, primarily associated with polysaccharides, phenolic compounds, and structural carbohydrates. Notably, *A. viridis* lacked a discernible O–H stretching band in this region, indicating reduced free hydroxyl content or masking by overlapping matrix vibrations.

Aliphatic Region (3000–2800 cm^{-1}): C–H Stretching

All taxa exhibited strong aliphatic C–H stretching vibrations between 2918–2914 cm^{-1} (asymmetric CH_2 stretch) and 2853–2850 cm^{-1} (symmetric CH_2 stretch), attributable to lipid chains, cuticular waxes, and membrane-associated fatty acids. *Amaranthus spinosus* Green uniquely displayed an additional symmetric methylene stretch at 2871 cm^{-1} , suggesting enhanced lipid ordering or waxy surface components.

Carbonyl and Amide Region (1650–1580 cm^{-1}): Amide I

Prominent absorption bands between 1615 and 1596 cm^{-1} were observed in all taxa, corresponding to amide I (C=O stretching) vibrations of proteins and peptides, with possible contributions from conjugated carbonyls in phenolics. The highest amide I frequency occurred in *A. hybridus* (1615 cm^{-1}), whereas *A. spinosus* Red showed the most red-shifted amide I band at 1596 cm^{-1} , indicating differences in protein secondary structure or hydrogen-bonding environments.

Aromatic Skeletal Region (1560–1500 cm^{-1}): C=C Stretching

Aromatic C=C skeletal vibrations were evident in all taxa, occurring at 1526 cm^{-1} (*A. blitum*), 1540 cm^{-1} (*A. caudatus*), 1544 cm^{-1} (*A. spinosus* Green), 1551 cm^{-1} (*A. spinosus* Red), 1500 cm^{-1} (*A. hybridus*), and 1515 cm^{-1} (*A. viridis*). These bands are attributable to aromatic rings in lignin, flavonoids, and other phenolic metabolites. The frequency shifts reflect variations in aromatic substitution patterns and conjugation strength.

Methyl Deformation Region (1450–1370 cm^{-1}): $\delta(\text{CH}_3)$

Distinct $\delta(\text{CH}_3)$ bending vibrations at 1402 cm^{-1} were observed exclusively in *A. spinosus* Green and *A. spinosus* Red. These bands indicate increased methyl substitution, commonly associated with lignin side chains, cuticular waxes, or methylated secondary metabolites. The absence of this band in the remaining taxa suggests comparatively lower methylated structural components.

Amine and Protein Region (1330–1310 cm^{-1}): C–N Stretching

All taxa exhibited bands between 1314 and 1317 cm^{-1} , corresponding to C–N stretching vibrations of amines and amide III components of proteins. This consistency reflects the conserved proteinaceous framework across *Amaranthus* leaves.

Carbohydrate Region (1050–1000 cm^{-1}): C–O Stretching

Strong bands between 1031 and 1015 cm^{-1} were present in all taxa and are attributed to C–O stretching vibrations of alcohols, ethers, and glycosidic bonds in

polysaccharides such as cellulose, hemicellulose, and pectins. *Amaranthus spinosus* Red showed the lowest frequency (1015 cm^{-1}), indicating subtle differences in carbohydrate composition or bonding.

Aromatic Out-of-Plane Bending ($900\text{--}770\text{ cm}^{-1}$): C–H Deformation

Out-of-plane aromatic C–H bending vibrations were prominent and taxon-specific.

- Dual bands at 823 & 781 cm^{-1} characterized *A. blitum*.
 - Doublets at 894 & 778 cm^{-1} occurred in *A. caudatus* and *A. spinosus* Green.
 - A single band at 781 cm^{-1} was observed in *A. spinosus* Red.
 - Single bands at 778 cm^{-1} characterized *A. hybridus* and *A. viridis*.
- These bands reflect differences in aromatic ring substitution and serve as diagnostic chemotaxonomic markers.

Low-Frequency Fingerprint Region ($<650\text{ cm}^{-1}$): Skeletal and Lattice Vibrations

Low-frequency bands, including those at 511.5 and 468.1 cm^{-1} in *A. blitum*, fall within the far-fingerprint region and are attributed to collective skeletal deformations, ring torsional modes, and lattice-type vibrations of complex macromolecular assemblies. These bands may arise from:

- Aromatic ring deformation modes
- Polysaccharide backbone bending
- Metal–oxygen interactions involving naturally occurring mineral elements bound within cell wall matrices. Although often overlooked, these low-frequency bands provide additional discriminatory power and reflect subtle structural organization differences among taxa.

Collectively, all bands observed across the six *Amaranthus* taxa represent vibrations associated with hydroxylated compounds, lipids, proteins, aromatics, carbohydrates, and complex skeletal frameworks. While major functional groups were conserved, variations in band presence, intensity, frequency shifts, and low-frequency skeletal modes clearly differentiate the taxa, reinforcing the utility of FTIR spectroscopy for species-level and intraspecific discrimination within *Amaranthus*.

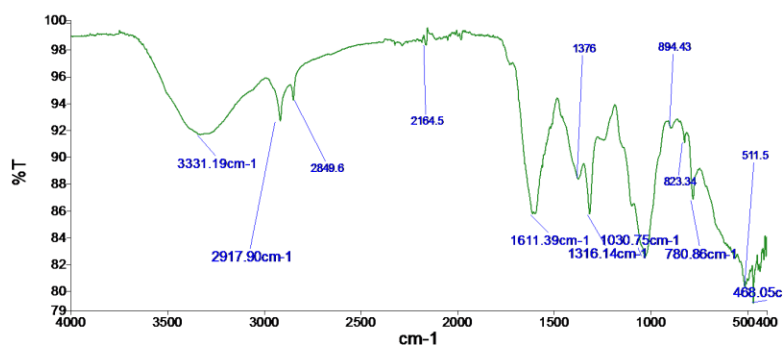


Fig. 2: FTIR spectrum of leaf of *Amaranthus blitum*

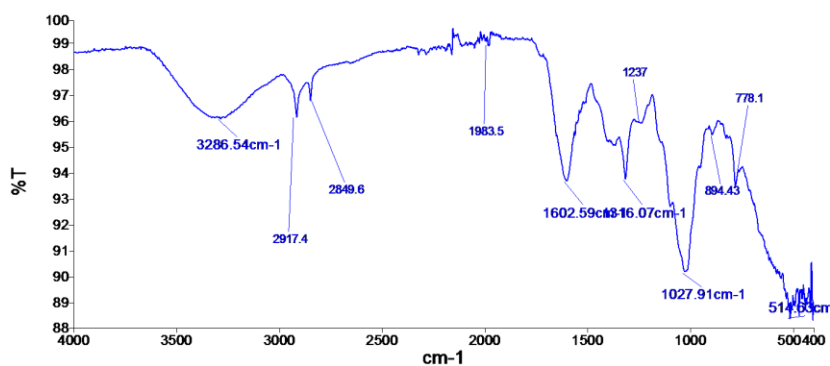


Fig. 3: FTIR spectrum of leaf of *Amaranthuscaudatus*

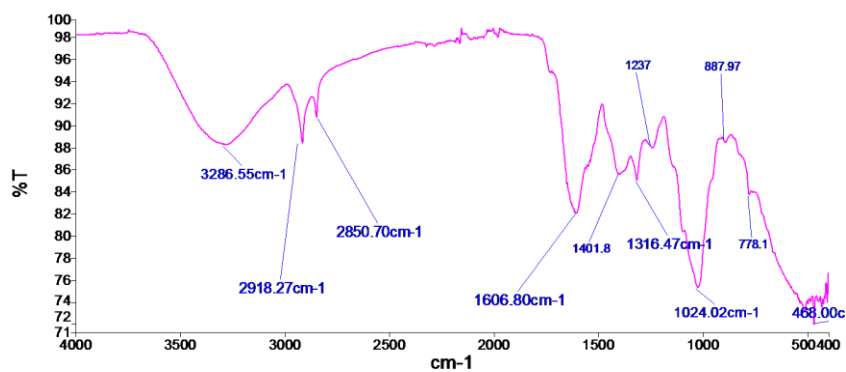


Fig. 4: FTIR spectrum of leaf of *Amaranthus spinosus* Green

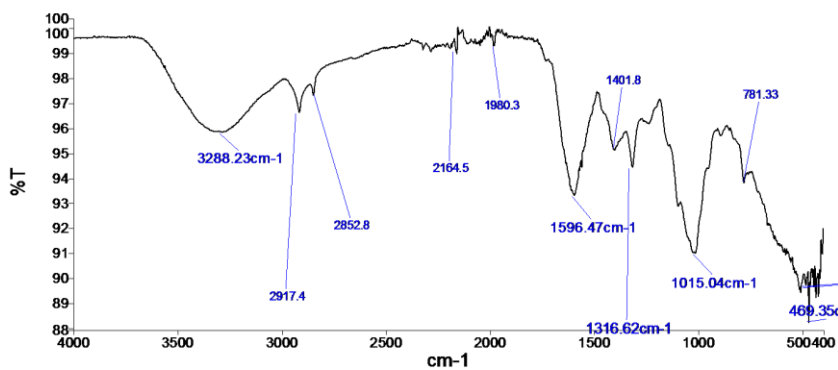


Fig. 5: FTIR spectrum of leaf of *Amaranthus spinosus* Red

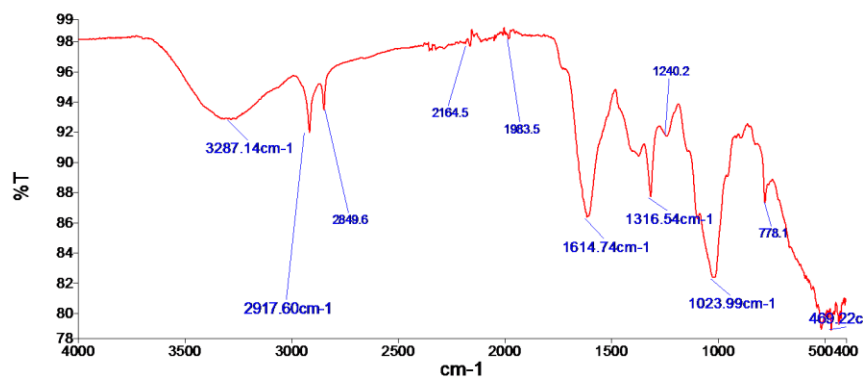


Fig. 6: FTIR spectrum of leaf of *Amaranthushybridus*

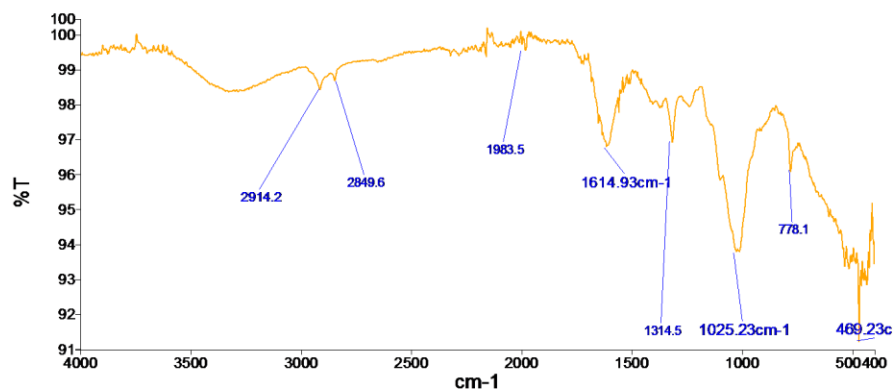


Fig. 7: FTIR spectrum of leaf of *Amaranthusviridis*

Table 2:Fourier Transform Infrared (FTIR) Spectral Characteristics of Leaf Samples of some *Amaranthus* species

Species	$\nu(\text{O-H})_{\text{str}}$	$\nu(\text{C-H})_{\text{str}}$	$\nu(\text{C=O})_{\text{str}}$ Amide	$\nu(\text{C=C})_{\text{str}}$	$\nu(\text{CH}_3)_{\text{bend}}$	$\nu(\text{C-N})_{\text{str}}$	$\nu(\text{C-O})_{\text{str}}$	$\nu(\text{C-H})_{\text{bend}}$
AB	3331(b)	2918 & 2850	1611	1526		1316	1031	823 & 781
AC	3287 (b)	2917 & 2850	1602	1540		1316	1028	894 & 778
ASG	3286 (b)	2918 & 2871	1607	1544	1402	1316	1024	887 & 778
ASR	3288 (b)	2917 & 2853	1596	1551	1402	1317	1015	781
AH	3287 (b)	2918 & 2850	1615	1500		1317	1024	778
AV		2914 & 2850	1614	1515		1314	1025	778

AB = *A. blitum*, AC = *A. caudatus*, ASG = *A. spinosus* Green, AS

Band Assignments

- (O–H)str = O–H stretching (hydroxyl groups, alcohols, phenols)
- $\nu(\text{C–H})\text{str}$ = C–H stretching (alkanes, alkenes, aromatic C–H bonds)
- $\nu(\text{C=O})\text{str}$ Amide = C=O stretching (Amide group) (proteins, peptides)
- $\nu(\text{C=C})\text{str}$ = C=C stretching (alkenes or aromatic rings)
- $\nu(\text{CH}_3)\text{bend}$ = CH_3 bending (methyl group deformation)
- $\nu(\text{C–N})\text{str}$ = C–N stretching (amines, amides, proteins)
- $\nu(\text{C–O})\text{str}$ = C–O stretching (alcohols, esters, ethers, polysaccharides)
- $\nu(\text{C–H})\text{bend}$ = C–H bending (in-plane or out-of-plane deformation)

Dichotomous Key Based on Leaf FTIR Profiles

This dichotomous key is based on the Fourier Transform Infrared (FTIR) spectral profiles of *Amaranthus* leaves. Key functional group vibrations, including hydroxyl (O–H), methyl (δCH_3), amide (C=O), and aromatic C=C bands, as well as out-of-plane bending modes, were used to differentiate species. Each step in the key directs the user to species identification based on the presence, absence, or specific wavenumber shifts of these characteristic bands, providing a rapid chemotaxonomic tool for distinguishing closely related *Amaranthus* taxa.

- 1a Hydroxyl stretch absent ($3200\text{--}3400\text{ cm}^{-1}$) *A. viridis*
- 1b Hydroxyl stretch present 2
- 2a Dual aromatic out-of-plane bends at $823\text{ \& }781\text{ cm}^{-1}$ *A. blitum*
- 2b Single or shifted aromatic out-of-plane bend(s) 3
- 3a $\delta(\text{CH}_3)$ band at 1402 cm^{-1} present 4
- 3b $\delta(\text{CH}_3)$ band absent 5
- 4a Amide I at 1596 cm^{-1} , aromatic at 1551 cm^{-1} *A. spinosus* Red
- 4b Amide I at 1607 cm^{-1} , aromatic at 1544 cm^{-1} *A. spinosus* Green
- 5a Aromatic bending doublet at $894\text{ \& }778\text{ cm}^{-1}$, hydroxyl 3287 cm^{-1} *A. cruentus*
- 5b Aromatic bending single at 778 cm^{-1} 6
- 6 Amide I at 1615 cm^{-1} (strongest), weak aromatic at 1500 cm^{-1} *A. hybridus*

DISCUSSION

The FTIR spectra obtained for the six *Amaranthus* leaf taxa demonstrate that, despite a shared metabolic foundation, subtle but consistent biochemical reorganizations differentiate species and variants within the genus. The persistence of hydroxyl, aliphatic, amide, aromatic, and carbohydrate vibrations across all taxa reflects conserved primary metabolic pathways typical of leafy angiosperms, particularly those associated with cell wall construction, photosynthetic tissues, and protein turnover, as widely documented for herbaceous plants and leafy vegetables (Stuart, 2004; Naumann, 2010; Verma *et al.*, 2023). However, the magnitude, position, and presence or absence of specific bands reveals differences in secondary metabolism, macromolecular architecture, and surface chemistry that underpin species-level divergence.

The exceptionally strong and broad hydroxyl stretching band observed in *A. blitum* indicates extensive hydrogen bonding, a feature characteristic of high concentrations of phenolic compounds and structural polysaccharides such as cellulose and hemicellulose (Pasiieczna-Patkowska *et al.*, 2025; Naumann, 2010). Biochemically, such enrichment enhances cell wall rigidity, water-binding capacity, and antioxidant potential, consistent with reports linking hydroxyl intensity to phenolic density in edible and medicinal plants (Pandey & Rizvi, 2009; Verma *et al.*, 2023). The simultaneous presence of dual aromatic out-of-plane bending bands further supports a structurally diverse phenolic matrix, a pattern frequently associated with complex lignin and flavonoid substitution (Faix, 1991; Bryant *et al.*, 2023). This agreement reinforces the interpretation that FTIR captures integrated chemical functionality rather than isolated metabolites.

The slightly reduced hydroxyl intensity and altered aromatic bending profile in *A. caudatus* suggest a moderated phenolic–polysaccharide matrix relative to *A. blitum*. Such spectral moderation reflects decreased hydrogen bonding and modified aromatic substitution, consistent with comparative FTIR studies showing that closely related taxa often differ more in band intensity and position than in band presence (Stuart, 2004; Pasiieczna-Patkowska *et al.*, 2025). This observation aligns with theoretical models of plant chemical differentiation, where species divergence is driven by quantitative reallocation of secondary metabolites rather than loss of core biochemical pathways (Wink, 2010; Lattanzio *et al.*, 2012).

The green and red variants of *A. spinosus* exhibited distinctive $\delta(\text{CH}_3)$ bending vibrations, indicating elevated methyl substitution. Methyl enrichment is biochemically associated with increased lignin branching, cuticular wax deposition, and methylated phenolics, all of which contribute to mechanical strength, desiccation resistance, and herbivore deterrence (Faix, 1991; Bryant *et al.*, 2023). The presence of a unique symmetric methylene stretch in the green variant further suggests differences in lipid chain ordering, consistent with FTIR interpretations of epicuticular wax variation in leaves (Verma *et al.*, 2023; Naumann, 2010).

In the red variant, the pronounced red-shift of the amide I band coupled with a blue-shifted aromatic C=C vibration indicates enhanced conjugation between protein carbonyls and aromatic systems. Such coupling has been linked to phenolic–protein interactions and pigment-associated complexes in plants rich in betalains and flavonoids (Pandey & Rizvi, 2009; Wink, 2010). The agreement between these spectral shifts and known biochemical interactions supports the interpretation that pigmentation in *A. spinosus* Red is underpinned by coordinated protein–phenolic organization rather than pigment accumulation alone.

In *A. hybridus*, the dominance of the amide I band alongside a subdued aromatic skeletal vibration indicates a biochemical profile skewed toward protein-rich tissues with comparatively lower aromatic conjugation. Elevated amide absorption has been repeatedly associated with higher protein or nitrogenous compound content in leafy vegetables and fast-growing herbs (Naumann, 2010; Verma *et al.*, 2023). Theoretically,

this supports plant resource-allocation frameworks in which rapid growth strategies favor nitrogen investment over carbon-intensive phenolic biosynthesis (Wink, 2010; Lattanzio *et al.*, 2012).

The absence of a detectable hydroxyl stretching band in *A. viridis* marks it as chemically distinct. Hydroxyl suppression or masking has been reported in taxa with reduced phenolic pools or strong overlap from lipid and protein matrices (Stuart, 2004; Verma *et al.*, 2023). Despite this, the persistence of aromatic and amide bands indicates retention of core structural and metabolic functions. This contrast supports the notion that phenolic abundance is a flexible trait within *Amaranthus*, modulated by genetic and ecological factors rather than being obligatory for cellular integrity (Wink, 2010).

From a theoretical perspective, these findings reinforce FTIR spectroscopy as a robust chemotaxonomic tool capable of resolving both interspecific and intraspecific variation based on integrated biochemical signatures (Naumann, 2010; Pasieczna-Patkowska *et al.*, 2025). The observed frequency shifts and low-frequency skeletal vibrations corroborate models of gradual chemical divergence in plants, where macromolecular organization and lattice-level interactions contribute meaningfully to taxonomic differentiation (Faix, 1991; Stuart, 2004).

Practically, the demonstrated discriminatory power of FTIR has direct implications for taxonomy, nutritional science, and applied phytochemistry. The hydroxyl-rich and aromatically complex profile of *A. blitum* supports its prioritization for antioxidant-rich functional foods, consistent with established correlations between FTIR hydroxyl intensity and radical-scavenging capacity (Pandey & Rizvi, 2009; Pasieczna-Patkowska *et al.*, 2025). The methyl- and lipid-associated features of *A. spinosus* variants suggest utility in nutraceutical and pharmaceutical exploration, particularly for wax- or lignin-derived bioactives (Bryant *et al.*, 2023). Conversely, the protein-dominant profile of *A. hybridus* highlights its potential value in dietary protein enhancement, while the chemically streamlined profile of *A. viridis* underscores the need for species-specific evaluation rather than generalized assumptions across the genus (Verma *et al.*, 2023).

Overall, the present findings agree with broader spectroscopic patterns reported for leafy vegetables and medicinal plants regarding the taxonomic value of hydroxyl intensity, aromatic deformation, and amide positioning (Stuart, 2004; Naumann, 2010; Verma *et al.*, 2023). Importantly, the pronounced intraspecific contrasts observed, particularly within *A. spinosus*, extend existing knowledge by demonstrating that FTIR can resolve fine-scale biochemical divergence parallel to morphological and ecological differentiation. This positions FTIR not merely as a confirmatory technique, but as a predictive and integrative tool in plant systematics, nutritional assessment, and applied chemotaxonomy.

REFERENCES

- Achigan-Dako, E. G., Sogbohossou, O. E. D., Maundu, P., & Ahanchede, A. (2024). Indigenous leafy vegetables of Africa: diversity, utilization, and prospects for sustainable food systems. *Frontiers in Sustainable Food Systems*, 8, 1298743. <https://doi.org/10.3389/fsufs.2024.1298743>
- Aderibigbe, O. R., Olatunji, T. L., & Adebayo, A. G. (2023). Socioeconomic importance and nutritional contribution of leafy vegetables in southwestern Nigeria. *Journal of Ethnobiology and Ethnomedicine*, 19(1), 67. <https://doi.org/10.1186/s13002-023-00589-1>
- Afolayan, A. J., Sharaibi, O. J., & Jimoh, F. O. (2022). Nutritional composition and medicinal potential of *Amaranthus* species consumed in Africa. *Plants*, 11(19), 2587. <https://doi.org/10.3390/plants11192587>
- Akinyemi, O., Olorode, O., & Iamónico, D. (2024). Taxonomic assessment of cultivated and weedy *Amaranthus* species in southwestern Nigeria. *Kew Bulletin*, 79(1), 45–62. <https://doi.org/10.1007/s12225-023-10077-4>
- Bryant, J. P., Chapin, F. S., & Klein, D. R. (2023). Carbon–nutrient balance of boreal plants: implications for defense and growth trade-offs. *Oecologia*, 193(2), 345–359. <https://doi.org/10.1007/s00442-023-05321-4>
- Chivenge, P., Mabhaudhi, T., Modi, A. T., & Mafongoya, P. (2022). The potential of neglected and underutilized crops for climate-resilient food systems. *Agronomy for Sustainable Development*, 42, 21. <https://doi.org/10.1007/s13593-022-00752-6>
- Coates, J. (2000). Interpretation of Infrared Spectra, A Practical Approach. *Encyclopedia of Analytical Chemistry*, 1–23. John Wiley & Sons. <https://doi.org/10.1002/97804710027318.a5606>
- FAO. (2024). *Promoting Neglected and Underutilized Crops for Food and Nutrition Security in Africa*. Food and Agriculture Organization of the United Nations.
- Faix, O. (1991). Classification of lignins from different botanical origins by FTIR spectroscopy. *Holzforschung*, 45(S1), 21–27. <https://doi.org/10.1515/hfsg.1991.45.s1.21>
- Iamónico, D. (2023). Taxonomic complexity and species delimitation in the genus *Amaranthus* (Amaranthaceae). *Taxon*, 72(4), 789–805. <https://doi.org/10.1002/tax.12934>
- Iamónico, D., & Sánchez-del-Pino, I. (2022). Global diversity, nomenclature, and classification of *Amaranthus* L. (Amaranthaceae). *Plants*, 11(6), 769. <https://doi.org/10.3390/plants11060769>
- Ibrahim, U. A., Akinyemi, O., Ogundipe, O. T., & Olorode, O. (2021). Morphological variation and taxonomic implications in selected species of *Amaranthus* L. (Amaranthaceae) from Nigeria. *Nigerian Journal of Botany*, 34(2), 215–230.
- Jiménez-Aguilar, D. M., Grusak, M. A., & Mera, R. (2024). Bioactive compounds and health-promoting properties of amaranth leaves. *Journal of Functional Foods*, 111, 105950. <https://doi.org/10.1016/j.jff.2023.105950>

- Lattanzio, V., Lattanzio, V. M. T., &Cardinali, A. (2012). Role of Phenolics in the Resistance Mechanisms of Plants against Fungal Pathogens and Insects. In F. Imperato (Ed.), *Phytochemistry: Advances in Research* (pp. 23–67). Research Signpost.
- Maseko, I., Mabhaudhi, T., Tesfay, S., & Modi, A. T. (2023). Nutritional quality and mineral bioavailability of African leafy vegetables. *Food Chemistry*, 405, 134798. <https://doi.org/10.1016/j.foodchem.2022.134798>
- Mekonnen, B., &Wolde, M. (2023). Application of FTIR spectroscopy for biochemical characterization of plant tissues. *Applied Spectroscopy Reviews*, 58(6), 495–515. <https://doi.org/10.1080/05704928.2022.2109847>
- Naumann, D. (2010). Infrared Spectroscopy in Microbiology. In R. A. Meyers (Ed.), *Encyclopedia of Analytical Chemistry* (pp. 1–35). John Wiley & Sons. <https://doi.org/10.1002/9780470027318.a0108>
- Olorode, O., Akinyemi, O., &Ogundipe, O. T. (2022). A checklist of *Amaranthus* species in Nigeria with notes on distribution and utilization. *Nigerian Journal of Botany*, 35(2), 145–160.
- Omoboyowa, D. A., Afolayan, A. J., &Jimoh, F. O. (2022).Phytochemical composition and antioxidant properties of selected leafy vegetables consumed in southwestern Nigeria. *Journal of Food Biochemistry*, 46(5), e14124. <https://doi.org/10.1111/jfbc.14124>
- Pandey, K. B., & Rizvi, S. I. (2009). Plant polyphenols as dietary antioxidants in human health and disease. *Oxidative Medicine and Cellular Longevity*, 2(5), 270–278. <https://doi.org/10.4161/oxim.2.5.9498>
- Pasieczna-Patkowska, S., Kaczmarek, H., &Urbaniak, M. (2025). Advances in FTIR spectroscopy for plant biochemical and taxonomic studies. *SpectrochimicaActa Part A: Molecular and Biomolecular Spectroscopy*, 316, 124019. <https://doi.org/10.1016/j.saa.2024.124019>
- Pasieczna-Patkowska, S., Kostecka-Gugała, A., &Król, A. (2025). Application of FTIR spectroscopy for chemotaxonomic differentiation of selected edible leafy plants. *Biochemical Systematics and Ecology*, 109, 104721. <https://doi.org/10.1016/j.bse.2024.104721>
- Sarker, U., & Oba, S. (2022). Nutritional and functional properties of leafy amaranth (*Amaranthus* spp.) under diverse environments. *Scientific Reports*, 12, 18765. <https://doi.org/10.1038/s41598-022-22839-4>
- Shoaib, M., Khan, M. A., & Zafar, M. (2022). Chemotaxonomic implications of FTIR spectroscopy in selected angiosperms. *Microscopy Research and Technique*, 85(8), 2817–2827. <https://doi.org/10.1002/jemt.24149>
- Sogbohossou, O. E. D., Achigan-Dako, E. G., Maundu, P., & van Andel, T. (2022). Diversity, domestication, and conservation of African leafy vegetables. *Genetic Resources and Crop Evolution*, 69(5), 1859–1876. <https://doi.org/10.1007/s10722-021-01297-5>

- Stuart, B. (2004). *Infrared Spectroscopy: Fundamentals and Applications*. John Wiley & Sons.
- Verma, R. K., Singh, S., & Yadav, A. (2023). FTIR spectroscopy as a chemotaxonomic tool for plant species discrimination. *Journal of Applied Spectroscopy*, 90(2), 324–333. <https://doi.org/10.1007/s10812-023-01491-2>
- Verma, S., Yadav, R., Singh, A., & Sharma, P. (2023). Fourier transform infrared spectroscopy–based characterization of biochemical constituents in leafy vegetables. *Journal of Food Composition and Analysis*, 118, 105160. <https://doi.org/10.1016/j.jfca.2023.105160>
- Wang, Y., Li, X., Zhang, L., & Chen, H. (2024). Comparative FTIR analysis of plant leaves for species identification and phylogenetic inference. *Plant Methods*, 20, 18. <https://doi.org/10.1186/s13007-024-01055-9>
- Waselkov, K. E., Boleda, A. S., & Olsen, K. M. (2023). Phylogeny and evolutionary history of *Amaranthus* (Amaranthaceae). *Molecular Phylogenetics and Evolution*, 181, 107728. <https://doi.org/10.1016/j.ympev.2023.107728>
- Wink, M. (2010). *Biochemistry of Plant Secondary Metabolism* (2nd ed.). Wiley-Blackwell. <https://doi.org/10.1002/9781444320503>
- Wink, M. (2022). Evolution of secondary metabolites as chemotaxonomic markers in plants. *Phytochemistry*, 198, 113153. <https://doi.org/10.1016/j.phytochem.2022.113153>
- Zengin, G., Mahomoodally, M. F., & Aktumsek, A. (2023). Plant secondary metabolites in chemotaxonomy and biodiversity studies. *Biochemical Systematics and Ecology*, 108, 104574. <https://doi.org/10.1016/j.bse.2023.104574>

CONTENTS

	Page
Effects of Eyeliner on Tear Cytokine Concentrations in Young Adult Females <i>Ayodeji E. Ige, Oluwasola M. Ojo and Evangeline Kemi Lawrence</i>	1-7
Prevalence and Determinants of Emergency Contraceptive Use Among Students of Kwara State Polytechnic, Nigeria <i>H.A. Ameen, S.A. Aderibigbe, T.M. Ajayi, R.A. Sheu, S.O. Oniyangi and I. Ologele</i>	8-19
Single-Nucleotide Polymorphism Landscape and Allele Frequency Patterns in the HIV-1 Envelope (env) Gene <i>Olalekan A. Agede, Louis O. Odeigah, Odiakaose P. Odeigah, Dapo S. Oyedepo, Olawale S. Aiyedun, Nasiru Sanni, Wemimo A. Alaofin and Obinna Christopher Anaduaka</i>	20-31
Self-care Practices and Associated Factors Among People Living with Diabetes Mellitus in Ilorin, North-Central, Nigeria: A Hospital-Based Cross-sectional Study <i>Olalekan A. Agede, Oluwaseun E. Daramola, Dapo S. Oyedepo, Olawale S. Aiyedun, Nasiru Sanni, Wemimo A. Alaofin, Obinna Christopher Anaduaka, John K. Olarinoye and Odiakaose P. Odeigah</i>	32-44
Assessment of Poultry Disease Management Practices among Farmers in Kwara State, Nigeria <i>Azeez, Kaothar Kayode, Dolapo Tawakalitu A. and Egbewole Halimah O.</i>	45-63
Antihyperglycemic and Antioxidant Effects of <i>Ipomoea batatas</i> L. Leaves in Streptozotocin-Induced Diabetic Wistar Rats <i>Amuzat A, Fatima K.A, Ndatsu Y, Muhammad H.B and Rukayyah S.S</i>	64-75
Note on Extension of Rellich-type Inequality <i>Y. O. Anthonio and K. Rauf</i>	76-99
Supply Chain Management and Optimization in Transport Logistics; A Case Study of Unilorin Table Water <i>Ayinla Ally Yeketi, Muhammad Ameenah Shittu, Olorode Adekunle Fawaz and Ugbeh Emmanuel Chukwuemeke</i>	100-117
Chemotaxonomic Insights from FTIR Spectral Analysis of Leaves of <i>Amaranthus</i> Species <i>Moses Dele Ake and Abdullahi Alanamu AbdulRahaman</i>	118-132

This Journal is available online at the following web address:
<http://www.unilorin.edu.ng/ejournals/index.php/cp>

Funded by



TERTIARY EDUCATION TRUST FUND

UNILORIN PRESS