ISSN:
Print - 2277 - 0755
Online - 2315 - 7453

Journal of Agricultural Science and Environment

PERCEPTIONS OF BIOINFORMATICS IN PLANT BREEDING AMONG NIGERIAN STUDENTS

[*1,2] A. A. LAWAL, [2]G. B. MANGSHIN, [3]O. R. ALAGBADA, [4]O. DOGUN, [4]R. A. OGENYI

*[1]Department of Agricultural Biotechnology, Federal College of Forestry, Jos, Nigeria.
[2]Department of Crop Production, Abubakar Tafawa Balewa University, Bauchi, Nigeria.
[3]Federal College of Forest Resources Management, Ishiagu, Ebonyi state, Nigeria
[4]Science Laboratory Technology Department, Federal College of Forestry, Jos, Nigeria

***Corresponding Author**: lawal.aa@frin.gov.ng **Tel:** +2348067670709
+2347019031413

ABSTRACT

Bioinformatics is increasingly essential across biology, agriculture, medicine, and environmental sciences due to the growing demand for advanced data-driven research. In plant breeding, it enables analysis of complex genomic datasets to enhance yield, resilience to biotic and abiotic stresses, and nutritional quality. This study assessed awareness, understanding, interest, and perceived challenges related to bioinformatics among plant breeding students in Nigerian Universities through an online survey distributed via Google Forms. Responses were collected from Undergraduate, Graduate, and Post-graduate students, with measures implemented to prevent duplication. Findings revealed high awareness (83.7%) and substantial understanding of bioinformatics concepts (71.8%). Interest was particularly strong among postgraduate students, with 89.7% recognizing its importance for the future of plant breeding. Key challenges included insufficient interdisciplinary training, curriculum limitations, and inadequate computational resources. Despite these barriers, 93.7% of respondents supported introduction of dedicated bioinformatics courses. Students further anticipated that bioinformatics would accelerate plant breeding through predictive modeling and contribute significantly to food security. The findings emphasize the urgent need for strengthened bioinformatics education, faculty training, and infrastructural support in Nigerian Universities to equip future plant breeders with essential computational skills.

Keywords: Bio information; Computational biology; Student awareness; Precision breeding.

INTRODUCTION

In recent years, bioinformatics has emerged as a pivotal discipline at the intersection of biology, computer science, and mathematics, offering transformative tools for data analysis in various fields, including agriculture. It is an interdisciplinary field at the intersection of computational and biological sciences that focuses on the analysis and interpretation of large biological data sets (Drew *et al.*, 2023). Bioinformatics plays a crucial role in advancing our understanding of genetics, genomics, and personalized medicine (Akintola *et al.*, 2024). It is important in modern plant breeding, enabling the analysis of large genomic datasets to accelerate crop improvement.

Crop Production remains a pillar of the economy and livelihoods in developing countries, especially Nigeria. With increasing global challenges such as climate change and food security, integrating bioinformatics into plant breeding education is imperative to equip future scientists with the necessary skills for precision breeding and sustainable agriculture. Bioinformatics is accelerating crop breeding by helping systematically leverage the genetic components of agronomic traits (Perez-de-Castro *et al*., 2012; Abberton *et al*., 2016). Crop sequences provide an important foundation for identifying agronomically relevant variations (Haifei *et al*., 2018). With the aid of sequencing technology, scientists in plant biology have revealed the genetic architecture of various plant and microorganism species, such as proteome, transcriptome, metabolome, and even their metabolic pathway (Gomez-Casati *et al*., 2018). Therefore, Bioinformatics holds a big promise in addressing many of the problems that are facing humanity today, including human health, agriculture, and the environment (Lyall, 1996; Xue *et al*., 2008; Weckwerth, 2011; Harper and Armelagos, 2013; Ginsburg, 2014; Merelli *et al*., 2014).

The credit for the first national bioinformatics training awareness in Nigeria can go to the region-wide training courses on molecular biology and bioinformatics organized by the West African Biotechnology Workshops Series between 2002 and 2005 (Fatumo *et al*.,2014). Bioinformatics-driven undergraduate curricula, when carefully designed, also have the potential to address traditional STEM access and diversity barriers (Elgin *et al*., 2021; Handelsman *et al*., 2022; The Genomic Data Science Community Network, 2022). Providing early skill development in bioinformatics, helps emerging scientists advance their research potential and primes them to seek out opportunities in higher education and the technical workforce (Porter and Smith, 2019).

Despite its growing importance, the level of awareness, understanding, and interest in bioinformatics among students in developing countries, particularly Nigeria, remains underexplored. However, adoption of bioinformatics in Nigerian education faces multiple challenges, including inadequate infrastructure such as limited computer facilities and unreliable internet access, a shortage of trained bioinformatics educators, and insufficient integration of bioinformatics into existing curricula. Limited awareness among students and faculty, financial constraints, and scarce opportunities for collaboration with international bioinformatics networks further hinder effective learning and application of bioinformatics in the country. To address this issue, it is crucial to establish a conducive setting that nurtures professional growth and scholarly prospects within the locality (Mboowa *et al*., 2021). Hence, this study evaluated the awareness, perceptions, challenges and exposure of Nigerian students to bioinformatics in plant breeding, to identify strategies for its effective integration into education.

METHODOLOGY

The study employed an online survey distributed via Google Forms. Participants included Undergraduate, Graduate, and Postgraduate students enrolled in plant breeding programs. To maintain data integrity, Google Form was configured to allow only one submission per participant, thereby preventing duplicate responses. The questionnaire survey link was disseminated through social media platforms used by undergraduate, graduate, and postgraduate plant breeding students, as well as the official platforms of the Nigerian Plant Breeders Association (NPBA). Data collection was conducted over a six-month period, from March to August, 2024.

Participants were Plant Breeding students enrolled in various tertiary institutions at different levels of education in Nigeria. The sample comprised 147 postgraduate students (currently pursuing Master's or Doctoral programs), 78 undergraduate students (pursuing first degrees), and 72 graduate students (those who have completed their first degree but are not currently enrolled in a postgraduate program).

Data collection

Participants were invited to participate in an anonymous survey through google form. The invitation to participate included the informed consent, the purpose of the study and the link to the survey. The online survey was available to the Participants for six months. The questionnaire comprised sections on demographic information, awareness and understanding of bioinformatics, interest levels, perceived challenges, and opinions on the future impact of bioinformatics in plant breeding. The survey for the study comprised 22 multiple-item questions presented in a Likert scale format. (Likert, 1932). In total, there were 300 respondents' data for the survey.

Data Analysis

Collected data were downloaded in Excel format, coded and exported to Statistical Package for Social Sciences (SPSS) statistical software for analysis. Descriptive statistics, Cross-tabulation and chi-square tests were used to examine variables, with significance at $p < .05$ using Statistical Package for Social Sciences – SPSS version 27.0.

RESULTS

Demographic Characteristics of Respondents

Majority of the participants were males (73.8%), while females accounted for 25.9% (Table 1). The largest age group was 31–40 years (36.9%), followed by those aged 25–30 years (27.9%) and 18–24 years (19.9%). Undergraduates constituted 27.3% of the respondents, graduates 23.9%, and postgraduates 48.8%, while other categories represented only 1%. Exposure to plant breeding courses, 36.9% had taken five or more courses, 23.9% had taken 3–4 courses, 21.9% had taken 1–2 courses, and 15.9% reported no exposure. There were significant differences across all variables (Table 1).

Awareness and Understanding of Bioinformatics

There was a high level of awareness of bioinformatics among plant breeding students. Majority of the respondents (83.7%) had heard of bioinformatics prior to the survey (Table 2). Most participants, 71.8% accurately defined bioinformatics as "use of computational methods to analyze plant genome data". Very few associated it with traditional breeding methods 7.0% misconstrued bioinformatics as traditional breeding methods while 4.0% admitted they did not understand any given definition. 64.8% of students recognized its comprehensive application, including identifying genetic markers, analyzing genomic data, and predicting gene function (Table 2).

Postgraduate students exhibited the highest awareness (46%), followed by undergraduates (21%) and graduates (17%) - Table 3. There was a highly significant ($p < .01$.) as-

Table 1: Demographic Characteristics of Respondents (N = 300)

Variable	Category	Frequency (n)	Percent (%)	χ^2	p-value
Age	Under 18	3	1	112.5	
	18–24	60	19.9		< .001
	25–30	84	27.9		
	31–40	111	36.9		
	41–50	42	14		
Gender	Male	222	73.8	69.12	< .001
	Female	78	25.9		
Academic Level	Undergraduate	78	27.3	138.48	
	Graduate	72	23.9		< .001
	Postgraduate	147	48.8		
Number of Plant Breeding Courses Taken	None	48	15.9	28.46	< .001
	1–2	66	21.9		
	3–4	72	23.9		
	5 or more	111	36.9		

Table 2: Level of awareness and understanding of bioinformatics among plant breeding students in Nigerian Universities.

Variable description	Frequency	Percentage (%)
Have you heard about bioinformatics before?		
Yes	252	83.7
No	48	15.9
How would you define bioinformatics in the context of plant breeding?		
Using computational methods to analyze plant genome data	216	71.8
Traditional breeding methods involving the use of biological organisms	21	7.0
The study of plants' genetic makeup and inheritance patterns	51	16.9
None of the above	12	4.0
What role do you think bioinformatics can play in developing crops with improved yield, resistance to pests and diseases, and nutritional value?		
Identifying genetic markers associated with desired traits	63	20.9
Analyzing genomic data to understand plant physiology	33	11.0
Predicting gene function and metabolic pathways	3.0	3.0
All of the above	195	64.8

sociation between academic level and awareness of bioinformatics.

Student Interest and Perceived Importance

Students demonstrated a generally high level of interest in learning bioinformatics for plant breeding (Table 4). Nearly three quarters of respondents (72.7%) expressed at least moderate to extreme interest, with 45.8% reporting they were "extremely interested" and 26.9% "moderately interested." Only a small fraction (3.0%) reported no interest. In terms of specific areas of application, 43.9% of respondents expressed equal interest in all key domains such as genome wide association studies, comparative genomics, and gene expression analysis, indicating recognition of bioinformatics as a broad and integrated discipline. A substantial majority (89.7%) believed bioinformatics to be important for the future of plant breeding, a perception that was highly significant (Table 4).

Table 3: Academic Level with Awareness of Bioinformatics

Academic Level	Yes	No	Total	χ^2	P-Value
Undergraduate	63 (21.0%)	18(6.0%)	81(27.0%)	23.437	<0.01
Graduate	51(17.0%)	21(7.0%)	72(24.0%)		
Postgraduate	138(46.0%)	9(3.0%)	147(49.0%)		

Table 4: Evaluation of students' interest, perception, and perceived importance of bioinformatics in plant breeding.

Variable description	Frequen-	Percent	χ^2	P-value
How interested are you in learning about bioin-				
Not interested at all	9	3.0	171.60	0.00
Slightly interested	33	11.0		
Neutral	39	13.0		
Moderately interested	81	26.9		
Extremely interested	138	45.8		
What aspects of bioinformatics in plant breeding interest you the most?				
Genome-wide association studies	51	16.9	58.32	0.00
Comparative genomics across plant species	57	18.9		
Gene expression analysis using RNA-seq	60	19.9		
All of the above	132	43.9		
Do you believe that bioinformatics is important for the future of plant breeding?				
Yes	270	89.7	436.38	0.00
No	3	1.0		
Maybe	27	9.0		

Postgraduate students showed the highest extreme interest (32%), compared to graduates (7%) and undergraduates (7%) –Table 5. There was a highly significant association between academic level and interest in bioinformatics.

Challenges and Barriers to Integration

A total of 47.8% of the respondents believed multiple, concurrent challenges rather than a single dominant issue were the challenges in integrating bioinformatics into plant breeding education (Table 6). 26.9% of respondents believed the major challenge is "*providing sufficient training and resources for students and educators*", followed by "*updating curriculum to reflect rapid advancements in bioinformatics*" (13.0%) and "*bridging the gap between biology and computational science*" (12.0%). About 42.9% identified multiple barriers to adoption, while 33.9% emphasized limited computational resources, with ethical concerns (14.0%) and breeder resistance (9.0%) less frequently noted. A strong majority (93.7%) supported introducing dedicated bioinformatics courses in plant breeding, with most (62.8%) favouring a comprehensive curriculum covering genome analysis, statistical tools, and programming skills (Table 6).

Table 5: Interest Level by Academic Level (Cross Tabulation)

Academic Level	Not Interested	Slightly Interested	Neutral Interested	Very Interested	Extremely interested	Total	χ^2	P-value
Undergraduate	3(1.0%)	21(7.0%)	18(6.0%)	18(6.0%)	19(7.0%)	81(21.0%)	84.545	< .001
Graduate	6(2.0%)	9(3.0%)	6(2.0%)	30(10.0%)	21(7.0%)	72(24.0%)		
Postgraduate	0(0.0%)	3(1.0%)	15(5.0%)	33(11.0%)	96(32.0%)	147(49.0%)		

Respondents anticipated that bioinformatics would accelerate breeding via predictive modeling (16.9%), enable climate-adaptive precision breeding (16.9%), and facilitate niche-market crop development (5.0%), with 60.8% endorsing all these outcomes (Table 7). 61.8% believed bioinformatics could drive the development of stress-tolerant varieties, enhance nutritional quality and breeding for specific environmental conditions precision breeding. 77.7% agreed that bioinformatics could improve the efficiency of traditional breeding methods (Table 7).

DISCUSSION

The results from the study reflect a largely positive disposition toward bioinformatics, high levels of awareness, strong interest in learning, and broad recognition of its role in modern plant breeding. This is in accord with the work of Fatumo *et al.*, (2014) who reported that, awareness on Bioinformatics is becoming more prevalent within the academia in Nigeria; so is the interest of new-generation scientists in this emerging scientific discipline. The significant association between academic level and awareness showed the impact of advanced studies in deepening engagement and the eagerness of integrating bioinformatics in plant breeding

Table 6: Challenges and Barriers to Integration of Bioinformatics into Plant Breeding Education

Variable description	Frequency	Percentage (%)	χ^2	P-Value
What do you perceive as the main challenges in integrating bioinformatics into plant breeding education?				
Bridging the gap between biology and computational science	36	12.0	101.52	< .001
Updating curriculum to reflect rapid advancements in bioinformatics	39	13.0		
Providing sufficient training and resources for students and educators	81	26.9		
All of the above	144	47.8		
Are there any barriers that prevent wider adoption of bioinformatics tools in plant breeding research and education?				
Lack of access to computational resources and expertise	102	33.9	93.84	< .001
Ethical concerns surrounding genetic modification	42	14.0		
Resistance from traditional breeders to adopt new technologies	27	9.0		
All of the above	129	42.9		
Do you believe there should be specific courses or training programs dedicated to bioinformatics in plant breeding?				
Yes	282	93.7	497.04	< .001
No	6	2.0		
Maybe	12	4.0		
What do you think should be included in such courses or programs?				
Genome assembly and annotation techniques	39	13.0	239.76	< .001
Statistical analysis of genomic data	54	17.9		
Programming languages like Python and R	18	6.0		
All of the above	189	62.8		

Table 7: Perceptions of Bioinformatics Applications in Plant Breeding

Variable description	Frequency	Percentage (%)	χ^2	P-Value
How do you think advancements in bioinformatics will impact the field of plant breeding in the next decade?				
Accelerating the pace of breeding through predictive modeling	51	16.9	218.88	< .001
Enabling precision breeding for climate change adaptation	51	16.9		
Facilitating the development of tailor-made crops for niche markets	15	5.0		
All of the above	183	60.8		
How can bioinformatics contribute to addressing global food security challenges through plant breeding?				
Accelerating the development of stress-tolerant crop varieties	51	16.9	223.92	< .001
Facilitating precision breeding for specific environmental conditions	39	13.0		
Enhancing crop nutritional content through gene editing	24	8.0		
All of the above	186	61.8		
What role do you think bioinformatics can play in developing crops with improved yield, resistance to pests and diseases, and nutritional value?				
Identifying genetic markers associated with desired traits	63	20.9	275.52	< .001
Analyzing genomic data to understand plant physiology	33	11.0		
Predicting gene function and metabolic pathways	9	3.0		
All of the above	195	64.8		
Do you think bioinformatics can enhance the efficiency and effectiveness of traditional plant breeding techniques?				
Yes, by providing insights into genetic diversity and trait inheritance	234	77.7	455.28	< .001
No, traditional methods are more reliable	15	5.0		
Maybe, but it depends on the specific crop and breeding goals	39	13.0		
Unsure	12	4.0		

to facilitate faster and more precise identification of genetic traits, offering plant breeders advanced tools for crop improvement.

Expression of interest in bioinformatics was generally high with "moderately" to "extremely" interested. This aligns with Porter and Smith, (2019), who reported that early skill development in bioinformatics, helps emerging scientists advance their research potential and primes them to seek out opportunities in higher education and the technical workforce. This is in agreement with Dinsdale *et al.*, 2015 which reported that integration of bioinformatics learning objectives across undergraduate life science degree programs can theoretically address the issue of bioinformatics literacy. The association between academic level and interest in bioinformatics further confirm that the interest in bioinformatics is significantly higher among postgraduate students, Consequently, the high level of interest emphasizes the growing demand for bioinformatics knowledge in plant breeding, critically for addressing challenges such as crop improvement, climate adaptation, and food security. It also highlights the need for educational programs to align with this demand by offering more specialized bioinformatics courses.

The significant level for challenges indicate that these barriers are widely recognized across academic levels and are major impediments to the effective use of bioinformatics in plant breeding. Integrating bioinformatics in education faces challenges such as gaps in resources, curriculum, and skills development. Insufficient training and resources were the most frequently cited challenge. Hence, there is a need for upgraded infrastructure and comprehensive bioinformatics training programs for both students and educators. These infrastructures include adequate power supply or alternative power supply, internet connectivity and computer systems. Isewon *et al.*, (2022) also reported, limited opportunities, resource constraints, migration for Bioinformatics education and career prospects and recognition are some of the several factors that contribute to the brain drain in bioinformatics in Africa. Ojo and Omabe, (2011) also reported that absence of specialized bioinformatics curricula is a prevalent issue in African universities, where comprehensive programs or courses that cater to the specific requirements of the region are not readily available. The insufficiency of qualified personnel poses a constraint on the accessibility of bioinformatics courses and the provision of guidance to students (Giovannietal *et al.*, 2023). Insufficient computational infrastructure and resources pose a challenge to bioinformatics research in numerous institutions in Africa (Rotimi *et al.*, 2017). Addressing these challenges is crucial for enhancing the integration of bioinformatics in plant breeding. A strategic investment in resources, educator training, and curriculum updates can foster a more robust understanding and application of bioinformatics tools, which in turn will facilitate more efficient and effective Breeding programmes.

Both the impact of bioinformatics on the field of plant breeding and contribution in addressing global food security challenges through plant breeding were significant. It implies the potential of bioinformatics to drive future innovations in plant breeding. With bioinformatics, breeders can make informed decisions that not only improve crop yields but also enhance crop resilience to stressors like drought and disease, which are becoming increasingly important as climate change continues to impact agricultural productivity.

The challenges facing integration of bioinformatics into plant breeding is significant. Lack of access to computational resources and expertise are the key limitation in the integration of bioinformatics tools in plant breeding. Overcoming these barriers is crucial for the continued development and integration of bioinformatics in plant breeding. Solutions such as partnerships with global research institutions, government funding for bioinformatics infrastructure, and ethical frameworks for gene editing can facilitate the broader adoption of bioinformatics tools in plant breeding. Effective teaching and learning of bioinformatics in Nigeria is predominantly affected by dearth of qualified and properly trained trainers, lack of funds and unavailability of basic infrastructure for bioinformatics training and research (Ojo and Omabe, 2011).

CONCLUSION

Respondents demonstrated a high level of awareness and positive attitudes toward bioinformatics, with stronger engagement observed at higher academic levels. However, curriculum gaps, limited training opportunities, and resource constraints continue to hinder effective integration into plant breeding education. Coordinated action by government agencies, universities, and funding bodies, through competitive remuneration, sustainable research support, and professional recognition, is essential to strengthen local expertise. By prioritizing curriculum reform, faculty training, infrastructural investment, and research collaboration, Nigerian institutions can align with global advances in genomics-driven agriculture and fully harness the potential of bioinformatics for crop improvement and food security.

REFERENCES

Abberton, M., Batley, J., Bentley A, Bryant J, Cai H, Cockram J, de Oliveira A. C., Cseke L. J., Dempewolf H., De Pace C., Edwards D., Gepts P., Greenland A., Hall AE., Henry R., Hori K., Howe G. T., Hughes S., Humphreys M., Lightfoot D., Marshall A., Mayes S., Nguyen H. T., Ogbonnaya FC., Ortiz R., Paterson AH., Tuberosa R., Valliyodan B., Varshney RK., Yano M. (2016). Global agricultural intensification during climate change: a role for genomics. *Plant Biotechnology Journal* 14 (4):1095-8. doi: 10.1111/pbi.12467. Epub 2015 Sep 11. PMID: 26360509; PMCID: PMC5049667.

Akintola, A. A., Aborode, A. T., Hamza, M. T., Amakiri, A., Moore, B., Abdulai, S., Iyiola, O. A., Sulaimon, L. A., Effiong, E., Ogunyemi, A., Dosunmu, B., Maigoro, A. Y., Lawal, O., Raheem K., Hwang, U. W. (2024). Bioinformatics proficiency among African students. *Front Bioinformatics*. 20:4:1328714. doi: 10.3389/fbinf.2024.1328714. PMID: 38966162; PMCID: PMC11222312.

Dinsdale, E., Elgin, S. C., Grandgenett, N., Morgan, W., Rosenwald, A., Tapprich, W., et al. (2015). NIBLSE: a network for integrating bioinformatics into life sciences education. *CBE Life Science Education* 14: 1–4. doi: 10.1187/cbe.15-06-0123

Drew, J., Morgan, W., Galindo, S., Kleinschmit, A. J., McWilliams, M., Pauley, M., Triplett, EW., Williams, J., Murdoch B and Rosenwald A. (2023). Revisiting barriers to implementation of bioinformatics into life sciences education. *Frontiers Education* 8:1317191. doi: 10.3389/ feduc.2023.1317191

Elgin, S. C. R., Hays, S., Mingo, V., Shaffer, C. D., & Williams, J. (2021). *Building Back More Equitable STEM Education: Teach Science by Engaging Students in Doing Science*. B*ioRxiv*. https:// doi.org/10.1101/2021.06.01.446616

Fatumo, S. A., Adoga, M. P., Ojo, O. O., Oluwagbemi, O., Adeoye T., Ewejobi, I., Adebiyi, M., Adebiyi, E., Bewaji, C., & Nashiru, O. (2014). Computational biology and bioinformatics in Nigeria. *PLoS Computational Biology* 24: 10(4):e1003516. doi: 10.1371/ journal.pcbi.1003516. PMID: 24763310; PMCID: PMC3998874.

Ginsburg, G. (2014). Medical genomics: Gather and use genetic data in health care. *Nature News* 508 (7497):451.

Giovanni, M. Y., Whalen, C., Hurt, D. E., Ware-Allen, L., Noble, K., McCarthy, M., et al. (2023). African Centers of excellence in bioinformatics and data intensive science: building capacity for enhancing data intensive infectious diseases research in Africa. *Journal of Infectious Diseases & Microbiology* 1 (1): 006. doi:10.37191/mapsci-jidm-1(2)-006

Gomez-Casati, D. F., Busi, M. V., Barchiesi, J., Peralta, D. A, Hedin, N., Bhadauria, V. (2018) Applications of bioinformatics to plant biotechnology. *Current Issues in Molecular Biology* 27:89–104. https:// doi.org/10.21775/cimb.027.089

Handelsman, J., Elgin, S., Estrada, M., Hays, S., Johnson, T., Miller, S., Mingo, V., Shaffer, C. & Williams, J. (2022). Achieving STEM diversity: Fix the classrooms. *Science.* 3:376 (6597):1057-1059. doi: 10.1126/ science.abn9515. Epub 2022 Jun 2. PMID: 35653460.

Harper, K.. N. & Armelagos, G. J. (2013) Genomics, the origins of agriculture, and our changing microbe-scape: time to revisit some old tales and tell some new ones. *American Journal of Physical Anthropology*.152 Suppl 57 (Suppl 57):135-52. doi: 10.1002/ ajpa.22396. PMID: 24249593; PMCID: PMC7159788.

Hu, H., Scheben, A., & Edwards, D. (2018). Advances in Integrating Genomics and Bioinformatics in the Plant Breeding Pipeline. *Agriculture 8* (6): 75. https://doi.org/10.3390/ agriculture8060075.

Isewon, I., Soremekun, C., Adebiyi, M., Adetunji, C., Ogunleye, A. J., Bajeh, A. O., Asani, E. O., Gbadamosi, B., Soremekun, O., Udosen, B,, Kintu, C., Ogundokun, R., Arowolo, M. O., Matiluko, O., Nashiru, O., Adebiyi, E., Ekenna, C., & Fatumo, S. (2022) Strengthening Bioinformatics and Genomics Analyses Skills in Africa for Attainment of the Sustainable Development Goals: Report of the 2nd Conference of the Nigerian Bioinformatics and Genomics Network. *American Journal of Tropical Medicine Hygiene* 16:107(1):21–3. doi: 10.4269/ ajtmh.21-1164. Epub ahead of print.

PMID: 35576945; PMCID: PMC9294681.

Likert R. (1932). A Technique for the Measurement of Attitudes. New York: *Archives of Psychology 140: 1 - 55.*

Lyall A. Bioinformatics in the pharmaceutical industry (1996). *Trends in Biotechnology*. 14(8):308-12. doi: 10.1016/0167-7799(96)10042-1. PMID: 8987464.

Mboowa, G., Sserwadda, I., & Aruhomukama, D. (2021). Genomics and bioinformatics capacity in Africa: no continent is left behind. *Genome* 64(5):503-513. doi: 10.1139/gen-2020-0013. Epub 2021 Jan 12. PMID: 33433259; PMCID: PMC12179689.

Merelli, I., Pérez-Sánchez, H., Gesing, S., & D'Agostino, D. (2014). Managing, analysing, and integrating big data in medical bioinformatics: Open problems and future perspectives. *BioMed Research International,* Article 134023. https://doi.org/10.1155/2014/134023

Ojo, O. O. & Omabe, M. Incorporating bioinformatics into biological science education in Nigeria: prospects and challenges. *Infection Genetics and Evolution* 11(4):784-787. doi: 10.1016/j.meegid.2010.11.015. Epub 2010 Dec 9. PMID: 21145989.

Pérez-de-Castro, A. M., Vilanova, S., Cañizares, J., Pascual, L., Blanca, J. M., Díez, M. J., Prohens, J., & Picó, B. (2012). Application of genomic tools in plant breeding. *Current Genomics.* 13(3):179-95. doi: 10.2174/138920212800543084. PMID: 23115520; PMCID: PMC3382273.

Porter, S. G., & Smith, T. M. (2019). Bioinformatics for the Masses: The Need for Practical Data Science in Undergraduate Biology. *OMICS*. 23 (6):297-299. doi: 10.1089/omi.2019.0080. Epub 2019 May 20. PMID: 31107144.

Rotimi, C. N., Bentley, A. R., Doumatey, A. P., Chen, G., Shriner, D., & Adeyemo, A. (2017). The genomic landscape of African populations in health and disease. *Human Molecular Genetics.* 26, R225–R236. doi:10.1093/hmg/ddx253

The Genomic Data Science Community Network (2022). Diversifying the genomic data science research Community. *Genome Research* 32: 1231–1241. doi: 10.1101/gr.276496.121

Weckwerth W. (2011). Green systems biology - From single genomes, proteomes and metabolomes to ecosystems research and biotechnology. *Journal of Proteomics* 10:75(1):284-305. doi: 10.1016/j.jprot.2011.07.010. Epub 2011 Jul 23. PMID: 21802534.

Xue, J., Zhao, S., Liang, Y., Hou, C., & Wang J. (2008). Bioinformatics and its Applications in Agriculture. In: Li D, editor. Computer and Computing Technologies *In Agriculture*, Volume II. Springer US. 977–982.

(Manuscript received: June 17, 2025; accepted: March 11, 2026).