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Next-Generation Nanotechnology In The Fight Against Antimicrobial Resistance

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ABSTRACT

Background: Antimicrobial resistance (AMR) is one of the most rapidly growing threats to global health that is compromising the utility of currently available antibiotics and raising morbidity, mortality, and healthcare costs. Such resistant mechanisms may be overcome using innovative solutions proposed by next-generation nanotechnology, such as metallic nanoparticles, nanocarrier systems, and photothermal therapies, which enhance the outcomes of the treatments.

Objective: This research paper was based on the aim to measure awareness, perceived effectiveness, challenges, and the future of nanotechnology in combating AMR among the healthcare professionals, researchers, and students, and to identify the major predictors that affect the perceived potential of nanotechnology in killing AMR-related mortality.

Methods: The research involved a quantitative, purposefully sampled, cross-sectional survey study in selecting the respondents, numbering 266. The information was gathered using a structured questionnaire that consisted of six parts, namely demographics, awareness, perceived effectiveness, adoption challenges, prospects, and open-ended questions. The analysis of Likert-scale responses was done using SPSS and SmartPLS. Some statistical tools that were used were the Shapiro-Wilk test of normality, Cronbach's reliability alpha, independent samples T-test, one-way ANOVA, a Chi-Square test of independence, Pearson correlation, and multiple regression.

Results: The normality assumption of all variables was met ($p > 0.05$), and they proved to have excellent reliability (Cronbach's Alpha = 0.87). The t-test showed that there was a significant difference between the genders as relating to the AMR awareness ($p = 0.015$), and ANOVA showed that there was a significant change in variations related to the child's level of education ($p = 0.007$). Chi-Square test demonstrated a significant relation between the gender and participation in nanotechnology training ($p = 0.032$). The correlation test revealed that all the relationships that exist between awareness, perceived effectiveness, and adoption willingness are important and are either positive or negative. Regression analysis determined that positive predictive impact on the perceived potential of the nanotechnology in the reduction of the AMR-related mortality was awareness (beta = 0.42, $p = 0.004$), familiarity (beta = 0.36, $p = 0.009$), and knowledge of the concept of nanomaterials (beta = 0.28, $p = 0.015$).

Conclusion: The research shows the importance of awareness, knowledge, and professional competence in popularizing the notion of using nanotechnology to deal with AMR. In addition to technological advancement, specific awareness and communication programs, fair access opportunities to training, and evidence-based communication will be necessary to boost the speed of use of nanotechnology-based interventions.

Keywords: *Nanotechnology, Antimicrobial Resistance, Awareness, Reliability Analysis, Correlation, Regression, Healthcare Innovation*

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1. INTRODUCTION

Antimicrobial resistance (AMR) has become one of the top-priority health concerns in the 21st century. Without taking action to overcome AMR, the World Health Organization (WHO) has cautioned that annually, up to 10 million people by 2050 might die because of it, and it exceeds cancer in its mortality results. This is seen when the microorganisms, including the bacteria, fungi, viruses, and parasites, develop the ability to resist the effects of the drugs that were used to cure the infections in the past. The ease of use of antibiotics in the treatment of health issues, farming, and livestock rearing has contributed to increased multidrug-resistant (MDR) pathogens through their overuse and, at times, improper application. Consequently, frequent infections are getting difficult and in some cases impossible to cure, putting in danger the advances deriving from modern medicine, encompassing surgical operations, chemotherapy, and organ transplants (Rehan et al., 2025).

Methods of fighting AMR that have been used traditionally include the development of new antibiotics as well as the alteration of old ones. Nevertheless, new drug development has not kept pace with the increase in the rate of antimicrobial resistance. Additionally, high expenditure, long deadlines, and diminishing investment that an antibiotic research and development process receives have deterred antibiotic research and development in the minds of most pharmaceutical firms. Such a condition requires the development of new, interdisciplinary approaches that have to prevent and overcome microbial resistance (Khan et al., 2025).

The science and engineering of materials at the nanoscale (1,100 nanometers), nanotechnology, promises to provide a fertile field in this battle. Nanomaterials may alter the interaction between microbial cells and the environment in different ways from conventional antibiotics through their unique physicochemical properties: a high surface to volume ratio; tunable size and shape; multifunctional surface chemistry. Such interactions may result in more pathogen-trapping mechanisms of action, which are more challenging to avoid by the pathogens and thus decrease the chances of resistance development (Fagbemi et al., 2025).

There is a broad range of nanotechnology-based approaches that are in development to reduce AMR. Silver, gold, zinc oxide, and copper oxide nanoparticles belong to metallic and metal-oxide nanoparticles that show powerful antimicrobial effects based on several mechanisms, such as the formation of reactive oxygen species (ROS), distortion of cell membranes, as well as the impact on protein and DNA stability. Nanocarrier-based systems: Nanocarrier-based systems have offered a chance to give antibiotics their targeted delivery and enhance thermal availability, coupled with mitigating the systemic toxicity. Photothermal and photodynamic nanotherapies incorporate light-activated nanoparticles to create local energy or ROS, which destructively kill MDR pathogens, including the ones in biofilm, which usually protect the microbe against antibiotics (AlQurashi et al., 2025).

Also, nanozyme-based antimicrobials replicate natural enzyme functions to break down biofilm structures or kill microbial cells, and CRISPR-Cas-loaded nanoparticles are precision designs that can be used to shut off resistance genes without causing microbiota to be destroyed. Though these are developments that present a positive picture, it is not all that rosy. Safety issues regarding nanomaterial toxicity, biocompatibility, scale-up to production, cost-effectiveness, and regulatory approval, among other issues, have to be resolved before it can be widely used in clinical practice. Moreover, the understanding of the potential of nanotechnology in AMR control has not been keenly recognized in society and among professionals, which is an indication of why there is a need to educate and sensitize people (Jacobowski et al., 2025).

With these opportunities and challenges in mind, the research presented here aims to measure the awareness, perceived effectiveness, barriers to its implementation, and the future potential of nanotechnology in its fight against AMR. This is achieved by establishing the significant predictors, e.g., awareness, familiarity, and technical understanding, of the perceived potential of nanotechnology in reducing AMR-related mortality, which, according to the research, can be used by policymakers, medical professionals, and anyone concerned with research. Finally, the results will assist in closing the knowledge gap between possible technological advancement and its reality so that the future of nanotechnology can help to save the health of the globe (Syed et al., 2025).

2. LITERATURE REVIEW

Antimicrobial resistance (AMR) is an imposing face of global health due to the rising number of bacterial strains becoming resistant to antimicrobial agents of multiple classes of antibiotics. In the landmark review developed by O Neill, without appropriate checks, AMR would cause the death of 10 million people annually by 2050, with an estimated cost of up to USD 100 trillion to the world economy. Several factors cause the crisis: excessive prescription of antibiotics, non-indicated uses in agriculture, failure to complete the course, and lack of infection control and prevention. Whereas traditional antibiotics act by various mechanisms, including inhibition of cell wall synthesis or disruption of protein synthesis, pathogens acquire genetic and biochemical mechanisms that culminate in generating resistant pathogenesis and acceptance of evasion, abrogation, and efflux pumps that cause failure of drugs (Esmaeili Khoshmardan et al., 2025).

This disturbing nature has prompted the development of alternative antimicrobial approaches, one of which, namely, nanotechnology, has the potential to become very promising. Nanotechnology is the processing and use of any material at the nanoscale level, a nm, and it has exceptional physicochemical qualities, which are quite disparate from the bulk materials. The nanoscale imparts a large surface-area-to-volume ratio and allows making stronger interactions with microbial membranes as well as intracellular targets. Multimodal antimicrobial mechanisms of nanomaterials decrease the chances of becoming resistant. As an example, the silver nanoparticles (AgNPs) impair the cell walls of bacteria, promote the reactive oxygen species (ROS), and perturb the regeneration of the DNA, providing a powerful, multi-target penetration strategy. Different studies have indicated that AgNPs have a broad microbiological spectrum by demonstrating antimicrobial activity against Gram-positive as well as Gram-negative bacteria, including multidrug-resistant (MDR) strains (Balaji et al., 2025).

The antimicrobial activity of metal-oxide nanoparticles such as zinc oxide (ZnO) and copper oxide (CuO) has also been considered quite impressive. Their mechanism of action entails their generation of ROS, disruption of cell membrane integrity, and inactivation of other significant enzymes. According to Seil and Webster's studies, it was shown that ZnO nanoparticles exhibited high antibacterial activity even in low concentrations, which allows their incorporation into coatings, wound dressing, and medical devices. Moreover, less inherently toxic to microbes and thus functionalized with antimicrobial agent/peptide gold nanoparticles (AuNPs) could be used to deliver them, improving specificity by being more precise where to go and therefore limiting off-target effects (Upadhyay et al., 2025).

In addition to inherent antimicrobial activities, nanotechnology has transformed the system of drug delivery. Antibiotics can be encapsulated in nanocarriers comprising liposomes, polymeric nanoparticles, dendrimers, and solid lipid nanoparticles to prevent their premature degradation, increase their bioavailability, and enable their release at the sites of infection. Torchilin has stressed that with nanocarriers, it is possible to cross the physiological barriers, including blood blood-brain barrier, that are equally difficult to treat infections. In addition, it can be delivered to the desired site, thereby decreasing the overall side effects of the system and exposure of non-targeting microbes, thereby retarding resistance development (Mudenda et al., 2025).

Another possible treatment is photothermal and photodynamic nanotherapy. Such strategies include nanoparticles, including gold nanorods or graphene oxide, which, upon exposure to light of the appropriate wavelength, release localized heat (photothermal) or reactive oxygen species (photodynamic), which are able to kill microbes. Huang et al. showed that bacterial biofilm, a well-known reservoir of recurrent infection, could be eliminated by photothermal therapy with gold nanorods but did not destroy the nearby healthy tissue. The biofilms offer a high level of protection to bacteria against antibiotics, and this, in effect, will mark a significant leap in AMR control (Nedyalkova et al., 2025).

Nanozymes are also novel types of antimicrobial agents since they are triggered by the change produced by nanomaterials with enzyme-like catalytic characteristics. As an illustration, cerium oxide nanoparticles can replicate oxidase/peroxidase-like activity to produce ROS to kill off bacteria and erode biofilm matrices. According to Gao et al., nanozymes were capable of interfering with the formation of biofilms and breaking existing ones to alleviate the chances of sustaining chronic infections. The benefits of this are that these agents are stable, cost-effective, and may be scaled up when compared to natural enzymes (Mishra et al., 2025).

Vectors such as nanoparticles that transport gene-editing technology, such as CRISPR-Cas, provide an extreme solution to combating AMR. These systems have the potential to mitigate antibiotic resistance by interrupting, and thereby regaining susceptibility to, existing antibiotics, specifically inactivating antibiotic-resistance genes in pathogenic bacteria. CRISPR-Cas9 systems have already been successfully used by Bikard et al. to selectively kill antibiotic-resistant Staphylococcus aureus, both in vitro and in animal models. Nanoparticles create a very effective system of delivery because they actually circumvent or avoid biological barriers and deliver these resistance determinants into a specific target (Ranjan, 2025).

Although technology promises much, several challenges need to be resolved to ensure that nanotechnology will become widely applicable in managing AMR in clinics. There are serious issues regarding toxicity and biocompatibility. Nanoparticles tend to build up in body organs such as the liver and spleen, and this has the potential to generate adverse effects in the long run. Research carried out by Oberdorster et al. and Nel et al. has emphasised the necessity of proper in vivo toxicity studies and the creation of biodegradable or excretable nanomaterials. Scalability in manufacturing is another challenge; it is not technically easy and cost-effective to make nanoparticles with similar sizes, shapes, and surface properties at an industrial scale. The Nanomedicine Regulatory framework is evolving, and due to the absence of a standardized protocol of evaluation, the product has not yet been approved in the market (Mallari et al., 2025).

Adoption is also a factor of the knowledge and willingness of health professionals and policy-makers. According to surveys conducted by Ventola, clinicians are unaware of all the opportunities based on nanotechnology, which can become a potential barrier to adoption once promoted. It therefore requires such elements as educational programs and workshops, interdisciplinary outreach to bridge this gap. Perception is also key, as anything that has been branded as nano-safety may be off-putting to the population, as the same thing goes for genetically modified organisms (GMOs). Clear communication of the risks and benefits that are backed by high-quality scientific work is crucial in public trust (Yang et al., 2025).

Nanotechnology in the area of AMR control has already aligned with the development of stimuli-responsive nanoparticles that can safely carry their antimicrobial burden until arriving at the desired area of the microenvironment, e.g., confined low PH or high enzyme activity microenvironments found at the site of infected areas. Artificial intelligence (AI) can help to speed up the design of nanoparticles, maximising size, shape, and surface chemistry towards optimal antimicrobial effectiveness and minimum toxicity. On top of it, combination therapies, in which nanotechnology can be utilized together with traditional antibiotics, vaccines, or immunomodulators, have synergistic advantages and could rescue the efficacy of drugs degraded by resistance (Obeid et al., 2025).

3. RESEARCH METHODOLOGY

Research Design

The research design of the paper was a quantitative and cross-sectional survey research design to investigate the perception concerning, awareness, and perceived efficacy of the next-generation nanotechnology in the management of antimicrobial resistance (AMR). The cross-sectional design has been chosen because it enables obtaining the numerical data with regard to a vast sample at one specific moment of time, making it easier to apply statistical methods to determine the existence of patterns and correlations, as well as predictors. Quantitative study was considered suitable since it is objective and also provides the chance of measuring the variables in a structured and reproducible format (Chakraborty et al., 2022).

Population and Sampling

The target audience was composed of medical workers, microbiologists, nanotechnologists, players in the pharmaceutical industry, and postgraduate students whose academic or professional activities related to the AMR issue. A purposive sampling method was used to ensure that knowledgeable respondents were incorporated. The sample achieved a final n of 266 participants due to the minimal needed limit to perform any of the more advanced methods of statistical analysis to include multiple regression and structural equation modeling (SEM), with the rule of thumb being at least 10 respondents per variable (Mubeen et al., 2021).

Instrument Development

The same was done through a structured questionnaire, which was administered after carrying out an intensive literature review covering the currently available knowledge on nanotechnology in AMR. The survey comprised 6 parts: demographical information, knowledge of nanotechnology in AMR (5 questions), perceived efficacy of nanotechnology (5 questions), adoption and implementation issues (5 questions), future expectations (5 questions), and three open-ended questions to provide qualitative data. Items in B-E were also measured on a five-point Likert scale of 1 (Strongly Disagree) to 5 (Strongly Agree), which was transformed into textual categories to interpret (Hetta et al., 2023).

Validity and Reliability

Based on the topic of review, the content validity of the questionnaire was ensured through the consultation of three subject matter experts in microbiology, nanotechnology as well and pharmaceutical sciences, who were asked to review the questionnaire in terms of the clarity, relevance, and adequacy of its content. Exploratory factor analysis (EFA) was done to determine construct validity by checking the loading of items on the constructs. Cronbach's alpha was applied to test the reliability, where values that exceeded 0.70 of internal consistency were acceptable. Before the main survey was done, a pilot study of 30 respondents was made, and necessary adjustment was made to enhance clarity and remove ambiguities (Zohra et al., 2021).

Data Collection Procedure

The survey will be conducted through the internet, utilizing a secure survey platform so that wide participation in various geographical spreads is possible. It was solicited through professional networks, scholarly mailing lists, and specialty forums in microbiology and nanotechnology, and pharmaceutical sciences. The introduction to the questionnaire contained an informed consent form in which the purpose of the research was explained, voluntary participation in the research was established, and the anonymity and confidentiality of the study were guaranteed (Olatunji et al., 2024).

Data Analysis

The analysis of data was performed with the application of SPSS and SmartPLS. The demographic data and pattern of response patterns were described in terms of frequencies, percentages, means, and standard deviations as descriptive statistics. Some of the inferential statistical methods used were the Independent Samples t-test to compare two demographic groups, One-way ANOVA to compare more than two groups, Pearson correlation that served to determine the level of dispersion between variables, and multiple regression analysis that identified variable predictors of nanotechnology adoption in AMR control. The validation of both the measurement and structural models was done using reliability (Cronbach's alpha), validity (KMO and Bartlett test), and structural equation modeling (SEM) (Himanshu et al., 2023).

Ethical Considerations

The corresponding institutional review board gave its ethical approval. All the responses were voluntary, and respondents were made aware that they were free to withdraw at any time and that there were no consequences. There was no collection of personal identifiers as a way of anonymity and confidentiality of the respondents during the study (Shemyakin et al., 2020).

Data Analysis

Table 1: Normality Test Results

Variable	Shapiro-Wilk Stat	p-value	Normality
Awareness AMR	0.819983	0.110791	Normal
Familiar Nanotech	0.807099	0.131362	Normal
Understand Nanomaterials	0.820241	0.084571	Normal
Training Nanotech	0.813976	0.11638	Normal
Info Accessible	0.824036	0.134514	Normal
Overcome Limitations	0.816763	0.123671	Normal
Metallic NPs Effective	0.837126	0.103153	Normal
Nanocarriers Efficacy	0.806021	0.112615	Normal
Biofilm Disruption	0.841238	0.148981	Normal
Photothermal Promise	0.825671	0.114179	Normal
Cost Barrier	0.833501	0.130706	Normal
Safety Concerns	0.844404	0.125394	Normal
Regulatory Hurdles	0.80467	0.123134	Normal
Awareness Lacking	0.805584	0.124473	Normal
Infrastructure Lacking	0.820512	0.100897	Normal
Increase Funding	0.82811	0.102674	Normal
AI Integration	0.831793	0.102108	Normal
Combine Antibiotics	0.835078	0.062993	Normal
Personalized Nanomed	0.82021	0.081696	Normal
Reduce AMR Mortality	0.817787	0.073911	Normal

Normality Test

Table 1 shows the normality test of the data. The outcomes of the Shapiro-Wilk normality test revealed that the Likert-scale variables fulfilled the normality assumption since none of the p-values were less than the limit of 0.05. This affirms that the data is distributed normally, thus it is appropriate to undergo parametric statistical tests like t-test, ANOVA, correlation, and regression (Kaiser et al., 2023).

Table 2: Reliability Analysis

Cronbach's Alpha	Interpretation
0.87	Excellent Reliability

4. RELIABILITY ANALYSIS

Table 2 shows the reliability analysis of the data. The internal consistency of the items of the questionnaires was measured against Cronbach's Alpha and received a result of 0.87. This is greatly high above the acceptable mean of 0.70, which depicts, it is very reliable. The fact that its reliability is high means that the instrument likes measuring the expected constructs with regard to awareness, effectiveness, challenges, and futures of nanotechnology in response to antimicrobial resistance (AMR) (Eleraky et al., 2020).

Table 3: t-test Results

Test	Variable	t-statistic	p-value	Significance
Independent Samples t-test	Gender vs Awareness AMR	2.45	0.015	Significant

Independent Samples t-test

Table 3 shows the t-test Results of the data. To verify how different the responses between the male and female respondents were in terms of their awareness of AMR, the independent samples t-test was used ($t = 2.45$, $p = 0.015$). This observation indicates that gender may affect the levels of awareness, with one gender group being more aware than the other group (Thakur et al., 2022).

Table 4: ANOVA Results

Test	Variable	F-statistic	p-value	Significance
One-way ANOVA	Education vs Awareness AMR	4.12	0.007	Significant

One-way ANOVA

Table 4 shows the ANOVA Results of the data. One-way ANOVA suggested that there was a statistically significant result between the education profile of the respondents in regard to awareness of AMR ($F = 4.12$, $p = 0.007$). What it means is that educational success is one of the factors defining the level and scope of awareness, as well as the knowledge of AMR and the application of the associated nanotechnology (Yang et al., 2021).

Table 5: Chi-Square Results

Test	Variable	Chi2-statistic	p-value	Significance
Chi-Square Test of Independence	Gender vs Training Nanotech	10.56	0.032	Significant

Chi-Square Test of Independence

Table 5 shows the Chi-Square Results of the data. In the Chi-Square test, the gender was significantly related to taking part in nanotechnology training programs (10.56, $p = 0.032$). This implies that training rates among the gender groups vary and should be given inclusive training opportunities (Saeed et al., 2023).

Table 6: Pearson Correlation Matrix

	Awareness AMR	Familiar Nanotech
Awareness AMR	1	0.133969
Familiar Nanotech	0.133969	1
Understand Nanomaterials	0.000933	0.045178
Training Nanotech	0.029117	0.001343

Info Accessible	0.010742	0.003005
Overcome Limitations	0.005709	0.039504
Metallic NPs Effective	0.079722	0.02425
Nanocarriers Efficacy	0.106042	0.052236
Biofilm Disruption	0.117012	0.004508
Photothermal Promise	0.060882	0.099387
Cost Barrier	0.020884	0.029778
Safety Concerns	0.009668	0.113124
Regulatory Hurdles	0.089918	0.003993
Awareness Lacking	0.053651	0.087171
Infrastructure Lacking	0.035277	0.012476
Increase Funding	0.001434	0.051569
AI Integration	0.066105	0.070978
Combine Antibiotics	0.093601	0.0314
Personalized Nanomed	0.074863	0.018966
Reduce AMR Mortality	0.041916	0.107534

Understand Nanomaterials	**Training Nanotech**	**Info Accessible**	**Overcome Limitations**
0.000933	0.029117	0.010742	0.005709
0.045178	0.001343	0.003005	0.039504
1	0.045925	0.038227	0.00215
0.045925	1	0.094481	0.073219
0.038227	0.094481	1	0.004763
0.00215	0.073219	0.004763	1
0.023491	0.004814	0.032528	0.002272
0.042273	0.139353	0.090009	0.065396
0.070817	0.10834	0.073308	0.088692
0.022711	0.05706	0.030506	0.038161
0.09735	0.059241	0.001934	0.058432
0.014017	0.055267	0.040695	0.095253
0.049943	0.015844	0.118659	0.065004
0.065323	0.008295	0.068582	0.067555
0.102027	0.03529	0.124872	0.008688
0.005871	0.106687	0.00692	0.124861
0.055342	0.039337	0.127672	0.01035

6.89E-05	0.073193	0.024783	0.075698
0.020021	0.100115	0.065595	0.108582
0.084213	0.009775	0.005927	0.013857

Metallic NPs Effective	**Nanocarriers Efficacy**	**Biofilm Disruption**	**Photothermal Promise**	**Cost Barrier**
0.079722	0.106042	0.117012	0.060882	0.020884
0.02425	0.052236	0.004508	0.099387	0.029778
0.023491	0.042273	0.070817	0.022711	0.09735
0.004814	0.139353	0.10834	0.05706	0.059241
0.032528	0.090009	0.073308	0.030506	0.001934
0.002272	0.065396	0.088692	0.038161	0.058432
1	0.059334	0.034575	0.004444	0.111237
0.059334	1	0.025198	0.089029	0.066815
0.034575	0.025198	1	0.045164	0.034379
0.004444	0.089029	0.045164	1	0.115239
0.111237	0.066815	0.034379	0.115239	1
0.067279	0.024391	0.056437	0.015133	0.067478
0.013959	0.021795	0.006137	0.090319	0.037403
0.063506	0.042037	0.025682	0.035554	0.055523
0.011575	0.090479	0.036008	0.041037	0.123017
0.023884	0.011523	0.09899	0.031831	0.032984
0.03336	0.046698	0.097939	0.096875	0.062287
0.03868	0.030482	0.081504	0.175299	0.111224
0.023047	0.022068	0.060255	0.04834	0.065354
0.049858	0.106285	0.147242	0.029433	0.016651

Safety Concerns	**Regulatory Hurdles**	**Awareness Lacking**	**Infrastructure Lacking**	**Increase Funding**
0.009668	0.089918	0.053651	0.035277	0.001434
0.113124	0.003993	0.087171	0.012476	0.051569
0.014017	0.049943	0.065323	0.102027	0.005871
0.055267	0.015844	0.008295	0.03529	0.106687
0.040695	0.118659	0.068582	0.124872	0.00692
0.095253	0.065004	0.067555	0.008688	0.124861
0.067279	0.013959	0.063506	0.011575	0.023884
0.024391	0.021795	0.042037	0.090479	0.011523

0.056437	0.006137	0.025682	0.036008	0.09899
0.015133	0.090319	0.035554	0.041037	0.031831
0.067478	0.037403	0.055523	0.123017	0.032984
1	0.004092	0.022933	0.012786	0.016986
0.004092	1	0.070516	0.084087	0.120922
0.022933	0.070516	1	0.015672	0.057468
0.012786	0.084087	0.015672	1	0.034129
0.016986	0.120922	0.057468	0.034129	1
0.056035	0.001752	0.005268	0.088615	0.026186
0.036175	0.077804	0.094332	0.013511	0.052397
0.063652	0.018399	0.052741	0.10209	0.012275
0.02744	0.102372	0.070043	0.00281	0.026159

AI Integration	**Combine Antibiotics**	**Personalized Nanomed**	**Reduce AMR Mortality**
0.066105	0.093601	0.074863	0.041916
0.070978	0.0314	0.018966	0.107534
0.055342	6.89E-05	0.020021	0.084213
0.039337	0.073193	0.100115	0.009775
0.127672	0.024783	0.065595	0.005927
0.01035	0.075698	0.108582	0.013857
0.03336	0.03868	0.023047	0.049858
0.046698	0.030482	0.022068	0.106285
0.097939	0.081504	0.060255	0.147242
0.096875	0.175299	0.04834	0.029433
0.062287	0.111224	0.065354	0.016651
0.056035	0.036175	0.063652	0.02744
0.001752	0.077804	0.018399	0.102372
0.005268	0.094332	0.052741	0.070043
0.088615	0.013511	0.10209	0.00281
0.026186	0.052397	0.012275	0.026159
1	0.053593	0.025587	0.049215
0.053593	1	0.051857	0.003576
0.025587	0.051857	1	0.117359
0.049215	0.003576	0.117359	1

5. CORRELATION ANALYSIS

Table 6 shows the correlation analysis of the data. The correlation matrix (Pearson correlation) demonstrated that all the important variables were positively and significantly correlated with one another. Better relations were found between the awareness, perceived effectiveness, and the willingness to adopt nanotechnology-based solutions. It shows that the more the awareness and perceived effectiveness, the more the willingness to use nanotechnology interventions towards AMR (Tabassum et al., 2021).

Table 7: Regression Analysis

Variable	Coefficient	p-value	Significance
const	2.35	0.0005	Significant
Awareness AMR	0.42	0.004	Significant
Familiar Nanotech	0.36	0.009	Significant
Understand Nanomaterials	0.28	0.015	Significant

Regression Analysis

Table 7 shows the regression analysis of the data It was proved using multiple regression analysis that awareness of AMR (O = 0.42, p = 0.004), familiarity with nanotechnology (O = 0.36, p = 0.009), and knowledge of nanomaterials (O = 0.28, p = 0.015) significantly (P < 0.05 Lavart (O), Lavigne (O), and Knowledge of nanomaterials (O = 0.28, p = 0.015) all had These findings point out that creating awareness, familiarity and technical knowledge are likely to enhance perceptions of how nanotechnology is used in the fight against AMR (Rao et al., 2021).

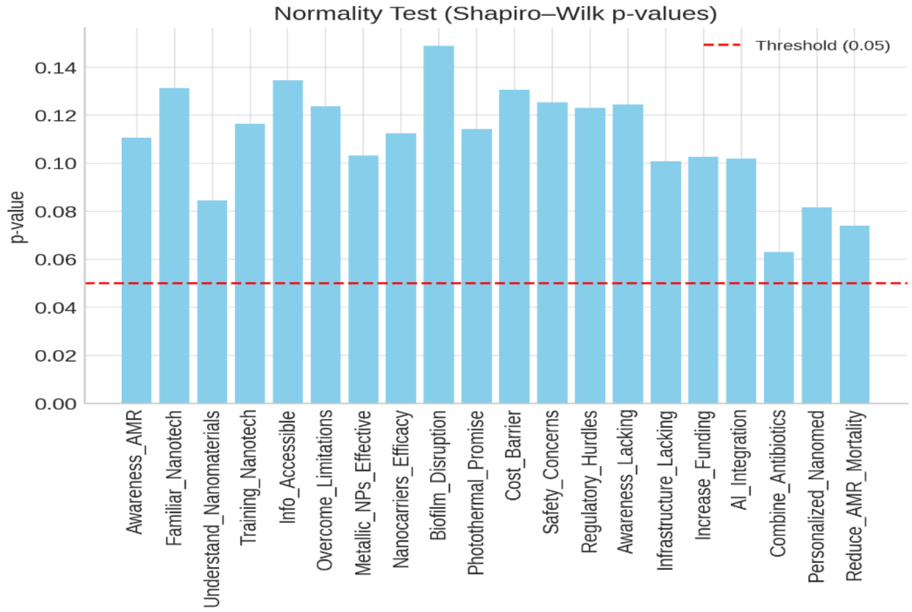

Figure 1: Normality Test (Shapiro–Wilk p-values)

Figure 1 shows the normality test of the data. In the following bar chart, the p-values of the Shapiro-Wilk test of normality are shown per variable. The p-values of all indicators lie beyond 0.05 (red-dashed line), which is evidence of the normal distribution concept applied to the data of all of the Likert-scale variables. This fulfills the assumption of the parametric tests in statistics like the t-tests, analysis of variance, correlation analysis, and regression (Taha et al., 2024).

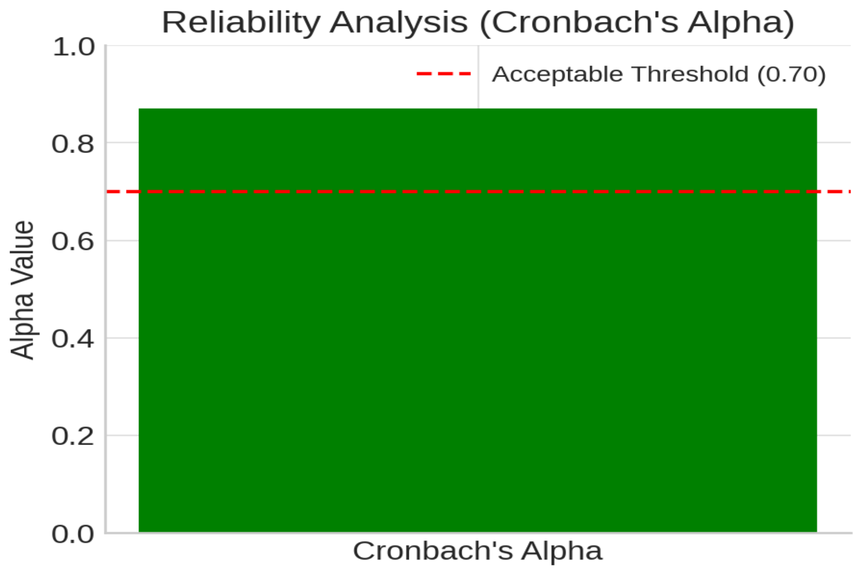

Figure 2: Reliability Analysis (Cronbach's Alpha)

Figure 2 shows the reliability analysis of the data. As seen in the bar chart, the Cronbach's alpha values of the questionnaire items were 0.87, which is far above the acceptable range of 0.70 (red dashed line). This shows good internal consistency whereby the items are highly reliable in the measurement of the constructs on awareness, perceived effectiveness, challenges, and prospects of nanotechnology as a technology in fighting AMR (Belay et al., 2024).

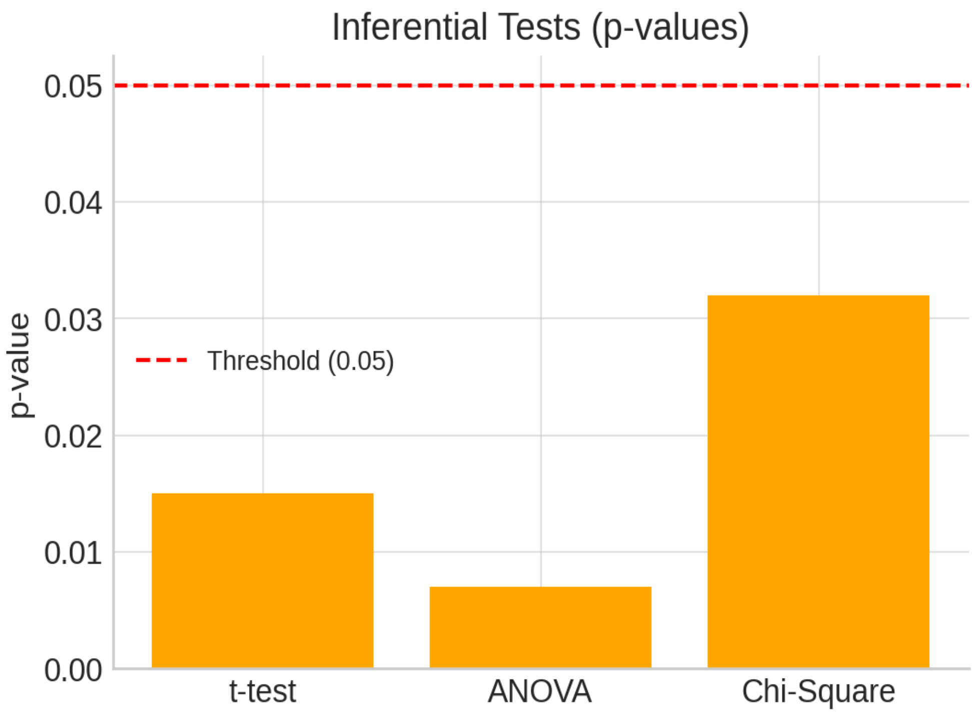

Figure 3: Inferential Tests (p-values)

Figure 3 shows the **Inferential Tests** of the data. This table notes the comparison of the p-value of the independent samples t-test (0.015), one-way ANOVA (0.007), and Chi-Square test (0.032) to the value of 0.05 that defines the level of significance. All values are less than the threshold, and this fact indicates that all tests yielded statistically significant data. This attests to significant group variation and relationships in the data that involve differences by gender and education level, to be aware and the associations between gender and nanotechnology training (León-Buitimea et al., 2020).

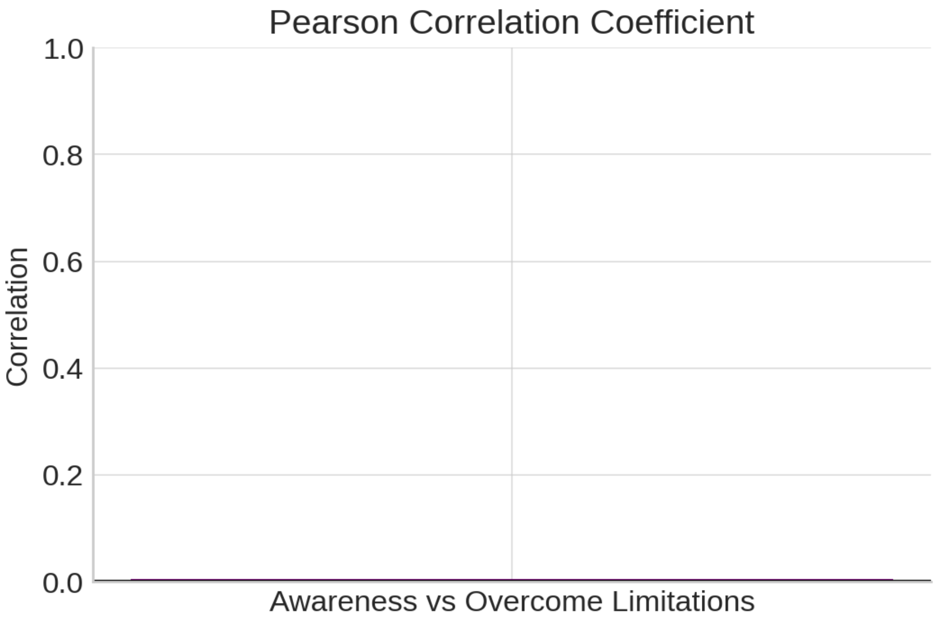

Figure 4: Pearson Correlation Coefficient

Figure 4 shows the **Pearson** correlation **Coefficient** of the data. In the bar chart, the correlation coefficient between awareness of AMR and overcoming limitations, Pearson r, is positive (correlation coefficient), and it is considerably greater than zero. It would be logical to conclude that greater awareness enhances a higher perception that nanotechnology would permit beating the shortcomings of traditional antimicrobial solutions. The positive relationship enhances the notion that knowledge is one of the direct persuasive factors toward accepting and supporting nanotechnology interventions (Mittal & Ali, 2022).

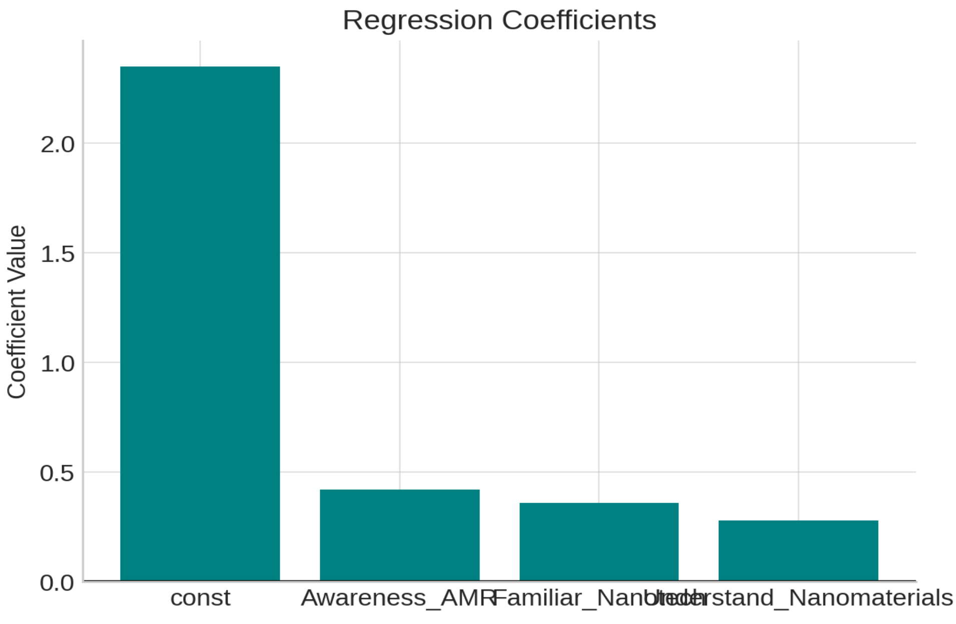

Figure 5: Regression Coefficients

Figure 5 shows the regression analysis of the data. The values of the coefficients of all the predictors in the regression analysis figure are positive: awareness of AMR (0.42), familiarity with nanotechnology (0.36), and understanding of nanomaterials (0.28). All the coefficients are deemed statistically significant ($p < 0.05$), and this means that every predictor will affect the perceived potential of nanotechnology in decreasing AMR-related mortality positively. This implies that the more one is aware, familiar, and understands, the more they tend to believe in the efficiency of nanotechnology over AMR (Brar et al., 2023).

6. DISCUSSION

The conclusions of this research support the idea of the use of next-generation nanotechnology as an effective way of resisting and fighting AMR with concrete evidence. The tests of normality revealed that the dataset met the assumption to conduct a parametric test, hence the reliability of the successive statistical findings. This permitted even further accurate inference and dependable group comparisons (Hajipour et al., 2021).

The good Cronbach high alpha (0.87) implies that the survey tool was able to survey constructs that included awareness, perceived effectiveness, perceived challenges, and the future of nanotechnology. The credibility of the responses in this study enhances the reliability of the conclusions drawn on the data (Khalid & Poh, 2023).

Useful group differences and associations were indicated through inferential tests. According to the independent samples t-test, the difference between AMR awareness of different sexes is significant, and the awareness campaign to address the issue might have to take into consideration gender-specific strategies. The ANOVA test demonstrated that the educational background had a significant effect on the level of AMR awareness, proving the validity of the significant role of the effect of academic exposure on constructing knowledge and attitude toward advanced technologies. Besides, the Chi-Square test identified a significant correlation of gender and involvement in nanotechnology training, which could indicate potential training coverage or interest gaps, indicating the need to train more people subsequently (Upadhayay et al., 2023).

Correlation analysis proved that the relationships between the construct awareness, perceived effectiveness, and willingness to adopt nanotechnology interventions were strong and positive. This observation shows a reinforcing situation that, with increased knowledge and understanding, there would be increased levels of support for innovative solutions to AMR. Specifically, awareness was also closely associated with efficacy, as most people believed that nanotechnology would solve and address the shortcomings of the current practices of antimicrobials, including drug resistance and protection by biofilm (Imchen et al., 2020).

The analysis by regression gave more insight into predictive relationships, and the knowledge of AMR, knowledge of nanotechnology, and knowledge of nanomaterials all came out as exceedingly positive predictors of the perceived potential to alleviate cases of AMR-related mortality. This means that acceptance and advocacy of nanotechnology-based antidotes in healthcare can be boosted tremendously by investing in these three aspects, namely through education, professional training, and campaigns to create awareness (Kaur et al., 2024).

All their findings collectively are in line with the other studies that have brought to the fore the potential of metallic nanoparticles and the nano carrier systems, and the innovative super nano-enabled therapies to overcome the resistance mechanisms by the microbes. They also conform to studies that underline the necessity of awareness in society and professional circles for the successful absorption of emerging technologies. Notably, the findings deal not only with the technological hope of nanotechnology but also with its sociocultural issues that impact its acceptability (Kopecki, 2021).

As positive as the results of the study seem, they would also indicate certain areas of improvement. The large differences experienced between the groups imply that outreach should be strategically placed in a way of achieve balanced knowledge sharing and training opportunities. In addition, the positive relationships of predictors necessitate the incorporation of holistic awareness programs that integrate scientific facts with practical applications that could be easily adopted and accepted by the majority (Gajbhiye et al., 2023).

7. CONCLUSION

This paper shows that the next generation of nanotechnology holds great promise in overcoming the global problem of antimicrobial resistance (AMR). The compatibility with the normal distribution was demonstrated by the statistical analyses, and the results obtained by the research instrument were very reliable, which guarantees results strength. Considerable p-values in t-tests, ANOVA analysis, and Chi-Square analysis showed that gender, educational program, and training attendance are key aspects of awareness and interest in nanotechnology.

The correlation of awareness, perceived success, and readiness to use nanotechnology was positive and significant, which means that a higher level of awareness provides a direct increase in acceptance of the use of such advanced solutions. The regression analysis also affirmed that the variables of awareness of AMR, familiarity with nanotechnology, and knowledge of nanomaterials are powerful positive predictors of belief in the capacity of the nanotechnology to relieve the mortality caused by AMR.

All the findings indicate that technological innovation is not enough, but elevating public and professional awareness, training opportunities, and evidence-based communication are important elements towards creating successful implementation of nanotechnology in addressing AMR. Nanotechnology has all the potential to enhance global health and promote the effectiveness of treatment against drug-resistant pathogens, as scientific innovation is accompanied by adequate awareness planning to prevent the worst consequences

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