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Comprehensive assessment of Indonesian Pharmacy Student's knowledge and perceptions of nanotechnology and its practical applications in pharmaceutical sciences

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ABSTRACT

Integrating nanotechnology education within the pharmacy curricula is essential for advancing pharmaceutical sciences. Nanotechnology is a key to innovations in drug delivery systems, diagnostics, and therapeutics. This study aimed to assess the awareness and understanding of nanotechnology lectures among Indonesian pharmacy students and examine the influence of demographic factors such as gender, type of university, and educational levels. Performed as an observational cross-sectional study design, data were collected from 486 students across various Indonesian universities using a validated questionnaire. The results showed that most participants were young (97.5% aged 20–25) and female (78.0%), with most enrolled in private universities (56.3%) and undergraduate programs (90.0%). Awareness levels were generally low, with 55.3% reporting poor knowledge and 21.2% having no knowledge. Significant gender differences were observed with female students confirming lower awareness levels. Undergraduate students represented higher awareness compared to professional degree students. Primary sources of information included media, academic courses, and self-reading. The findings outline the urgent need for integrating comprehensive nanotechnology education into pharmacy curricula to better prepare students for future advancements. Addressing these educational gaps is essential to ensure that pharmacy graduates are well-equipped to navigate the evolving landscape of pharmaceutical sciences.

INTRODUCTION

Integrating nanotechnology knowledge into pharmacy curricula is critical for developing pharmaceutical sciences. Nanotechnology, literally defined as the use of nanoscale materials (typically between 1 and 100 nanometers), is essential in the innovation of drug delivery systems, diagnostics, and therapeutics [1]. The integration of nanotechnology education equips the pharmacy students with essential knowledge and skills, enabling them to contribute effectively to the field upon entering the professional workforce. As highlighted in this study, despite the increasing number of nanotechnology-based pharmaceutical products on the market, a significant portion of pharmacy students lack adequate knowledge of this scientific field [2]. This gap underscores the necessity for dedicated courses within the pharmacy curriculum to ensure students are well-versed in both theoretical and practical aspects of nanotechnology.

Globally, there is a concerted effort to incorporate nanotechnology subject into pharmacy education. Various universities have adopted diverse approaches to embed this subject into their curricula. For instance, some institutions have designed specialized courses that include extensive laboratory experiments, providing hands-on experience with nanotechnology applications [3]. Such initiatives are crucial for fostering a

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deeper understanding of the subject and enhancing the student's practical skills. Furthermore, elective courses on nanotechnology subject, as discussed in this previous study [4], are increasingly introduced to improve teacher's qualifications and prepare them to effectively teach this complex subject. This global trend reflects a recognition of the importance of nanotechnology in the future of pharmaceuticals and the need to prepare students adequately for the challenges and opportunities it presents.

Despite the growing significance of nanotechnology in the pharmaceutical sector, there is a notable gap in research assessing the awareness and understanding of this field among Indonesian pharmacy students. This study found that many pharmacy students possess limited knowledge of nanotechnology, with less than 10% having participated in related laboratory experiments [5]. This lack of exposure is concerning given the increasing prevalence of nanotechnology-based products in the pharmaceutical market. Without a thorough understanding of these technologies, future pharmacists may struggle to effectively utilize them in their practice, potentially compromising the quality of care they provide [6]. The lack of research on this topic in Indonesia further exacerbates this point, as it hinders the development of targeted educational interventions aimed at improving nanotechnology literacy among pharmacy students [7]. Addressing such a gap is essential for ensuring that pharmacy graduates are adequately prepared to navigate the evolving landscape of pharmaceutical sciences.

The lack of knowledge of nanotechnology among pharmacy students causes significant challenges. First, it may limit their ability to fully understand and leverage the benefits of nanotechnology-based pharmaceuticals, which can lead to the suboptimal patient outcomes [8]. For example, nanotechnology enables targeted drug delivery systems that enhance the efficacy of treatments while minimizing side effects. Without a proper understanding of these systems, pharmacists may not be able to effectively counsel patients or make informed decisions about their use. Second, such a gap in knowledge may hinder the professional development of pharmacy students, as they may be less competitive in the job market when compared to their peers from institutions with more robust nanotechnology education programs [9]. As confirmed in this study, the evolving landscape of nanomedicine requires pharmacists to be well-versed in the complexities of nanotechnology and its applications. Failure to provide adequate training in this area can impede student's ability to contribute to advancements in the field and limit their career opportunities.

To address the issue of insufficient nanotechnology education among Indonesian pharmacy students, it is essential to first assess their current level of awareness and understanding. This assessment will provide a baseline for developing and implementing targeted educational strategies. According to a prior study, incorporating activities such as research proposals into the curriculum relatively helps students engage with nanotechnology-related concepts in a more meaningful way [10]. This approach not only enhances their understanding of the subject but also stimulates critical thinking and fosters the development of academic and professional skills.

A comprehensive assessment should involve both qualitative and quantitative methods, including surveys, interviews, and knowledge tests. This multi-faceted approach will provide a detailed understanding of the student's current knowledge and identify specific areas where improvements are needed. The findings from this assessment will be instrumental in informing the design of targeted educational interventions aimed at enhancing nanotechnology literacy among pharmacy students.

This study represents one of the first systematic evaluations of nanotechnology knowledge within Indonesian pharmacy education. The findings of this study will offer valuable insights into the current state of nanotechnology education in Indonesia and highlight areas for improvement. By identifying specific gaps in knowledge and understanding, this study will inform the development of targeted curricula enhancements aimed at enhancing pharmacy students' comprehension of nanotechnology. The anticipated contributions of this study are twofold. First, it provides a detailed assessment of the current level of nanotechnology knowledge among Indonesian pharmacy students, identifying specific gaps and areas for improvement. Second, it will offer recommendations for integrating nanotechnology education into the pharmacy curriculum, ensuring that future graduates are well-equipped to leverage these technologies in their professional practice. Based on these backgrounds, the main objective of this study is to comprehensively assess the awareness and understanding of nanotechnology and its pharmaceutical applications among Indonesian undergraduate and professional pharmacy students.

MATERIALS AND METHODS

Study design and participants

This study employed a pre-experimental research design with a single-group pre-test and post-test approach to evaluate the awareness of nanotechnology and its pharmaceutical applications among Indonesian pharmacy students. Additionally, it was structured as an observational cross-sectional study to capture awareness levels at a specific point in time. Technically, the study was conducted over 3 months, from December 2023 to February 2024, involving multiple faculties of pharmacy across universities in Sumatera, Java, Kalimantan, and Sulawesi, Indonesia. The target population included third-year, fourth-year, and fifth-year students enrolled in the pharmacist professional program.

Participants were eligible if they were actively enrolled in one of these academic years and provided informed consent. Those unwilling to participate were excluded. The sample size was calculated based on prior studies, assuming an estimated awareness rate of 50%. A total of 500 students were required to achieve a 95% confidence level with a 5% margin of error [2]. To ensure a balanced and representative sample, random sampling was applied, considering the academic year and university type (public or private) for classification and comparison.

Research instruments

The research instrument applied in this study was a questionnaire specifically designed to assess the pharmacy student's awareness of nanotechnology and its applications, originally developed and validated in this study [2]. The questionnaire covers several aspects of nanotechnology awareness among students, including general knowledge of nanotechnology, pharmaceutical applications, sources of information, and perceptions of safety and efficacy. Additionally, the main sections of the questionnaire primarily consist of demographic information, knowledge assessment: sources of information, and perceptions and attitudes.

Data collection

Potential participants were recruited through a combination of social media platforms (such as Instagram), personal WhatsApp accounts, and WhatsApp groups affiliated with student organizations across multiple universities. This multi-channel recruitment approach aimed to maximize outreach and ensure broad participation across different academic years and institutions. Before participation, informed consent was obtained from all students. The questionnaire was administered through a Google Form (G-Form) platform during scheduled sessions, with participants allotted approximately 20 minutes to complete all question items. Participation was entirely voluntary, and responses were anonymized to protect participant privacy. To further enhance confidentiality, all collected data were securely stored and accessible only to the research team. To mitigate potential selection bias, recruitment efforts were extended across multiple faculties and student organizations to reach a diverse and representative sample of pharmacy students. However, given the voluntary nature of participation, self-selection bias cannot be entirely ruled out.

Data analysis

Completed questionnaires were collected, coded, and entered into a secure database. In the context of statistical analysis, descriptive statistics (i.e., frequencies and percentages) were calculated to summarize the demographic characteristics and awareness levels. Additionally, to examine the association between demographic variables and awareness levels, chi-square models were employed, with a p-value of < 0.05 indicating statistical significance. All the statistical analyses were conducted using IBM SPSS Statistics 26 software.

To categorize awareness levels, a rubric-based scoring system was applied, assigning a total score range from 0 to 40 points based on correct responses to knowledge-related questions. A score of 0 indicated a complete lack of awareness, while 1–10 points (poor knowledge) reflected minimal exposure with limited understanding. Participants scoring 11–20 points (moderate knowledge) had partial comprehension but struggled with the application, whereas those in the 21–30 range (good knowledge) demonstrated clear conceptual knowledge with some practical understanding. Finally, scores of 31–40 (excellent knowledge) indicated advanced comprehension and the ability to apply nanotechnology concepts effectively. The distinction between scores, such as 2 versus 9, was based on incremental knowledge levels, where higher scores indicated progressively better recognition and understanding of nanotechnology-related concepts. This categorization ensured meaningful differentiation of awareness levels, enabling more precise analysis of student knowledge.

Moreover, completed questionnaires were coded and analyzed using IBM SPSS Statistics version 26. Descriptive statistics (frequencies and percentages) were used to summarize participant characteristics and awareness levels. Associations between categorical variables were examined using chi-square tests, with Cramer's V calculated to assess effect sizes and contextualize the strength of associations. To control for potential confounders such as age, gender, region, and academic level, binary logistic regression analyses were performed, reporting adjusted odds ratios with 95% confidence intervals. Statistical significance was set at $p < 0.05$.

Pilot test and reliability analysis

Before full-scale data collection, a pilot test was conducted with 30 pharmacy students to assess the clarity, reliability, and validity of the questionnaire. The sample size for the pilot test was determined based on methodological guidelines suggesting that a minimum of 30 respondents is sufficient for preliminary reliability assessments in survey-based research. To evaluate the internal consistency of the questionnaire, Cronbach's alpha was calculated, yielding a value of 0.89, which exceeds the minimum acceptable threshold of 0.60, indicating a high level of reliability. This confirms that the questionnaire items were internally consistent and appropriate for use in the study. However, it is acknowledged that Cronbach's alpha does not serve as a statistical test but rather as a measure of scale reliability. The pilot test aimed to refine the questionnaire rather than provide definitive psychometric validation. Future studies with larger pilot samples and additional reliability measures, such as test-retest reliability and confirmatory factor analysis, are recommended to further strengthen the validity of the instrument.

RESULTS AND DISCUSSION

Study participants

The demographic characteristics of the participants are presented in Table 1. A total of 500 online forms were distributed, yielding a high response rate of 97.2% (n = 486). This study involved 486 students from various universities. The age distribution of the participants showed that the vast majority, 97.5% (n = 474), were aged between 20 and 25 years old, with only 2.5% (n = 12) being older than 25 years old. In the context of gender, there was a predominance of female participants, who accounted for (78.0%; n = 379) of the sample. Meanwhile, the participants were drawn from both public and private universities with a slightly higher representation from the private ones. Specifically, 43.8% (n = 213) of the participants were enrolled in public universities, whereas 56.3% (n = 273) were from private universities. Regarding their academic level, the majority of participants were enrolled in undergraduate pharmacy programs, comprising 90.0% (n = 437) of the study sample, while the remaining 10.0% (n = 49) were students in the pharmacist professional degree program.

The academic year distribution (Fig. 1) confirmed that the participants were fairly spread across the later years of their programs. Specifically, 30.0% (n = 146) were in their third-year, 35.0% (n = 170) in their fourth-year, and another 35.0%

Table 1. Demographic information of the participants (n = 486).

Demographic information	Total N (%)
Age	
20–25 years	474 (97.5)
>25 years	12 (2.5)
Gender	
Female	379 (78.0)
Male	107 (22.0)
Institution type	
Private	273 (56.3)
Public	213 (43.8)
Educational level	
Undergraduate	437 (90.0)
Postgraduate (professional degree program)	49 (10.0)
Academic year	
Third-year	146 (30.0)
Fourth-year	170 (35.0)
Fifth-year	170 (35.0)
Participant's Origins	
Java	194 (40.0)
Sumatera	122 (25.0)
Kalimantan	97 (20.0)
Sulawesi	73 (15.0)

(n = 170) in their fifth-year. The origins of the participants were also diverse, with a significant proportion hailing from Java, which accounted for 40.0% (n = 194) of the sample. Sumatera was the origin for 25.0% (n = 122) of the involved students, followed by Kalimantan at 20.0% (n = 97), as well as Sulawesi at 15.0% (n = 73).

Student's awareness levels of nanotechnology and its industrial applications

The analysis of awareness levels among the participants found significant variations across different demographic factors (i.e., gender, type of university, and specialization). Regarding their self-evaluation of knowledge on nanotechnology and its applications, a dominant 55.3% of the participants reported having poor knowledge, while 21.2% had no knowledge at all. Only 21.6% described their knowledge as good, and a mere 1.9% considered themselves to have excellent nanotechnology knowledge. When comparing gender differences, it was found that a higher proportion of females (56.5%) reported poor knowledge compared to males (51.4%), although this difference was not statistically significant (p = 0.237). Similarly, the comparison between public and private university students revealed insignificant differences in the knowledge levels (p = 0.961). However, a significant difference was reported between undergraduate and professional pharmacy students with 71.7% of the undergraduates finding poor knowledge compared to 53.5% of the postgraduate students (p = 0.005).

The perception of nanomedicine safety also varied among the participants as shown in Table 2. Overall, 40.7% of participants perceived nanomedicine as safe, with a higher

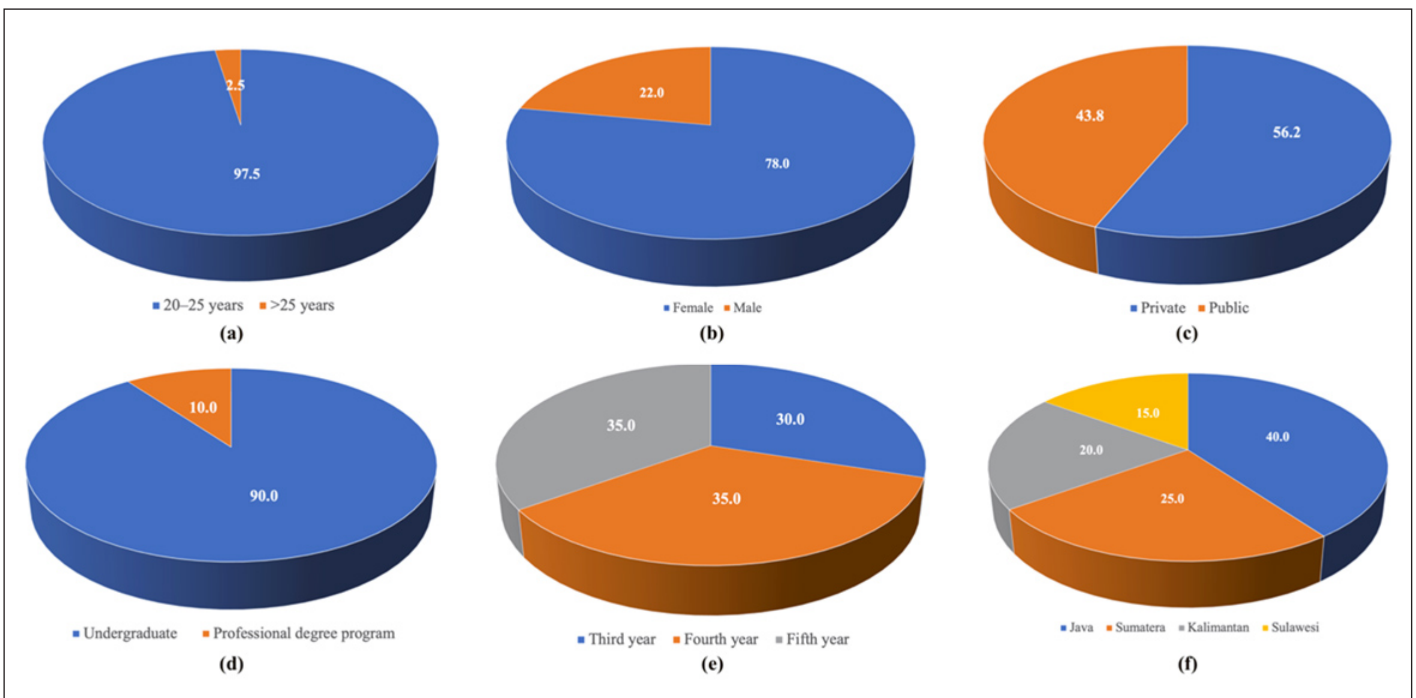

Figure 1. Demographic information of study participants: (a) Age; (b) Institution type; (c) Gender; (d) Educational Levels; (e) Academic Year; and (f) Origins.

Table 2. The responses of the participants were based on the gender (n = 486).

Question item	*N*	Male	Female	*p*-value
How do you evaluate your knowledge of nanotechnology and its applications?				
a) Poor knowledge	269 (55.3)	55 (51.4)	214 (56.5)	0.237
b) No knowledge	103 (21.2)	20 (18.7)	83 (21.9)	
c) Good knowledge	105 (21.6)	39 (36.4)	66 (17.4)	
d) Excellent knowledge	9 (1.9)	2 (1.9)	7 (1.9)	
Is nanomedicine safe?				
a) Safe	198 (40.7)	57 (53.3)	141 (37.2)	0.152
b) Very safe	48 (9.9)	12 (11.2)	36 (9.5)	
c) I don't know	234 (48.1)	46 (43)	188 (49.6)	
d) Not safe	6 (1.2)	1 (0.9)	5 (1.3)	
Do you think that you need to know more about nanotechnology?				
a) Yes	440 (90.5)	91 (85.1)	349 (92.1)	0.037
b) No	26 (5.3)	6 (5.6)	20 (5.3)	
c) Neutral	20 (4.1)	10 (9.3)	10 (2.6)	
Did you study nanotechnology in any course?				
a) Yes	185 (38.1)	52 (48.6)	133 (35.1)	0.001
b) No	301 (61.9)	55 (51.4)	246 (64.9)	
If you answered 'Yes' to the previous question, how many courses?				
a) 0	276 (56.8)	46 (43.00)	230 (60.7)	0.001
b) 1	169 (34.8)	52 (48.6)	117 (30.9)	
c) 2	71 (14.6)	19 (17.8)	52 (13.7)	
d) 3	11 (2.3)	3 (2.8)	8 (2.1)	
e) 4	1 (0.2)	0 (0.0)	1 (0.3)	
Did you get your information about nanotechnology from the media?				
a) Yes	143 (29.4)	40 (37.4)	103 (27.2)	0.077
b) No	343 (70.6)	67 (62.6)	276 (72.8)	
Did you get your information about nanotechnology from academic courses?				
a) Yes	174 (35.8)	44 (41.1)	130 (34.3)	0.203
b) No	312 (64.2)	63 (58.9)	249 (65.7)	
Did you get your information about nanotechnology from self-reading?				
a) Yes	115 (23.7)	28 (26.2)	87 (22.9)	0.521
b) No	371 (76.3)	79 (73.8)	292 (77.1)	
Did you get your information about nanotechnology from other sources?				
a) Yes	46 (9.5)	9 (8.4)	37 (9.8)	0.684
b) No	440 (90.5)	98 (91.6)	342 (90.2)	
Did you attend a workshop related to nanotechnology?				
a) Yes	31 (6.4)	8 (7.5)	23 (6.1)	0.667
b) No	455 (93.6)	99 (92.5)	356 (93.9)	
Did you attend any experiments related to nanotechnology?				
a) Yes	46 (9.5)	15 (14.0)	31 (8.2)	0.149
b) No	440 (90.5)	92 (86.0)	348 (91.8)	

(Continued)

Question item	*N*	Male	Female	*p*-value
Do you think that nanotechnology gives safe and easy ways to diagnose diseases?				
a) Yes	(361) 74.2	(86) 80.4	275 (72.6)	0.227
b) No	(125) 25.8	21 (19.6)	(014) 27.4	
Do you think that nanotechnology enhances therapy outcomes?				
a) Yes	414 (85.2)	96 (89.7)	318 (83.9)	0.396
b) No	72 (14.8)	11 (10.3)	61 (16.1)	
Do you think that nanotechnology enhances a material's physicochemical properties that enhance manufacturing processes?				
a) Yes	425 (87.5)	98 (91.6)	327 (86.3)	0.446
b) No	61 (12.5)	9 (8.4)	52 (13.7)	
Do you think that we must support research related to nanotechnology?				
a) Strongly agree	226 (46.5)	53 (49.5)	173 (45.6)	
b) Agree	235 (48.4)	48 (44.9)	187 (49.3)	0.776
c) Disagree	25 (5.0)	6 (5.6)	19 (5.0)	
Are you interested in learning more about nanotechnology?				
a) Strongly agree	206 (42.4)	43 (40.2)	163 (43)	
b) Agree	254 (52.3)	54 (50.5)	200 (52.8)	0.403
c) Disagree	26 (5.3)	10 (9.3)	16 (4.2)	

proportion of male students (53.3%) holding this view. However, the difference between genders was not statistically significant ($p = 0.152$). Among public university students, 41.8% believed nanomedicine to be safe, which was slightly higher than the private universities ($p = 0.768$). Particularly, professional degree students had a higher perception of safety (53.1%) when compared to undergraduates (39.4%), yet this difference still did not reach statistical significance ($p = 0.123$).

An overwhelming 90.5% of pharmacy students expressed a need to know more regarding nanotechnology, which was more pronounced among the females (92.1%) compared to the males (85.1%) with a significant *p*-value of 0.037, indicating a real difference between genders. The comparison between public and private university students, as shown in Table 3, showed no significant difference (p = 0.837), nor did the comparison between the undergraduates and the postgraduates ($p = 0.121$). Regarding the inclusion of nanotechnology in their coursework, 38.1% of study participants had studied nanotechnology in at least one course. Male students (48.6%) were significantly more likely to have studied nanotechnology than female students (35.1%), with a *p*-value of 0.001. There was no significant difference between public (39.0%) and private (37.4%) universities ($p = 0.764$), or between the undergraduates (37.5%) and the postgraduates (42.9%) with a *p*-value of 0.307.

Regarding sources of information, 29.4% of participants reported acquiring their knowledge of nanotechnology from the media. Males (37.4%) were more likely than females (27.2%) to rely on media as a source; however, this difference was not statistically significant ($p = 0.077$). In the same way, there was no significant difference between the public (28.6%) and private (30.0%) university students ($p = 0.677$), or between undergraduates (29.3%) and postgraduates (30.6%) with a *p*-value of $p = 0.848$). Additionally, 35.8% of all the participants reported acquiring their knowledge from academic courses, with males (41.1%) again more likely than females (34.3%) ($p = 0.203$), and a slightly higher percentage in private universities (38.5%) compared to public universities (32.4%) ($p = 0.157$). There was also no significant difference between undergraduate (34.8%) and postgraduate (44.9%) students ($p = 0.162$), shown in Table 4. Self-reading was another important source of information, with 23.7% of the participants using this method. The difference between males (26.2%) and females (22.9%) was not significant ($p = 0.521$). However, a significantly higher percentage of postgraduates (36.7%) engaged in self-reading compared to undergraduates (22.2%), with a *p*-value of 0.028. The comparison between public (21.6%) and private (25.3%) university students showed no significant difference ($p = 0.329$).

In addition to chi-square analysis, logistic regression was conducted to assess factors associated with low nanotechnology awareness (defined as scoring in the "poor" or "no knowledge" categories) as shown in Table 5. Female students were 1.42 times more likely to report low awareness than male students (AOR = 1.42, 95% CI: 1.01–1.98, $p = 0.045$). Undergraduate students had significantly higher odds of low awareness compared to professional degree students (AOR = 2.11, 95% CI: 1.14–3.88, $p = 0.017$). No significant associations were observed with age group or island of origin. For chi-square analyses, Cramer's V values were reported, indicating small-to-moderate effect sizes in significant associations (e.g., V = 0.13 for educational level *vs.* knowledge level).

Table 3. The responses of the participants were based on the type of university (*n* = 486).

Question item	N	Public	Private	*p*-value
How do you evaluate your knowledge of nanotechnology and its applications?				
a) Poor knowledge	269 (55.3)	117 (54.9)	152 (55.6)	0.961
b) No knowledge	103 (21.2)	45 (21.1)	58 (21.2)	
c) Good knowledge	105 (21.6)	47 (22.1)	58 (21.3)	
d) Excellent knowledge	9 (1.9)	4 (1.9)	5 (1.9)	
Is nanomedicine safe?				
a) Safe	198 (40.7)	89 (41.8)	109 (39.9)	0.768
b) Very safe	48 (9.9)	22 (10.3)	26 (9.5)	
c) I don't know	234 (48.1)	96 (45.1)	138 (50.5)	
d) Not safe	6 (1.2)	2 (0.9)	4 (1.5)	
Do you think that you need to know more about nanotechnology?				
a) Yes	440 (90.5)	192 (90.1)	248 (90.8)	0.837
b) No	26 (5.3)	9 (4.2)	17 (6.2)	
c) Neutral	20 (4.1)	12 (5.6)	8 (2.9)	
Did you study nanotechnology in any course?				
a) Yes	185 (38.1)	83 (39.00)	(102) 37.4	0.764
b) No	301 (61.9)	130 (61.00)	(171) 62.6	
If you answered 'Yes' to the previous question, how many courses?				
a) 0	276(56.8)	121 (56.8)	155 (56.8)	0.999
b) 1	169 (34.8)	52 (24.4)	117 (42.9)	
c) 2	71 (14.6)	19 (8.9)	52 (19)	
d) 3	11 (2.3)	3 (1.4)	8 (2.9)	
e) 4	1 (0.2)	0 (0.0)	1 (0.4)	
Did you get your information about nanotechnology from the media?				
a) Yes	143 (29.4)	61 (28.6)	82 (30.0)	0.677
b) No	343 (70.6)	152 (71.4)	191 (70.0)	
Did you get your information about nanotechnology from academic courses?				
a) Yes	174 (35.8)	69 (32.4)	105 (38.5)	0.157
b) No	312 (64.2)	144 (67.6)	168 (61.5)	
Did you get your information about nanotechnology from self-reading?				
a) Yes	115 (23.7)	46 (21.6)	69 (25.3)	0.329
b) No	371 (76.3)	167 (78.4)	204 (74.7)	
Did you get your information about nanotechnology from other sources?				
a) Yes	46 (9.5)	18 (8.5)	28 (10.3)	0.442
b) No	440 (90.5)	195 (91.5)	245 (89.7)	
Did you attend a workshop related to nanotechnology?				
a) Yes	31 (6.4)	14 (6.6)	17 (6.2)	0.839
b) No	455 (93.6)	199 (93.4)	256 (93.8)	
Did you attend any experiments related to nanotechnology?				
a) Yes	46 (9.5)	20 (9.4)	26 (9.5)	0.949
b) No	440 (90.5)	193 (90.6)	247 (90.5)	
Do you think that nanotechnology gives safe and easy ways to diagnose diseases?				
a) Yes	(361) 74.2	153 (71.8)	208 (76.2)	0.308
b) No	(125) 25.8	60 (28.2)	65 (23.8)	

(Continued)

Question item	N	Public	Private	*p*-value
Do you think that nanotechnology enhances therapy outcomes?				
a) Yes	414 (85.2)	178 (83.6)	(236) 86.5	0.396
b) No	72 (14.8)	35 (16.4)	37 (13.5)	
Do you think that nanotechnology enhances a material's physicochemical properties that enhance manufacturing processes?				
a) Yes	425 (87.5)	179 (84.0)	246 (90.1)	0.078
b) No	61 (12.5)	34 (16.0)	27 (9.9)	
Do you think that we must support research related to nanotechnology?				
a) Strongly agree	226 (46.5)	109 (51.2)	117 (42.9)	0.078
b) Agree	235 (48.4)	965 (44)	140 (51.3)	
c) Disagree	25 (5.0)	9 (4.2)	16 (5.9)	
Are you interested in learning more about nanotechnology?				
a) Strongly agree	206 (42.4)	92 (43.2)	114 (41.8)	0.768
b) Agree	254 (52.3)	102 (47.9)	152 (55.7)	
c) Disagree	26 (5.3)	10 (4.6)	16 (5.9)	

Table 4. The responses of the participants were based on their educational levels (n = 486).

Question item	*N*	Under	Professional	*p*-value
How do you evaluate your knowledge of nanotechnology and its applications?				
a) Poor knowledge	269 (55.3)	234 (53.5)	35 (71.7)	
b) No knowledge	103 (21.2)	95 (21.7)	8 (17.0)	0.005*
c) Good knowledge	105 (21.6)	95 (22.7)	5 (11.3)	
d) Excellent knowledge	9 (1.9)	9 (2.1)	0 (0.0)	
Is nanomedicine safe?				
a) Safe	198 (40.7)	172 (39.4)	26 (53.1)	0.123
b) Very safe	48 (9.9)	41 (9.4)	7 (14.3)	
c) I don't know	234 (48.1)	207 (47.4)	27 (55.1)	
d) Not safe	6 (1.2)	6 (1.4)	0 (0.00)	
Do you think that you need to know more about nanotechnology?				
a) Yes	440 (90.5)	392 (89.7)	48 (98.00)	0.121
b) No	26 (5.3)	24 (5.5)	2 (4.1)	
c) Neutral	20 (4.1)	21 (4.8)	0 (0.00)	
Did you study nanotechnology in any course?				
a) Yes	185 (38.1)	164 (37.5)	21 (42.9)	0.307
b) No	301 (61.9)	273 (62.5)	28 (57.1)	
If you answered 'Yes' to the previous question, how many courses?				
a) 0	276 (56.8)	234 (53.5)	42 (85.7)	0.003*
b) 1	169 (34.8)	152 (34.8)	17 (34.7)	
c) 2	71 (14.6)	67 (15.3)	4 (8.2)	
d) 3	11 (2.3)	10 (2.3)	1 (2.0)	
e) 4	1 (0.2)	1 (0.2)	0 (0.0)	
Did you get your information about nanotechnology from the media?				
a) Yes	143 (29.4)	128 (29.3)	15 (30.6)	0.848
b) No	343 (70.6)	309 (70.7)	34 (69.4)	
Did you get your information about nanotechnology from academic courses?				
a) Yes	174 (35.8)	152 (34.8)	22 (44.9)	0.162
b) No	312 (64.2)	285 (65.2)	27 (55.1)	

(Continued)

Question item	*N*	Under	Professional	*p*-value
Did you get your information about nanotechnology from self-reading?				
a) Yes	115 (23.7)	97 (22.2)	18 (36.7)	0.028*
b) No	371 (76.3)	340 (77.8)	31 (63.3)	
Did you get your information about nanotechnology from other sources?				
a) Yes	46 (9.5)	40 (9.1)	6 (12.2)	0.401
b) No	440 (90.5)	397 (90.9)	43 (87.8)	
Did you attend a workshop related to nanotechnology?				
a) Yes	31 (6.4)	27 (6.2)	4 (8.2)	0.537
b) No	455 (93.6)	410 (93.8)	45 (91.8)	
Did you attend any experiments related to nanotechnology?				
a) Yes	46 (9.5)	(41) 9.4	(5) 10.2	0.856
b) No	440 (90.5)	396 (90.6)	44 (89.8)	
Do you think that nanotechnology gives safe and easy ways to diagnose diseases?				
a) Yes	(361) 74.2	321 (73.5)	40 (81.6)	0.243
b) No	(125) 25.8	116 (26.5)	9 (18.4)	
Do you think that nanotechnology enhances therapy outcomes?				
a) Yes	414 (85.2)	368 (84.2)	46 (94.3)	0.049*
b) No	72 (14.8)	69 (15.8)	3 (5.7)	
Do you think that nanotechnology enhances a material's physicochemical properties that enhance manufacturing processes?				
a) Yes	425 (87.5)	380 (87.4)	47 (10.2)	0.784
b) No	61 (12.5)	57 (12.6)	4 (11.3)	
Do you think that we must support research related to nanotechnology?				
a) Strongly agree	226 (46.5)	205 (47.2)	21 (42.9)	0.486
b) Agree	235 (48.4)	204 (46.7)	31 (50.9)	
c) Disagree	25 (5.0)	21 (4.8)	4 (8.2)	
Are you interested in learning more about nanotechnology?				
a) Strongly agree	206 (42.4)	187 (42.8)	19 (39.6)	0.628
b) Agree	254 (52.3)	223 (51)	31 (55.6)	
c) Disagree	26 (5.3)	24(5.5)	2 (4.1)	

*Statistically significant at $p < 0.05$.

Table 5. Logistic regression of low nanotechnology awareness among students ($n = 486$).

Variable	Adjusted Odds ratio (AOR)	95% confidence interval	*p*-value
Gender (Female *vs.* Male)	1.42	1.01–1.98	0.045
Educational level (Undergrad *vs.* Professional)	2.11	1.14–3.88	0.017
Age (>25 *vs.* 20–25)	1.07	0.52–2.19	0.861
Region (Outside Java *vs.* Java)	1.15	0.77–1.72	0.488

Note: AOR = Adjusted Odds Ratio. Reference groups: Male (for gender), Professional degree (for educational level), 20–25 years (for age), and Java (for the region).

DISCUSSION

Key findings of the study

This study surveyed 486 pharmacy students to assess their awareness and understanding of nanotechnology and its industrial applications. The participants were predominantly young (20–25 years old) and female, representing 97.5% and 78.0% of the sample, respectively. The majority of participants (90.0%) were undergraduate students, while only 10.0% were enrolled in a professional degree program. Among undergraduates, the distribution across academic years was as follows: 30.0% in the third-year, 35.0% in the fourth-year, and

35.0% in the fifth-year, which primarily included professional degree students. Geographically, the involved participants came from diverse origins with significant representation from Java (40.0%).

The findings of this study revealed that the majority of participants had poor or no knowledge of nanotechnology with significant gender differences observed in awareness levels. Female participants reported lower levels of awareness compared to their male counterparts. Additionally, there were differences based on the specialization with professional degree students showing lower awareness compared to undergraduate ones. Participant's perceptions of nanomedicine's safety varied from participant to participant, and many expressed a need for more information. Finally, the primary sources of information about nanotechnology were from media, academic courses, and self-reading.

Interpretation of results

The predominance of the young and female participants in this study reflects broader trends in pharmacy education, where female enrolment has been increasing. This shift towards a more female-dominated student body is consistent with global patterns in healthcare education. The high female representation may influence the study results, as previous research suggests that females may have different learning preferences and interests compared to male students, which is potentially affecting their awareness levels in specific scientific fields [11–13]. Meanwhile, the slightly higher representation of participants from private universities could be due to the availability and accessibility of private education in the region. Private institutions may offer more specialized courses and resources, potentially influencing student's exposure to emerging fields like nanotechnology. However, despite this, the study found no significant difference in terms of awareness levels between students from public and private universities, indicating that the type of institution alone does not account for differences in knowledge [14,15].

The dominance of the undergraduates and their relatively higher awareness levels compared to the professional degree students can be attributed to the curriculum structure. While undergraduate programs typically offer broader coursework in pharmaceutical sciences, including nanotechnology, this study found that professional degree students demonstrated comparatively higher awareness levels. A significant difference was observed, with 71.7% of undergraduates reporting poor knowledge compared to 53.5% of professional degree students ($p = 0.005$). This suggests that despite formal exposure in undergraduate curricula, professional degree students may have gained additional knowledge through self-directed learning, clinical exposure, or specialized training, contributing to their relatively better awareness and perception of nanotechnology safety (53.1% *vs.* 39.4%) [16,17]. The relatively consistent awareness levels across different academic years indicate that exposure to nanotechnology topics during pharmacy education may not be progressively reinforced. This suggests potential gaps in the curriculum, where the introduction of nanotechnology—while present—may not be sufficiently integrated or emphasized at advanced levels to significantly enhance student knowledge over time.

The regional diversity of the participants underscores the broad reach of the study and suggests potential regional disparities in educational resources and access to information. Students from Java, being the majority, might have better access to educational facilities and information compared to those from more remote regions such as Kalimantan and Sulawesi. This regional variation could influence the overall awareness and understanding of nanotechnology among students [18].

Additionally, logistic regression findings reinforced the bivariate results, highlighting that female students and undergraduates were more likely to report poor or no knowledge of nanotechnology. Specifically, being female was associated with a 42% higher likelihood of low awareness, while undergraduate status more than doubled the odds. These findings suggest that demographic characteristics independently influence nanotechnology awareness, beyond what is captured in unadjusted comparisons. The effect sizes based on Cramer's V were small to moderate, indicating that while associations were statistically significant, the strength of relationships was not large—underscoring the multifactorial nature of awareness gaps.

Awareness levels and knowledge gaps

The study's finding of generally low awareness and understanding of nanotechnology among participants aligns with previous research in similar educational contexts. For instance, a study regarding nanomedicine in pharmacy education published in 2022 confirmed that pharmacy students in several Asian countries had limited knowledge of nanotechnology, emphasizing the need for enhanced educational efforts [3]. Meanwhile, the statistically significant difference in awareness levels between male and female participants suggests that gender-specific factors may play a role. Cultural and sociocultural factors, such as gender stereotypes in science, technology, engineering, and math fields, may contribute to these differences [19,20].

The significant disparity in the knowledge between undergraduate students and professional degree students could be due to the differing focus of their programs. Undergraduate programs typically provide a stronger foundation in the scientific aspects of pharmacy sciences, including emerging technologies like nanotechnology, while professional degree programs emphasize clinical skills [21,22]. This difference underscores the need for a more integrated approach to nanotechnology education across all pharmacy programs. The participant's mixed perceptions of the safety of nanomedicine reflect a broader uncertainty on the implications of this emerging field. While some studies suggest that nanomedicine offers significant benefits, including enhanced drug delivery and reduced side effects [23,24], concerns about toxicity and long-term effects persist. It highlights the importance of providing comprehensive education on both the benefits and risks of nanotechnology in medicine.

Sources of information and education gaps

The findings of this study identified media, academic courses, and self-reading as the primary sources of information about nanotechnology for students. Media, including online articles and news reports, play a significant role in shaping the public perception of new technologies [25,26]. However, reliance on media alone may lead to incomplete or biased understanding. Academic courses are essential for providing structured and accurate information, yet the study found significant gaps in the current pharmacy curriculum regarding nanotechnology education. This finding is consistent with previous studies that highlight the need for curriculum reforms to include more comprehensive coverage of nanotechnology [22,27]. Additionally, self-directed learning and attendance at workshops emerged as important sources of nanotechnology-related knowledge. Encouraging students to engage in self-learning and providing opportunities for workshops and hands-on experiences can enhance their understanding and interest levels in nanotechnology [28,29]. Integrating more formal education opportunities into the curriculum, such as dedicated courses or modules on nanotechnology, could address these educational gaps and better prepare students for the evolving field of pharmacy.

Strengths and limitations of the study

The high response rate of this study (97.2%) ensures robust data collection and increases the reliability of the findings. The large and diverse sample size, representing different regions and university types, provides a comprehensive overview of the demographic factors influencing awareness levels. The implementation of statistical analysis to identify significant differences based on gender, specialization, and other factors adds to the study's credibility. However, the study has limitations that shall be acknowledged. The findings have limited generalizability because of the specific geographical and educational context in which the study was conducted. Additionally, the reliance on self-reported data introduces the potential for response bias, as participants may overestimate or underestimate their knowledge and perceptions. The lack of qualitative data may limit the ability to gain deeper insights into the participant's attitudes and motivations. Finally, variations in the curriculum and exposure to nanotechnology topics across different universities were not accounted for, which could influence the results.

Another limitation is that, while the study found significant differences between undergraduate and professional degree students in terms of awareness levels and perceptions of nanotechnology, it is important to note that the number of postgraduate participants was relatively small (n = 49, 10% of the total sample). This limited representation may affect the generalizability of the findings regarding postgraduate students and should be interpreted with caution. Future studies with a more balanced sample size across academic levels are recommended to validate these observations and provide a more comprehensive understanding of knowledge disparities in nanotechnology education.

Finally, the sample was predominantly female (78%) and from private universities (56.3%), which may limit generalizability. These demographic skews may influence awareness levels due to potential differences in curriculum exposure, learning preferences, or institutional emphasis on emerging technologies. Future studies should aim for a more balanced representation to validate these trends. Additionally, the study relied on self-reported knowledge, which may be subject to recall bias or social desirability bias—potentially leading to under- or overestimation of actual awareness. However, self-assessment remains a valid initial approach for gauging perceived competence and has been commonly used in similar educational assessments, particularly when objective testing is impractical at scale.

Implications for future research and practice

The study findings suggested the need for incorporating comprehensive nanotechnology education in pharmacy curricula. Addressing the disparities of gender and specialization in knowledge is crucial for ensuring that all students are equally prepared for advancements in the field. Policymakers should develop standardized guidelines for nanotechnology education to ensure consistent and high-quality instruction across all institutions [30,31]. Universities are encouraged to enhance interdisciplinary learning opportunities, integrating nanotechnology topics into both scientific and clinical courses.

To bridge the identified knowledge gaps, pharmacy curricula should incorporate mandatory nanotechnology modules covering both theoretical foundations and practical applications, such as drug delivery systems, diagnostic tools, and regulatory aspects. Hands-on laboratory experiments and simulation-based workshops—such as nanoparticle formulation, characterization, and case-based exercises—can significantly enhance experiential learning. Introducing interdisciplinary electives involving materials science or biomedical engineering may also support a deeper comprehension of nanomedicine. Furthermore, faculty development programs are essential to equip educators with the competencies needed to deliver current, practice-oriented nanotechnology instruction.

Further research

Future research should include qualitative research or studies to explore the underlying reasons for knowledge gaps and to gain a deeper understanding of student's perceptions and attitudes toward nanotechnology. Longitudinal studies are needed to assess the impact of curriculum changes on the student's knowledge and perceptions over time. Comparative studies with other regions or countries can help identify global trends and best practices, thus providing valuable insights for improving nanotechnology education in pharmacy programs worldwide.

CONCLUSION

This study highlights significant gaps in nanotechnology awareness among pharmacy students, revealing that the majority possess poor or no knowledge, with notable disparities influenced by gender and educational specialization. Female students and those with professional degrees confirmed lower awareness levels compared to their male and undergraduate counterparts. The main sources of information included media, academic courses, and self-reading, underscoring the need for more structured and comprehensive nanotechnology education within pharmacy curricula. The findings emphasize the urgent requirement for targeted educational interventions and curriculum reforms to better prepare pharmacy students for advancements and challenges posed by nanotechnology in the pharmaceutical field.

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All authors made substantial contributions to conception and design, acquisition of data, or analysis and interpretation of data; took part in drafting the article or revising it critically for important intellectual content; agreed to submit to the current journal; gave final approval of the version to be published; and agree to be accountable for all aspects of the work. All the authors are eligible to be an author as per the International Committee of Medical Journal Editors (ICMJE) requirements/guidelines.

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The study protocol was reviewed and approved by the Institutional Review Board of the Faculty of Medicine and Health Sciences, Universitas Muhammadiyah Yogyakarta, Indonesia (number 288/EC-KEPK FKIK UMY/XII/2023). The written informed consent was obtained from all involved participants prior to the administration of the questionnaire. Meanwhile, participant's anonymity and confidentiality were maintained throughout the study with data securely stored and accessible only to the research team.

DATA AVAILABILITY

All data generated and analyzed are included in this research article.

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USE OF ARTIFICIAL INTELLIGENCE (AI)-ASSISTED TECHNOLOGY

The authors declare that they have not used artificial intelligence (AI)-tools for writing and editing the manuscript, and no images were manipulated using AI.

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