

NARRATIVE REVIEW

Knowledge, perceptions, and attitudes toward pharmacogenomics among pharmacists and pharmacy students: A systematic review

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Abstract

Background and Aims: Pharmacists have been recognized as one of the most qualified healthcare professionals in the clinical implementation of pharmacogenomics, yet its widespread implementation in clinical pharmacy practice has remained limited. The review aims to systematically investigate knowledge, perceptions, and attitudes toward pharmacogenomics among pharmacists and pharmacy students to inform the future delivery of pharmacogenomics education programs.

Methods: PubMed, MEDLINE, Embase, Scopus, and the International Pharmaceutical Abstracts were searched up to May 17, 2022. Studies were selected if they included data on pharmacists' or pharmacy students' knowledge, perception, or attitude about pharmacogenomics and were published in a peer-reviewed, English-language journal with full-text availability. Any published study not deemed original research was excluded. All included studies were critically appraised using the Center for Evidence-Based Management's critical appraisal tools. The data were descriptively analyzed and presented based on pharmacists' and pharmacy students' knowledge/awareness, perception/attitudes toward pharmacogenomic (PGx), confidence in using or interpreting PGx testing results, and their desire to get further PGx education or their most preferred method of further education.

Results: A combined total of 12,430 pharmacists and pharmacy students from 26 countries are represented in the 52 included studies. Despite overwhelmingly positive attitudes and perceptions toward pharmacogenomics among pharmacists and pharmacy students, an overall lack of adequate knowledge and confidence was found. The review also found a strong desire for further pharmacogenomics education among pharmacists and pharmacy students.

Amanda Wondrasek and Amber Fryza contributed equally to this study.

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Conclusion: Pharmacists and pharmacy students have positive perceptions and attitudes toward pharmacogenomics, which is hindered by a lack of knowledge and confidence. However, inadequate control for confounders, limited representativeness of the studied population or region, and small sample sizes diminish the generalizability of the review results. Knowledge and confidence could be improved through enhanced delivery of pharmacogenomic courses within the pharmacy curriculum and continuing education programs.

KEYWORDS

attitudes, knowledge, perceptions, pharmacist, pharmacogenomics, pharmacy education, pharmacy student

1 | INTRODUCTION

Interindividual variability is a major concern in optimal drug therapy. Although most licensed medications are effective and well-tolerated, up to 50% of individuals do not get any benefit from some medications, while other medications cause adverse drug reactions (ADRs). This leads to reduced adherence to treatment, increased morbidity and mortality, or requires further treatment that increases psychological distress and economic burden to the individual and the society.^{1,2} ADRs are estimated to be the fourth leading cause of death in the United States.³ In Canada, an estimated 200,000 severe ADRs are reported annually, leading to as many as 22,000 deaths, costing the Canadian healthcare system between \$13.7 and \$17.7 billion.⁴ Similar figures have been reported in other countries rendering the issue a significant healthcare challenge worldwide, particularly with an increasingly aging population and rising multimorbidity.^{5,6} To partly counteract interindividual variation in drug response, the “precision medicine” concept has been developed that strives to achieve individualization of treatment plans and optimize patient outcomes. It has been estimated that up to 95% of variation in drug efficacy and tolerability can be attributed to genetic differences between individuals, and between 80% and 99.5% of the population carry an actionable genetic variant that could affect drug selection and/or dosing of at least one drug.^{5,7-9} Over the past two decades, pharmacogenomic (PGx) testing has emerged as one of the essential tools for precision medicine that can aid in determining how a person processes and reacts to drugs based on their genetic makeup.

PGx testing can potentially improve drug efficacy and safety, reduce time to therapeutic response, prevent ADRs, increase treatment compliance, and ultimately reduce morbidity and mortality risk. This testing aims to tailor pharmacotherapy based on interpretation of the patient's genetic sequences, which code for drug-metabolizing enzymes, functional proteins, transporters, receptors, and immune response molecules. This interpretation is accomplished by translating the genotype information from a genetic test into a phenotype of how a patient is likely to respond to therapy, such as whether they will be a poor versus ultrarapid metabolizer. When

combined with other laboratory results, clinical symptoms, concomitant medications, and environmental factors, this information can allow healthcare professionals to practice precision medicine by providing an individualized therapeutic plan that takes into account the patient's genetic results in addition to other clinical factors.^{10,11}

Currently, more than 200 licensed medications have therapeutic management (use of alternative drug or dose change) and/or warnings about potential ADRs on their labels¹² or have prescribing guidelines based on genotype results recommended by several expert groups, for example, the Dutch Pharmacogenetics Working Group (DPWG),¹³ the Clinical Pharmacogenetics Implementation Consortium (CPIC),¹⁴ and the Canadian Pharmacogenomics Network for Drug Safety (CPNDS).¹⁵ These guidelines have been endorsed by the American Society of Health-System Pharmacists (ASHP),¹⁶ the American Society for Clinical Pharmacology and Therapeutics (ASCPT),¹⁷ Canadian Pediatric Society,¹⁸ the European Association for Clinical Pharmacology and Therapeutics (EACPT), the European Association of Hospital Pharmacists (EAHP), and Irish Pharmacy Union (IPU). More than 50 healthcare systems worldwide are already utilizing PGx testing, and commercial companies offer several options, including direct-to-consumer tests.¹⁹ Pharmacists, the medication experts, are leading the clinical implementation of PGx in various practice settings (e.g., hospitals, primary care, or community pharmacies).²⁰⁻²⁴

Pharmacists have been recognized as among the most qualified healthcare professionals due to their knowledge of pharmacokinetics and pharmacodynamics for interpreting PGx test results.²⁵ They are also well positioned to lead interprofessional efforts to implement PGx testing due to their accessibility. In a recent position statement, the ASHP clearly outlined pharmacists' role in the clinical implementation of PGx.²⁶ A recent scoping review reported the demonstrated feasibility of PGx testing and improved medication outcomes in pharmacy practice.²⁷ Yet, some hesitate to share PGx information with other healthcare providers due to the lack of standardized PGx education currently incorporated into pharmacy programs.²⁸⁻³¹

Despite the advancement in high-quality PGx research, increased test and guideline availability, demonstrated feasibility and applicability of testing in pharmacy workflow, its widespread

implementation in clinical pharmacy practice has remained limited.^{22,27,32} To inform the future delivery of PGx education and clinical implementation, we aim to provide an overview of what is currently known regarding the knowledge, attitudes, perceptions, and confidence of pharmacists and pharmacy students toward PGx. To accomplish this, we systematically reviewed and critically appraised available PGx literature on the knowledge, attitudes, perceptions, and confidence of pharmacists and future pharmacists (pharmacy students) toward PGx.

2 | METHODS

This systematic review was registered with PROSPERO (CRD2022333026) and followed PRISMA 2020 (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) recommendations.³³

Two reviewers (A. W. and A. F.) independently searched PubMed, MEDLINE, Embase, Scopus, and International Pharmaceutical Abstracts (IPA) for English-language, original research. All database searches included studies published up to May 17, 2022. The search strategy was developed from keywords for the main concept of the review: “pharmacists,” “pharmacy students,” “pharmacogenetics,” “pharmacogenomics,” “precision medicine,” “individualized medicine,” “knowledge,” “awareness,” “understanding,” “perception,” “view,” “opinion,” “perspective,” “attitude,” “interest,” “belief,” “confidence,” “competence,” “qualified,” “capability,” and “experience.” Search strategies were refined through discussions with a librarian specializing in health sciences. Supporting Information S1: Table 1 details the search strategy. Both reviewers independently screened titles and abstracts of all articles identified during the systematic search and assessed full-text copies of the relevant articles. For articles where a consensus between the two reviewers was not achieved, a third reviewer (A. A. M.) assessed and resolved the conflict. The conflicts were mostly related to studies where separate data were not available for pharmacists or pharmacy students. The review was managed by Covidence systematic review software (Veritas Health Innovation).

Studies were selected for data extraction if the following inclusion criteria were met: (1) included data about pharmacists' or pharmacy students' knowledge, perception, or attitude about PGx, and (2) published in a peer-reviewed, English-language journal and full-text was available. Review articles, case studies, posters/abstracts, commentaries, perspectives, books, book chapters, editorial pieces, or any published material not deemed original research were excluded. Extracted information included authors, publication year and country, study title, participant characteristics, and main findings (knowledge or awareness of PGx, perceptions or attitudes toward PGx, confidence in using PGx in their practice, and desire for further education and/or the most desired format for further education). The level of knowledge (e.g., low/moderate/positive/negative/poor) was designated as per the original study. No statistical comparisons were made between the studies.

All included studies were critically appraised by two independent reviewers (A. W. and A. F.) using the Center for Evidence-Based Management (CEBMA)'s critical appraisal tools for surveys and qualitative studies.³⁴

3 | RESULTS

3.1 | Study selection

Figure 1 provides an overview of the article selection process. The literature search generated 1773 articles, duplicates were removed, and 865 articles underwent title and abstract screening. Eight hundred seven articles were excluded as they did not meet the inclusion criteria. For the full-text screening, 58 articles were assessed, and six articles were excluded. A total of 52 articles underwent complete data extraction and critical appraisal.

3.2 | Study characteristics

Twenty-six countries were represented by the included studies (Figure 2). The studies were predominantly conducted in the United States ($n = 12$) and Canada ($n = 4$), followed by Jordan, Saudi Arabia, Malaysia, Australia, and United Arab Emirates, with three studies each.

The included studies were conducted in different settings and used diverse methodologies for data collection (Table 1). Data were mainly gathered via convenience sampling from selected locations within the country or nationwide from pharmacists working in private and retail pharmacies, private and government hospitals, academic research institutes, or primary care facilities. Pharmacy students were recruited from educational institutes offering pharmacy programs. Most studies utilized cross-sectional surveys ($n = 49$) to gather data on knowledge, perception, attitudes, or confidence regarding PGx. Semistructured and focus group interviews were the primary methodologies of the three qualitative studies included. The findings for pharmacists and pharmacy students were presented separately to observe whether there was a difference in opinions about the clinical use of PGx and current PGx education delivery. A total of 8092 pharmacists (range 11–1313) and 4002 pharmacy students (range 62–637) were surveyed or interviewed among the 49 included studies. Three studies had combined data (pharmacists and pharmacy students) that included 336 participants. A total of 12,430 pharmacists and pharmacy students were represented among the 52 included studies.

3.3 | Synthesis of results

The data were descriptively analyzed and presented based on pharmacists' and pharmacy students' knowledge/awareness, perception/attitudes toward PGx, confidence in using or interpreting PGx

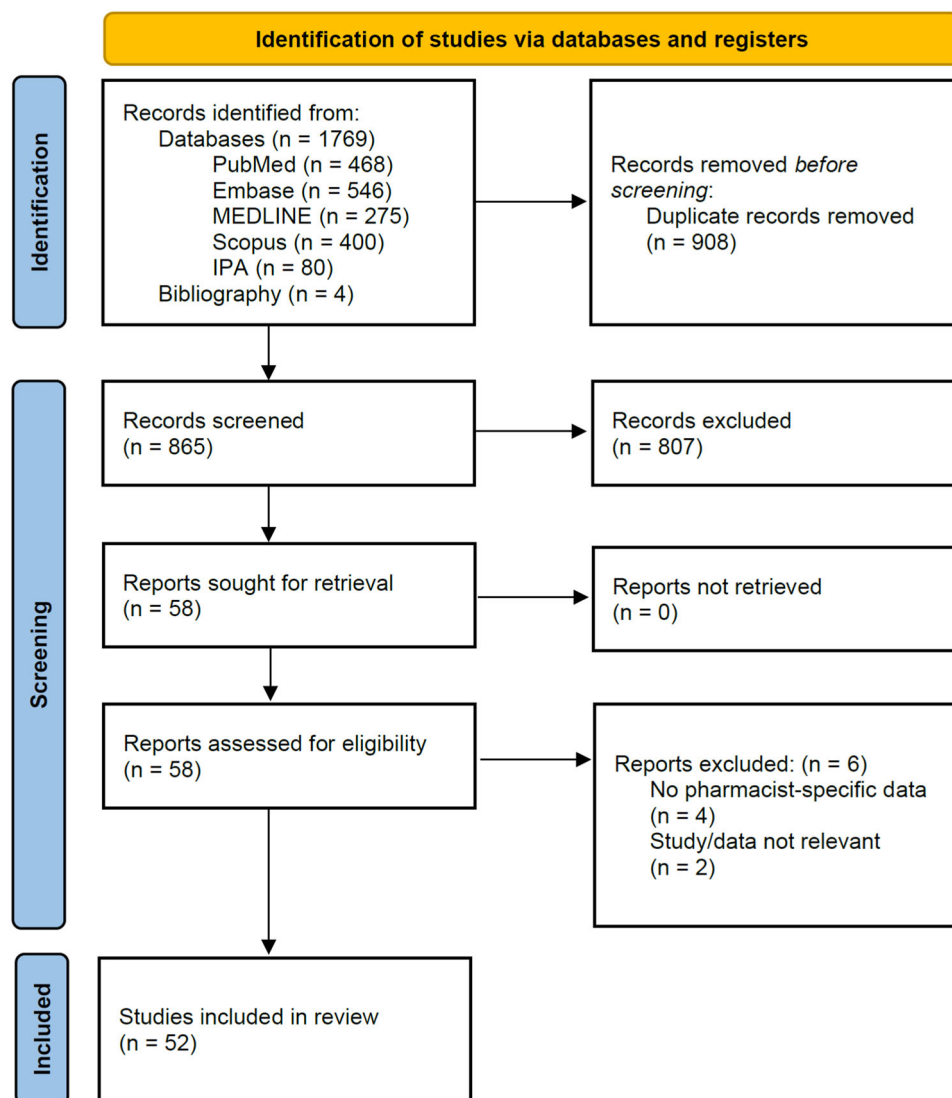


FIGURE 1 PRISMA flow diagram of the article selection process. IPA, International Pharmaceutical Abstracts; PRISMA, Preferred Reporting Items for Systematic Reviews and Meta-Analyses.

testing results, and their desire to get further PGx education or their most preferred method of further education (Table 1).

3.4 | Knowledge and awareness of PGx

There was an overall lack of PGx knowledge and awareness among pharmacists and pharmacy students. However, across studies, there was a consensus that PGx is relevant to pharmacy practice and pharmacists should be required to have adequate PGx knowledge (Table 1). Many respondents believed it was important for pharmacists to provide information on the appropriate use of PGx testing and know how to order/recommend and interpret the subsequent results.^{35,39,45,47,48,53,56,58,59,83,84} Out of the 34 studies that reported on PGx knowledge or awareness among pharmacists, 23 found that the majority of the respondents had a low or inadequate level of PGx knowledge or awareness.^{31,35–38,41,44,46,47,50–52,54,55,57,59,60,66,67,76,82,83,85}

None of the analyzed studies reported that most respondents had adequate PGx knowledge. In comparison, most studies with pharmacy students found a good or fair level of knowledge among most participants.^{69,73,74,76–81} Some studies only reported self-assessed (subjective) knowledge of PGx, which was generally reported as “low.” However, self-assessed knowledge did not always correlate with actual expertise in studies that assessed both.³⁷ While many studies did not report data on “biological sex,” one study noted a difference in the knowledge level of pharmacy students between males and females. However, the reasons for this were not examined in detail.⁷²

3.5 | Perception or attitudes toward PGx testing

The perceptions and attitudes of pharmacists and pharmacy students toward PGx were overwhelmingly positive (>80% of participants) (Table 1). Studies ($n = 33$) that measured the perception of

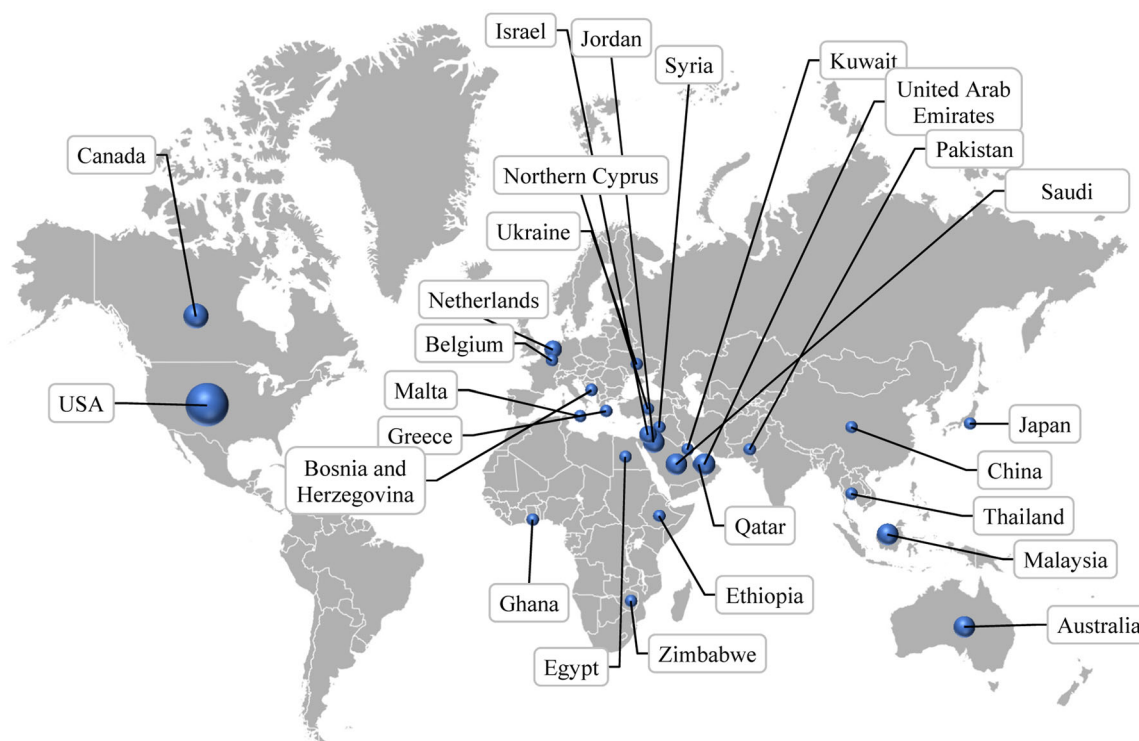


FIGURE 2 World map with locations of included articles. Bubble size represents the number of studies conducted.

pharmacists reported that most respondents were “positive” toward PGx testing^{31,35–42,44,46–48,50–56,58–64,66–68,82–84} in its use in choosing the right drug and dose and reducing ADRs. Some articles even reported almost 100% positive responses to attitude- and perception-based questions.^{39,41,48} The same statement is valid for the studies that measured the perception of pharmacy students (Table 1). There appears to be an increasing awareness about the applicability of PGx in precision medicine, as evidenced by studies from more than 8 years ago which reported less consensus on a positive perception toward PGx, compared to a more widespread favorable agreement found in articles from more recent years (Table 1). Two articles that reported an unfavorable attitude toward PGx were Dias et al.,⁴⁵ which found that the majority of respondents (Australian pharmacists, 2014 Study) felt there was a lack of clinical evidence to support PGx and Shishko et al.,⁶⁵ which reported a slight difference in perceptions (psychiatric pharmacists from the United States, Indonesia, Singapore, United Arab Emirates, Canada, 2015 Study) among those with varying levels of PGx knowledge. The fewer positive perceptions toward PGx among hospital pharmacists in Australia might have also been driven by the lack of timely education and pharmacists' time and work constraints at that time.⁴⁵ In focus group interviews, some Qatari pharmacists expressed that PGx will not benefit them or why learn it if they do not use it in practice.⁶¹

A correlation between the generally positive perception of PGx and the potential benefits of PGx testing became apparent as respondents believed PGx testing could improve overall patient safety, guide the selection of appropriate therapy, and improve future

pharmacy practice. At least 16 studies concluded that most pharmacists felt the use of PGx testing would improve overall patient safety through reduced risk of adverse events and improved therapeutic efficacy.^{37,39,41,42,44,46,48,49,52,54,55,66,67,70,82,83} Twelve articles specifically asked whether pharmacists should be knowledgeable of PGx and whether PGx testing was relevant to their pharmacy profession, to which most respondents agreed.^{35,39,47,53,56,66,69,71,75,77,83,84} At least seven articles concluded that most pharmacists and pharmacy students felt that PGx had a role in selecting the most appropriate therapy.^{31,47,49,50,67,68,73} Two studies found less than 40% of the pharmacists agreed that PGx was applicable to their current practice (Malta),⁶⁸ and 14.3% of the participants felt that pharmacists should be knowledgeable about PGx (Australia).⁴⁵ Shah et al.⁷⁷ reported that 83.6% of pharmacy students believed that PGx could improve future pharmacy practice, a statement shared by most other studies with pharmacy students (Table 1).

3.6 | Confidence in utilizing PGx testing in patient care

Of the 22 articles that assessed the confidence of pharmacists regarding the application of PGx testing in their practice, all studies reported that the majority of participants had a low level of confidence.^{31,35,37–39,43–46,50–53,55–58,64,68,82–84} This was often described as the proportion of participants who felt they could identify medications that require PGx testing, recommend the

TABLE 1 Summary characteristics of included articles (n = 52).

Pharmacists							
Main findings							
Reference	Location	Settings	Participants (% female)	Knowledge or awareness	Perceptions or attitudes	Confidence	Desire for further education and/or the most desired format
Albassam et al. ³⁵	Kuwait	Public hospitals	238 (60.5%)	Low (%knowledge score 48.8%)	Positive (mean perception score 4.5 out of six); 69% agree PGx is relevant to current practice; 74.4% think they are capable of providing information on PGx testing	Low (mean confidence score 1.1 out of 4); 26.9% agree they can accurately apply PGx test result	Workshop or Seminars (82%)
Albitar and Alchamat ³⁶	Syria	Internet-based, nationwide	74	Low (%knowledge score 48.9%)	Positive (71.62% favored PGx testing before prescribing to predict efficacy)		College education (42.9%)
AlEjjeilat et al. ³⁷	Jordan	Face-to-face distribution in three cities	128 (78%)	Very low (mean knowledge score 2.63 out of five)	Positive; PGx testing is associated with reduced ADRs (78% agree) and improved efficacy (69% agree)	About 50% are confident in their ability to apply their knowledge and identify which medications require testing accurately	73% interested in further PGx education
Alexander et al. ³⁸	United States	Community pharmacists affiliated with American Pharmacy Services Corporation (APSC)	101 (37%)	Low (26% self-reported to be qualified to provide personalized medicine services at their pharmacies)	Positive (69% willing to participate in PGx screening)	63% expressed a lack of confidence in counseling patients based on the results of a PGx screening	81% interested in further PGx education; 78% would prefer to live CE programs
Algahtani ³⁹	Saudi Arabia	Hospitals	206	Moderate to low level as per knowledge indicator questions	Positive (around 85% of the participants had a positive perception about the practical aspects of PGx); 76% agreed PGx should be used in pharmacy	32% can use PGx test for recommendation and 35.5% can identify drugs that need PGx testing	83% felt the need to know more about PGx
Alsalmoumi et al. ⁴⁰	North Cyprus	Community pharmacists	103 (60.2%)	Knowledge score is 6.9 out of 10; 62.1% felt they had sufficient knowledge of PGx testing	Positive (mean score 28.3 out of 40); 40.8% agree PGx testing can reduce ADRs		50.5% would prefer CE programs

TABLE 1 (Continued)

Pharmacists							
Main findings							
Reference	Location	Settings	Participants (% female)	Knowledge or awareness	Perceptions or attitudes	Confidence	Desire for further education and/or the most desired format
Bagher et al. ³¹	Saudi Arabia	Five randomly selected hospitals	119 (58%)	Low (2.4 out of five)	Positive (mean score 10.1 out of 12); 52.9% agree PGx is relevant to their current practice; 80.7% agree testing should be applied in practice	Moderate (mean score 4.3 out of eight); 37.8% confident in using PGx testing for drug selection/dosing	60.5% preferred workshops/seminars
Bank et al. ⁴¹	Netherlands	Internet-based, nationwide	667 (54.3%)	14.1% feel informed about PGx	99.7% believe in the concept PGx	27% feel qualified to interpret PGx test results and advise HCP or patient	88.8% would like to receive additional training
Bannur et al. ⁴²	Malaysia	Nationwide	324 (55.7%)	Mean score 3.38 out of five	Mean score 28.10 out of 40		96.3% were interested in further education; 99% preferred web-based CE
Benzeroual et al. ⁴³	United States	New York state-licensed pharmacists	102			Somewhat confident (mean score 22 out of 64); 3.9% confident/extremely confident in identifying the key PGx tests available for determining the therapeutic and ADRs	44.2% interested in further PGx education
De Denus et al. ⁴⁴	Canada	Internet-based; practicing pharmacists in Québec	284 (72.8%)	Limited (22.1% knew that the US FDA includes PGx information on drug monographs)	Positive; moderately hopeful that PGx would prevent wrong drug/dose (80%), detect most effective drug/dose (82.6%), and minimize adverse effects (79.1%)	7.7% were comfortable receiving PGx results and advising patients; 86.4% would feel comfortable once they received proper training	96.6% were interested in further PGx education; 69.9% prefer e-learning
^a Dias et al. ⁴⁵	Australia	Four public hospitals in Adelaide, South Australia	21		61.9% felt a lack of evidence to support the use of PGx testing; 33.3% felt PGx application is role of a medical practitioner, 14.3% reasonable to expect pharmacists to know about PGx testing	28.6% did not feel confident using PGx information	Interactive learning 42.8%

(Continues)

TABLE 1 (Continued)

Pharmacists							
Main findings							
Reference	Location	Settings	Participants (% female)	Knowledge or awareness	Perceptions or attitudes	Confidence	Desire for further education and/or the most desired format
Edris et al. ⁴⁶	Belgium	Internet-based, nationwide	100 (77%)	Mean percentage of correct answers is 37%	Positive; 79% "agree" or "totally agree" PGx can improve safety/efficacy		67% prefer lectures
Elewa et al. ⁴⁷	Qatar	Hamad Medical Corporation Hospitals	108 (50.5%)	Low (mean awareness score 1.95 out of five)	Positive; 92.6% agree that it is important to identify medications that require PGx tests; 63.2% agree they could be responsible for applying PGx to drug therapy		86.2% interested in further PGx education
^a Frigon et al. ⁴⁸	Canada	Registered pharmacists in Quebec	11 (81.82%)	Most knew about PGx but had limited clinical experience	All mentioned that the reduction of adverse events as being one of the main benefits of PGx testing; pharmacists could prescribe a PGx test and choose the drug according to the results of the test mentioned by the pharmacists' groups		Pharmacy programs and as part of CE
Guo et al. ⁴⁹	China	Internet-based, nationwide	132 (66.7%)		Overall positive (>50%); pharmacists knew PGx helps select optimal drug (61.4%), use correct dose (51.5%) and prevent severe ADRs (66.7%)	64.4% would advocate for implementing PGx	
Ho et al. ⁵⁰	United States	Tampa General Hospital and the University of South Florida Health	41	Approximately half of the participants were not aware of clinically reputable resources and/or guidelines on how to apply PGx results to patient care	86% "agreed" or "strongly agreed" PGx testing could optimize medications	39% are confident in their ability to interpret and apply PGx results	CE credits

TABLE 1 (Continued)

Pharmacists							
Main findings							
Reference	Location	Settings	Participants (% female)	Knowledge or awareness	Perceptions or attitudes	Confidence	Desire for further education and/or the most desired format
Hundertmark et al. ⁵¹	United States	A large, multistate healthcare system	75 (60%)	37.4% felt "knowledgeable" or "somewhat knowledgeable" about PGx guidelines and resources	57.3% felt PGx has a very/somewhat impact on current practice and pharmacists are best suited for PGx testing (58.7%)	25.3% felt very/somewhat comfortable interpreting PGx test and providing recommendations (21.3%)	
Huston et al. ⁵²	United States	Southeastern Pharmacy Experiential Education Consortium	94	Inadequate (mean score is two out of five); PGx users' self-assessed knowledge was significantly higher than nonusers			
Jarrar et al. ⁵³	West Bank of Palestine	Internet-based, eight cities in the West Bank of Palestine	370 (65.5%)	–	43.2% agreed PGx testing is relevant to current practice; 94% agreed pharmacists should have some PGx knowledge	88% feel able to provide information on PGx testing; 26.1% can accurately apply results of PGx; 38% can identify medications that require PGx testing	
Karuna et al. ⁵²	Thailand	21 hospitals across Thailand	123 (69.1%)	Low (mean score 4.3 out of 10); 46.3% had knowledge scores <5 points	More than 90% "agreed/strongly agreed" PGx testing is important for patient care, helps improve efficacy and ADRs	30.9% indicated national PGx guidelines would support confidence	Conferences (20.1%)
Kudzi et al. ⁵⁴	Ghana	Seven health institutions in the Greater Accra Region and four academic institutions	29	42.8% rated their knowledge as "very poor" and "poor"	100% felt PGx relevant to profession and should be part of diagnosis and treatment; 65.5% feel likely/very likely that PGx can decrease ADRs		Continuing professional development training (100%)

(Continues)

TABLE 1 (Continued)

Pharmacists							
Main findings							
Reference	Location	Settings	Participants (% female)	Knowledge or awareness	Perceptions or attitudes	Confidence	Desire for further education and/or the most desired format
Mai et al. ⁵⁵	Greece	Pharmacists from three cities, mainly in western Greece	86 (44.2%)	Some 58% considered that they knew very little or nothing about PGx and personalized medicine	70% believe PGx testing could have a positive impact on patient medical care by rationalizing their drug prescription and dosage, frequency of medical appointments, and overall diagnoses	79% could not provide sufficient information or explain the results of PGx tests	58% interested in further PGx education
McCullough et al. ⁵⁶	United States	A large, academic, multicampus healthcare system	303		85% agree pharmacists should be required to have PGx knowledge; 48.5% agree PGx is relevant to clinical practice	14.2% agree they could apply the results of PGx tests; 25.8% agree they can identify medications that need PGx testing	Lecture format (live or online) (64%)
McMahon and Tucci ⁵⁷	Australia	Pharmacists practicing in Victoria	291	78% indicated PGx understanding was (score) <5 out of 10		37.2% felt they would counsel "poorly"	Seminars/workshops (79%)
Meloche et al. ⁵⁸	Canada	Pharmacists practicing in Quebec; internet-based	199 (67.8%)		Pharmacists (75%) were optimistic that PGx could determine either which drug or dosing could be more efficacious for a given patient; over 82% indicated they would feel comfortable recommending to their patients to undergo a PGx test to examine their genes if this test could identify an effective drug	14% felt comfortable receiving PGx test results and advising a patient or a physician right away and without further training	91% expressed interest in participating in a future PGx training program; the most popular learning method was e-learning through interactive video sessions (69%)
Nagy et al. ⁵⁹	Egypt	Paper-based, Children's Cancer Hospital Egypt	125	Low (mean score 43.2% out of 100%)	Mostly positive; 69.6% "strongly agree" that it is important to identify		95.2% interested in further PGx education

TABLE 1 (Continued)

Reference	Location	Settings	Participants (% female)	Main findings			Confidence	Desire for further education and/or the most desired format
				Knowledge or awareness	Perceptions or attitudes	Confidence		
Pearce et al. ⁶⁰	Australia	Three tertiary care hospitals located in Sydney	25 (49%)	Low (mean rating score 1.96 out of five)	PGx had a significantly higher utility in determining the optimal dose	PGx had a significantly higher utility in determining the optimal dose	medications that require PGx testing; 77.6% "agree" or "strongly agree" that it is their responsibility to apply PGx; 74.4% "agree" or "strongly agree" pharmacists should counsel on PGx results	
^a Rahma et al. ⁶¹	United Arab Emirates	Hospitals, clinics, and community pharmacies	38	More than one-third rated their knowledge of genomics and PGx as "poor"	Overall positive; some negative attitudes that PGx will not benefit them or why to learn it if not going to practice			
Rahma et al. ⁶²	United Arab Emirates	Internet-based, hospitals or clinics	232 (63.4%)	Fair (mean score 5.1 out of nine); 50.4% felt they had a fair knowledge				
Roederer et al. ⁶³	United States	Pharmacists licensed in the state of North Carolina	728	83% rated understanding of PGx as fair/poor	Overall positive; mean total positive attitude increased as self-reported knowledge increased			90.5% interested in further PGx education
Schwartz and Issa ⁶⁴	United States	Pharmacists from US hospitals	149 (51.4%)	68% are aware that PGx is currently being used in clinical practice	83% believe PGx will benefit patients; 87% optimistic PGx will change clinical practice	25% confident in interpreting PGx test results	94% were interested in PGx-related CE; online self-training (85%) was the most preferred method	
Shishko et al. ⁶⁵	United States, Indonesia,	Psychiatric pharmacists who belonged to the	91	47.2% perceived themselves as less	Perception was not significantly different			

(Continues)

TABLE 1 (Continued)

Pharmacists							
Main findings							
Reference	Location	Settings	Participants (% female)	Knowledge or awareness	Perceptions or attitudes	Confidence	Desire for further education and/or the most desired format
	Singapore, United Arab Emirates, Canada	College of Psychiatric and Neurologic Pharmacists (CPNP)		knowledgeable about PGx	between those with more perceived knowledge and those with less; Most agreed PGx testing has clinical utility in patient care; 17.1% said they did not see current and/or future advantages		
Tsuji et al. ⁶⁶	Japan	Pharmacists who were members of the Japanese Society of Pharmaceutical Health Care and Sciences (JSPHCS)	1313	62.1% disagree they understand PGx well	93.6% report PGx tests useful for personalized medicine; 72.6% report needing PGx knowledge for current work	95.3% agree PGx tests can improve efficacy and 91.7% agree PGx tests can decrease ADRs	65.3% prefer educational PGx books
Tuteja et al. ⁶⁷	United States	Community pharmacists in Ohio, internet-based	580 (47%)	Mean score 2.8 out of five; PharmDs had higher knowledge than BSc in both self-assessed and measured knowledge	Overall positive; PGx tests will decrease ADRs (87%), improve drug efficacy (86%), and optimize drug dose (87%); 44% agree PGx is relevant to practice setting		
Xuereb et al. ⁶⁸	Malta	Nationwide	179 (64.2%)	72.6% were aware of PGx resources but only 5% felt sufficiently competent	Positive; agreed PGx testing has clinical benefit (91.1%), can guide therapy selection (95.5%), and is applicable in practice (39.1%)	Low; 8.9% felt confident interpreting and 15.6% discussing PGx tests and results	
Pharmacy students							
Arafah et al. ⁶⁹	Saudi Arabia	King Saud University in Riyadh	552 (70.3%)	65.4% had moderate knowledge	58.3% may consider genetic tests to assess disease risk; 59.1% feel pharmacists should explain genome report		61.2% were interested in attending PGx course

TABLE 1 (Continued)

Pharmacists							
Main findings							
Reference	Location	Settings	Participants (% female)	Knowledge or awareness	Perceptions or attitudes	Confidence	Desire for further education and/or the most desired format
Bank et al. ⁷⁰	Netherlands	Internet-based, nationwide	148 (70.3%)		All responders believed in the concept of PGx; strongly believed PGx test will prevent wrong drug (37.2%), detect the most efficacious drug (44.6%), and reduce ADRs (29.1%)	27.7% felt qualified to receive PGx results, interpret genotype, and advise; 75% felt qualified to recommend PGx testing	
Coriolan et al. ⁷¹	United States	Eight schools or colleges of pharmacy in New York and New Jersey	339 (62.8%)		81% believed that PGx was a useful tool that pharmacists and medical professionals could use to optimize medication effectiveness and/or prevent adverse events; 63% affirmed that it was an integral part of the pharmacy profession		56% indicated their intentions of reading PGx-related literature after graduation
Filiptsova et al. ⁷²	Ukraine	National university of pharmacy	637 (87.4%)	37.7% of males and 43.9% of females answered correctly about PGx definition			
Jarrar et al. ⁷³	Jordan, West Bank of Palestine	Five Universities in Jordan and West Bank of Palestine	466 (77.3%)	84.1% knew some patients do not respond or have a high risk of toxicity (80.3%) due to genetic variants; 68.5% responded that the drug response could be predicted through PGx testing	90.3% felt PGx test can improve drug/dose choice; 82.4% want to apply PGx		Most (>92.7%) students wished to know more about PGx

(Continues)

TABLE 1 (Continued)

Pharmacists							
Main findings							
Reference	Location	Settings	Participants (% female)	Knowledge or awareness	Perceptions or attitudes	Confidence	Desire for further education and/or the most desired format
Mahmutovic et al. ⁷⁴	Bosnia and Herzegovina	Several universities	165 (85%)	57% heard about PGx testing companies	57% agree that personalized medicine represents a new and promising healthcare model; 31% were not sure		65% were interested in continuing postgraduate education in the field of personalized medicine
Moen and Lamba ⁷⁵	United States	The University of Minnesota	328	12.8% agreed or strongly agreed they knew which medications required PGx testing	Over 90% agreed or strongly agreed that PGx could improve patient care; 88.1% agreed or strongly agreed that their profession should be required to have some knowledge of PGx	61.9% disagreed or strongly disagreed that they were comfortable answering questions on PGx	
Rahma et al. ⁷⁶	United Arab Emirates	Universities or colleges, nationwide	149	Mean knowledge score 5.6 out of nine; 81.2% had either "good" or "fair" knowledge			
Shah et al. ⁷⁷	Pakistan	Different universities in Punjab, Pakistan	511 (58.9%)	Good (mean knowledge score 12.6) (<14 = good knowledge)	Good (mean score 5.23) (<6 = good attitude); 83.6% thought PGx testing could improve future work		58.9% wanted to study PGx in their postgraduate program
Siamoglou et al. ⁷⁸	Malaysia	The University of Malaya	82 (72.6%)	Students appeared moderately confident regarding their familiarity with the term, PGx and its as-association with individualized drug treatment; mean score 3.27 (felt adequately trained to draw a pedigree)	Overall positive; Mean scores of 3.90 (believe genetic tests should be available to everyone) and 3.90 (believe their use should be promoted)		

TABLE 1 (Continued)

Pharmacists							
Main findings							
Reference	Location	Settings	Participants (% female)	Knowledge or awareness	Perceptions or attitudes	Confidence	Desire for further education and/or the most desired format
Yau and Haque ⁷⁹	Malaysia	The Universiti Sains Malaysia	62 (69.85%)	Good (mean score 9.23); 91.94% were exposed to some aspect of PGx	Mostly positive (mean score 27.77)		
Yehya and Matalgah ⁸⁰	Jordan	Yarmouk University	161	Moderate (mean score of knowledge of genetics is 70.4 out of 100)	90% felt PGx tests improve the likelihood of achieving therapeutic goals, and 84% support providing PGx testing	Approximately 42% think they can explain the rationale of PGx testing	76% interested in further PGx education
Zawiah et al. ⁸¹	Jordan	The University of Jordan and Jordan University of Science and Technology	402 (74.4%)	Fair (mean percentage knowledge score is 49 out of 100)	Overall positive (mean score 4.65 out of seven)		
<i>Pharmacy and pharmacy students (combined results)</i>							
Abdela et al. ⁸²	Ethiopia	The University of Gondar Referral and Teaching Hospital	70 (40.4%)	Limited (mean score 2.67 out of five)	Positive; 90% agree PGx will allow the right drug to be selected with fewer ADRs	35.7% can accurately apply the results of PGx tests	83.2% requested to have further training
Muzoriana et al. ⁸³	Zimbabwe	Practicing pharmacists in Zimbabwe and students from the University of Zimbabwe-College of Health Sciences	131 (36%)	88% had below-average knowledge scores; 61% self-assessed as average or very weak for PGx knowledge	Overall positive; 80% felt PGx tests will decrease ADRs; 74% felt PGx relevant to current practice, and 94% felt pharmacists should be knowledgeable in PGx		

(Continues)

TABLE 1 (Continued)

Pharmacists							
Main findings							
Reference	Location	Settings	Participants (% female)	Knowledge or awareness	Perceptions or attitudes	Confidence	Desire for further education and/or the most desired format
Petit et al. ⁸⁴	Canada	Practicing pharmacists in Quebec and students from the University of Montreal and Laval University	135	Mean "right answer" score 8.49 out of 15; 95.6% agreed that there is a risk of misinterpretation of direct-to-consumer tests if offered without counseling by a professional	Very positive (mean score 11 out of 12); 83% agreed pharmacists should take a leadership role in PGx tests; 80.7% agree PGx will become common in their future practice	9.6% felt competent in interpreting and recommending PGx tests	90.3% interested in further PGx education

Note: The level of knowledge (e.g., low/moderate/positive/negative/poor) was designated as per the original study. No statistical comparisons were made between the studies.

Abbreviations: ADRs, adverse drug reactions; CE, continuing education; PGx, pharmacogenomics.

^aQualitative studies.

appropriate PGx test and interpret and apply the test results to a therapeutic plan. Only five studies out of 16 studies investigated the confidence level of pharmacy students in utilizing PGx testing, which is understandable as they are yet to get clinical experience, and there was a consensus of low or weak confidence among pharmacy students in using PGx testing.^{70,75,80,82,84} In one study in Thailand, more than 30% of the pharmacists felt that national PGx guidelines would increase their confidence in clinical implementation.⁵² It is worth noting that some PGx testing has been adopted (e.g., human leukocyte antigens testing) at the national level via genetic ID card systems in Thailand⁸⁶ and via electronic drug prescribing and dispensing systems in the Netherlands.⁸⁷ Interestingly in a 2018 study, 75% of the pharmacy students from the Netherlands felt qualified to recommend PGx testing in their future practice.⁷⁰ A low level of PGx knowledge combined with pharmacists' low self-confidence has been identified as one of the critical barriers to clinical implementation in most of the included studies, and this trend is not country-specific (Table 1).

3.7 | PGx education need

Looking to the future of integration of PGx in pharmacy practice and how to best prepare current and future pharmacists, 27 articles assessed participants' desire for further PGx education.^{31,37-40,42-44,46,47,55-59,63,64,66,69,71,73,74,77,80,82,84} They found most participants were interested in PGx education, while some reported more than 90% of respondents desired further PGx education.^{42,44,58,59,63,64,84} Some even commented that their confidence in using PGx in practice depends on if they get further PGx education or training.⁵⁸ Two studies that reported a slightly lower level of interest (44.2% and 58%) were conducted in 2012 (United States) and 2014 (Greece), respectively.^{43,55} Regarding the delivery of PGx education, the most desired formats were online or live lectures, seminars, workshops, or web-based continuing education (CE) (Table 1). In a study in the Canadian province of Quebec, 69% of the respondents preferred e-learning through interactive video sessions.⁵⁸

3.8 | Critical appraisal

The CEBMa's critical appraisal tools for surveys and qualitative studies³⁴ were used to appraise 49 survey-based studies (Supporting Information S1: Table 2) and the three qualitative studies (Supporting Information S1: Table 3). Most studies were very clear in their objectives and used appropriate tools (new or updated versions of previously used tools) to support research findings. The questionnaires (measurements) used in the studies are likely to be valid; however, the reliability of these measurements is unclear. The studies used convenience sampling which introduced some obvious bias in sampling methodology. Very few studies^{31,35,40,47,53,62,73,79} calculated sample size based on a priori

samples. In most cases, the sample size did not represent the total population, and the participation rate was around 10% (higher for studies with pharmacy students) which is typical for these types of studies. Most studies used descriptive analyses and measured statistical significance.

4 | DISCUSSION

One previous systematic review investigated the attitudes of patients, general practitioners, and pharmacists in primary care (included six studies with pharmacists),⁸⁸ and a recent one investigated the knowledge and attitudes of medical and pharmacy students toward PGx (included 13 studies with pharmacy studies).²⁹ The findings from this review and previous reviews reveal a global consensus among researchers and pharmacy professionals that PGx is gaining traction as a key avenue for applying precision medicine in healthcare. However, we have more work to do to prepare current and future pharmacists to take on the “PGx expert” role as a new standard of patient care.

Despite the general absence of PGx currently being incorporated into pharmacy practice, there is enough known about the benefits of PGx testing in precision medicine for pharmacists and pharmacy students to feel positive about using PGx in pharmacy practice.^{11,27,89} This perception seemed to be held globally, as there was no regional distinction between those studies that reported strong positive attitudes and those that revealed slightly more conservative views toward PGx by some pharmacists in Australia (2014 study)⁴⁵ and Syria (2021 study).³⁶ Furthermore, studies from more than 8 years ago may have been affected by the lack of robust clinical evidence and education at that time.^{45,65} The perceptions and attitudes toward PGx illustrated that pharmacists and pharmacy students agreed PGx testing would improve patient safety through individualization of treatment plans and avoidance of adverse effects linked to genetic differences in drug metabolism. Few studies reported that PGx is not applicable to their current practice,^{37,61,68} which may be a reflection of a lack of infrastructure for the incorporation of PGx testing into practice rather than a negative view of its applicability. Previous research revealed that other healthcare professionals also feel that pharmacists should take on a leadership role in providing PGx services and should be a resource that other healthcare providers can turn to for recommendations on the appropriate use of testing.^{35,48,88} The National Health Service Improvement and Genomics England announced plans in 2020 to implement PGx testing within the next 10 years. They also acknowledged the essential roles of pharmacists within the implementation model.⁹⁰ With various pharmacy groups worldwide advocating that pharmacists be the face of these implementation efforts and the anticipated widespread availability of low-cost direct-to-consumer PGx tests, it is not now a question of “whether,” but “when” and “how” pharmacists, the most accessible healthcare professionals, will be incorporating PGx testing into their day-to-day practice.⁹¹

Several barriers exist to the implementation of PGx testing into pharmacy practice. These include uncertainty about clinical efficacy, difficulty selecting who and when to test, lack of standardization and regulation, and difficulty coordinating with the prescribing physician. In addition, the lack of access to electronic medical records (EMR) to document PGx results, lack of automated EMR infrastructure to flag potential PGx interactions, and pharmacists being at the point of dispensing rather than the point of prescribing causes inconvenience for patients. Moreover, the lack of reimbursement for pharmacists' time to educate patients, some jurisdiction's view of collecting samples is out of scope of pharmacy practice, religious or cultural values, and the cost burden for patients associated with the testing further contribute to the complexity of integration. This adds to an overall lack of knowledge about PGx and a low confidence level in applying knowledge into practice without proper training.^{27,32} It appears that pharmacy students were more likely to report a moderate to good level of knowledge (Table 1), which may be due to updates in pharmacy curriculums to include newer concepts of individualized healthcare. This theory is supported by Tuteja et al.,⁶⁷ who reported that participants with Doctor of Pharmacy (PharmD) degrees (the most up-to-date pharmacy degree) had a higher level of knowledge, reflecting an increased prevalence of PGx education in current pharmacy programs. A 2019 global survey concluded that over 82% of pharmacy and medical programs worldwide contained PGx as a standalone subject or part of the “pharmacology” courses.⁹² Currently, the Accreditation Council for Pharmacy Education in the United States requires that all colleges/schools of pharmacy teach PGx in their curricula.⁹³ A 2018 study in Kuwait found that pharmacists with 10 or more years of experience had significantly better knowledge than those less experienced.³⁵ This contrasts with another study in Malaysia that found pharmacists with fewer years of experience had more PGx knowledge, likely highlighting differences in PGx education.⁷⁸ The noted discrepancy in subjective (self-assessed) and objective knowledge about study participants is another key barrier to the implementation of PGx in pharmacy practice, reflecting a low level of confidence in their ability to identify medications that require PGx testing, and then accurately interpret, advise, and counsel on the results.²⁷ Some researchers attributed this confidence deficit to a limited familiarity with PGx in general, which again describes a widespread lack of knowledge on the topic. The Kuwait study noted that most respondents identified a lack of education or training as their most significant barrier to implementing PGx testing in practice.³⁵ The lack of standardized PGx guidelines and resources for pharmacy practice also contributes to pharmacists' hesitation to incorporate PGx testing into standard patient care, further illustrating the lack of awareness about available PGx resources. A low level of recognition of available PGx resources, including the US FDA labeling available on certain medications regarding PGx, also adds to the clinical implementation problem. These barriers are not solely isolated to the pharmacy profession, as several studies included in this review also surveyed physicians who identified a similar lack of knowledge and confidence toward PGx. This highlights the need for more comprehensive PGx education

across healthcare professions, hopefully facilitating a collaborative multidisciplinary approach that we strive toward in the 21st century and improving trust and communication between healthcare professionals when providing individualized, patient-centered care.

Improved education for pharmacists would facilitate their ability to educate other healthcare professionals and patients about the benefits of PGx testing and its application in optimized care.³¹ About half of the articles included in this review assessed participants' desire for further education on the topic of PGx, with a majority of these reporting a strong desire for future education in the form of CE (Table 1). Studies that reported a moderately positive response were from 2012 to 2014, once again reflecting an increased understanding of the need for PGx knowledge and awareness in the profession in more recent years. Although there was not one specific format for CE delivery that was more highly requested, e-learning or web-based CE was mentioned in several articles and would likely be the most convenient format for the widespread delivery of PGx education for practicing pharmacists.^{41,42,44,56,58,64}

5 | LIMITATIONS

This systematic review has some caveats. First, we included articles up to May 17, 2022. As the field of PGx is progressing rapidly, we acknowledge that the review may not represent the most "up-to-date" scenario on this topic. Second, we recognize that we may have missed some articles if they were not in the included databases or they were not in English. Third, the methodology and tools used for measuring or understanding knowledge, perception, or confidence vary between studies. Therefore, caution should be taken in generalizing the findings from the review for specific countries, regions, or practice settings. Fourth, the "time (year)" when the study was conducted could influence as more interest/education is being received on PGx for pharmacists and pharmacy students over time. Finally, the conclusions drawn from this review are not unexpected. However, the strength of this review lies in its coverage of the observations made by researchers across the globe.

Regarding limitations of the included studies, most acknowledged that confounding factors were not accounted for due to research methodology and the method of choosing participants. Most studies did not represent the population or region being studied due to convenience sampling, only including participants from a particular practice setting, regions, or institutions of the country, and a small sample size. This reduces the generalizability of the results. The reliability of the questionnaires (measurements) is also unclear and future studies should address this gap to draw definitive conclusions. No studies used behavioral theories in understanding confidence and attitudes toward PGx. Other limitations included a variety of biases noted by the study authors. Recall or response bias was a significant issue as responses were mainly voluntary and based on self-assessed knowledge, attitude, and confidence. There is also a risk of self-selection bias, as those with more PGx knowledge or interest may be more likely to participate in the studies. Similarly,

many surveys were delivered in a web-based format that may have encouraged younger or more tech-savvy participants to complete the survey. Moreover, varying outcomes reported in the results section (e.g., confidence and interest in education) may depend on whether pharmacists received PGx training in pharmacy school or as a CE. Most surveys used a Likert or Likert-type scale to measure responses introducing the risk of central tendency bias. Participants may respond with more neutral answers resulting in less accurate responses. Finally, there was a risk of survey fatigue for longer questionnaires, and some studies noted an inability to identify duplicate survey responses that might have skewed data.

6 | CONCLUSION

This review identified a limited application of PGx in pharmacy practice, overwhelming agreement of pharmacists and pharmacy students on the benefits of using PGx in routine pharmacy practice from across the globe, and the need for additional PGx training and education despite inherent limitations of PGx testing and numerous barriers to implementation. The inclusion of PGx education as a required course in pharmacy programs would prepare the next generation of pharmacists to take PGx counseling as a regular part of their standard patient care duties. Academic pharmacy programs should also focus on developing training programs for practicing pharmacists, which should be accessible (online-based or hybrid, low-cost), interactive (hands-on clinical training, experiential education), and rewarding (CE credits, certifications).

AUTHOR CONTRIBUTIONS

All authors have read and approved the final version of the manuscript. Abdullah Al Maruf (corresponding author) has full access to all of the data in this study and takes complete responsibility for the integrity of the data and the accuracy of the data analysis.

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CONFLICT OF INTEREST STATEMENT

The authors declare no conflict of interest.

DATA AVAILABILITY STATEMENT

All data generated/analyzed during this study are included in this article.

TRANSPARENCY STATEMENT

The lead author Abdullah Al Maruf affirms that this manuscript is an honest, accurate, and transparent account of the study being reported; that no important aspects of the study have been omitted;

and that any discrepancies from the study as planned (and, if relevant, registered) have been explained.

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