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RESEARCH ARTICLE

Five decades of cancer research in Jordan: A thematic mapping of clinical, translational, and emerging technological trends (1974–2024)

Yasser Bustanji[1,2,3], Amani A. Harb[4], Jalal Taneera[1,2,3], Shereen M. Aleidi[1,3,5], Rula Darwish[1], Ahmad Y. Abuhelwa[3,5], Mahmoud Al-Masri[6], Islam Hamad[7], Kamal Al-Rabi[6], Waseem El-Huneidi[2,3], Eman Abu-Gharbieh[1,2,3] and Mohammad H. Semreen[3,5]

1. School of Pharmacy, The University of Jordan, Amman 11942, Jordan.
2. College of Medicine, University of Sharjah, Sharjah 27272, United Arab Emirates.
3. Research Institute of Medical and Health Sciences, University of Sharjah, Sharjah 27272, United Arab Emirates.
4. Department of Allied Sciences, Faculty of Arts and Sciences, Al-Ahliyya Amman University, Amman 19111, Jordan.
5. College of Pharmacy, University of Sharjah, Sharjah 27272, United Arab Emirates.
6. King Hussein Cancer Center, Amman, Jordan.
7. Department of Pharmacy, Faculty of Health Sciences, American University of Madaba, Amman, Jordan.

ABSTRACT

Background and Aim: Cancer represents a major public health challenge in Jordan and remains one of the leading causes of morbidity and mortality. Over the past five decades, Jordan has developed a substantial body of cancer-related research spanning clinical, epidemiological, translational, and technological domains. However, the thematic evolution and intellectual structure of this research landscape have not been comprehensively characterized. This study aimed to map the thematic organization, temporal evolution, and citation impact of cancer research conducted in Jordan between 1974 and 2024.

Materials and Methods: A thematic mapping study was performed using the Scopus database. Peer-reviewed English-language journal articles published between January 1974 and December 2024 and involving at least one Jordanian institutional affiliation were retrieved. After manual screening and removal of irrelevant records, eligible publications were exported and analyzed using VOSviewer version 1.6.20. Author-keyword co-occurrence analysis was conducted to identify major research themes. Temporal and normalized citation overlay visualizations were generated to evaluate thematic development and scholarly influence over time. A custom thesaurus file was applied to standardize keyword variations and improve clustering accuracy.

Results: Of 5,073 retrieved records, 4,567 met the inclusion criteria. Analysis identified 33 high-frequency keywords grouped into five major thematic clusters. These included: (i) epidemiology, diagnostics, and computational approaches in major cancers; (ii) clinical management, prognosis, survival outcomes, and pediatric oncology; (iii) experimental therapeutics, cytotoxicity screening, apoptosis, molecular docking, and quantitative structure–activity relationship studies; (iv) palliative care and quality-of-life research; and (v) nanotechnology-based drug delivery and targeted therapeutics. Temporal overlay analysis demonstrated a progressive shift from predominantly clinical and epidemiological investigations toward translational, computational, and nanomedicine-oriented research. Citation analysis showed that established clinical themes maintained strong scholarly influence, whereas emerging areas such as machine learning, molecular modeling, and nanotechnology exhibited rapid growth and increasing scientific attention. The integration of experimental models, computational tools, and translational approaches highlighted the maturation of Jordan's oncology research ecosystem.

Conclusion: Cancer research in Jordan has evolved from a strong clinical and epidemiological foundation into an increasingly interdisciplinary and technology-driven field. The growing integration of artificial intelligence, molecular research, nanotechnology, and translational oncology reflects enhanced research capacity and alignment with global scientific priorities. These findings provide valuable evidence for future research planning, capacity building, policy development, and collaborative initiatives aimed at advancing cancer control and oncology innovation.

Keywords: artificial intelligence, bibliometric analysis, cancer research, Jordan, nanomedicine, oncology, thematic mapping, translational research.

Corresponding Author: Yasser Bustanji
E-mail: ybustanji@sharjah.ac.ae
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Co-authors: AAH: a.harb@ammanu.edu.jo; JT: jtaneera@sharjah.ac.ae; SMA: s.aleidi@ju.edu.jo; RD: rulad@ju.edu.jo; AYA: Ahmad.Abuhelwa@sharjah.ac.ae; MAM: malmasri@khcc.jo; IH: i.hamad@aum.edu.jo; KAR: ka.10798@khcc.jo; WEH: welhuneidi@sharjah.ac.ae; EAG: eabugharbieh@sharjah.ac.ae; MHS: msemreen@sharjah.ac.ae
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INTRODUCTION

Cancer continues to be a significant global health challenge. In 2023, approximately 18.5 million new cancer cases and 10.4 million cancer-related deaths were reported worldwide [1]. The global cancer burden is projected to increase substantially, with incidence expected to reach approximately 30.5 million new cases and mortality 18.6 million deaths by 2050, reflecting population growth, aging demographics, and evolving risk factor profiles [1].

The projected increase is particularly pronounced in countries with lower levels of development. Low Human Development Index (HDI) countries are expected to experience a 142% increase in cancer incidence, whereas medium-HDI countries may experience a 99% increase [2, 3]. Similarly, cancer-related mortality in these regions is anticipated to increase dramatically by 2050 [2, 3]. These projections highlight substantial global expansion of the cancer burden, with disproportionately greater increases occurring in lower-HDI settings.

These trends emphasize the need for continuous advances in cancer prevention, early detection, treatment, and research. Despite the global prevalence of cancer, research output remains heavily concentrated in high-income countries. Low- and middle-income countries (LMICs), which account for an increasing proportion of the global cancer burden, contribute comparatively less to the cancer research literature, raising concerns regarding the availability of evidence tailored to regional cancer patterns, risk factors, and health-system challenges [4]. Strengthening research capacity in LMICs is therefore essential for generating locally relevant evidence, informing context-specific interventions, and supporting global cancer control efforts.

Cancer remains a major public health challenge in Jordan and is currently the second leading cause of death in the country [5]. According to GLOBOCAN 2022 estimates, Jordan recorded 12,328 new cancer cases and 6,458 cancer-related deaths across all age groups and both sexes [6]. The national cancer burden is expected to increase further in the coming decades because of demographic transitions and lifestyle-related risk factors [2, 3]. Breast, colorectal, and lung cancers are among the most commonly diagnosed malignancies in Jordan, reflecting patterns observed globally. To address this growing challenge, Jordan launched the National Cancer Control Plan (2023–2030) following an imPACT review conducted in collaboration with the International Atomic Energy Agency, the World Health Organization, and the International Agency for Research on Cancer [7].

Jordan is recognized as a regional leader in cancer care and research within the Arab world. Despite considerable advances in cancer infrastructure, including the King Hussein Cancer Center (KHCC) and national screening initiatives such as the Jordan Breast Cancer Program (JBCP), Jordan's contribution to the global cancer literature has historically been underrepresented. KHCC was established in 1997 as a comprehensive, non-governmental, non-profit cancer institution dedicated to providing specialized cancer care for adults and children in Jordan and neighboring countries. The King Hussein Cancer Foundation was established in 2001 by Royal Decree to lead national cancer control initiatives and support strategic oncology programs [8, 9].

KHCC manages more than 60% of cancer cases diagnosed nationally and leads major public health initiatives, including breast and colorectal cancer screening programs, tobacco-control campaigns, and public education activities that facilitate both service delivery and research translation [10]. The JBCP, established in 2007 in collaboration with the Ministry of Health, focuses on increasing awareness, promoting early diagnosis, and facilitating the detection of breast cancer at more treatable stages [11, 12]. Subsequent evaluations have demonstrated improvements in public awareness, increased screening participation, and earlier-stage diagnosis among participants [10–12]. Furthermore, cancer treatment for Jordanian citizens is largely funded by national healthcare services and the KHCC, promoting equitable access to screening, treatment, and follow-up care [10].

Over the past five decades, cancer research in Jordan has expanded across clinical, epidemiological, translational, and technological domains. This growth has contributed valuable insights to the global oncology literature, as demonstrated in our previous bibliometric assessment [13]. While the earlier study quantified research productivity, publication trends, and citation impact, it did not explore the thematic structure, intellectual organization, or temporal evolution of research topics [13]. Understanding how research themes emerge, interact, and evolve over time is critical for identifying strengths, knowledge gaps, and future opportunities within the national oncology research ecosystem.

Although several bibliometric investigations have evaluated cancer research productivity in different countries, comprehensive thematic evolution studies remain scarce, particularly in Jordan and the broader Arab and Middle East and North Africa region. Existing studies have largely focused on publication volume, citation indicators, institutional productivity, or specific clinical topics, providing limited insight into the conceptual

structure and interdisciplinary development of cancer research. Moreover, no previous study has systematically integrated author-keyword co-occurrence analysis with temporal and citation overlay mapping to examine how research priorities have evolved over an extended period. Consequently, important questions remain regarding the thematic organization of Jordanian cancer research, the emergence of translational and technology-driven fields, the integration of computational and experimental approaches, and the extent to which national research activities align with contemporary global oncology priorities. Addressing these knowledge gaps is essential for guiding future research investment, capacity building, collaborative initiatives, and evidence-based cancer control policies.

Therefore, this study aimed to comprehensively map the thematic landscape and temporal evolution of cancer research conducted in Jordan between 1974 and 2024. Using VOSviewer-based bibliometric mapping of author-assigned keywords, we sought to identify major research themes, characterize their conceptual relationships, evaluate their temporal development, and assess their relative citation impact. Furthermore, the study aimed to examine the progression of Jordanian oncology research from predominantly clinical and epidemiological investigations toward increasingly translational, computational, molecular, and nanotechnology-oriented domains. By providing a systems-level understanding of thematic evolution over five decades, this work offers evidence to support future research prioritization, infrastructure development, interdisciplinary collaboration, policy formulation, and innovation in cancer prevention, diagnosis, and treatment. In addition, the findings highlight the growing integration of molecular research, computational methodologies, and experimental models, including animal-based studies, which collectively contribute to advancing both human and veterinary medicine within a One Health framework.

MATERIALS AND METHODS

Ethical approval

Ethical approval was not required for this study because all data were obtained from publicly available bibliographic records indexed in the Scopus database. The study did not involve human participants, animals, biological specimens, confidential patient information, or interventions requiring institutional ethical review. All analyses were conducted using published metadata and bibliographic information in accordance with the terms of use of the Scopus database.

Study period and location

The study analyzed cancer-related research publications affiliated with institutions in Jordan and indexed in the Scopus database between January 1974 and December 2024. Data retrieval, screening, and bibliometric analyses were performed during 2025.

Study design

This study employed a bibliometric thematic mapping design to evaluate the thematic structure, temporal evolution, and citation impact of cancer research conducted in Jordan. Author-keyword co-occurrence analysis was combined with temporal and normalized citation overlay visualization to identify major research themes and emerging trends. The integration of these complementary bibliometric approaches enabled a comprehensive assessment of the evolution of cancer research over a 50-year period. While many bibliometric studies rely on a single mapping technique, the present study combined keyword co-occurrence mapping, temporal overlay analysis, and normalized citation overlay analysis to provide a more comprehensive understanding of thematic development and scholarly influence in Jordanian cancer research.

Data source and search strategy

The search methodology was adapted from our previously published bibliometric studies [14–16] with minor modifications. A comprehensive literature search was conducted using the Scopus database because of its extensive multidisciplinary coverage, robust bibliometric architecture, and substantial indexing overlap with major scientific databases, including PubMed and Web of Science [14–16]. These characteristics make Scopus particularly suitable for large-scale thematic mapping and citation-based analyses.

The search retrieved cancer-related research articles affiliated with institutions in Jordan and published between January 1974 and December 2024. The following search query was applied:

TITLE-ABS-KEY ((*cancer OR cytotoxicity OR malignan** OR *carcinoma OR *sarcoma OR "cytotoxic effect" OR "anti-proliferative" OR "antiproliferative")) AND PUBYEAR > 1973 AND PUBYEAR < 2025 AND (LIMIT-TO

(AFFILCOUNTRY, "Jordan")) AND (LIMIT-TO (PUBSTAGE, "final")) AND (LIMIT-TO (LANGUAGE, "English")) AND (LIMIT-TO (DOCTYPE, "ar")) AND (LIMIT-TO (SRCTYPE, "j"))

The search strategy was designed to capture a broad spectrum of cancer-related research. In addition to conventional oncology terms, the query deliberately included preclinical terminology such as cytotoxicity and antiproliferative activity to ensure the inclusion of experimental and translational studies. This approach enabled the identification of both clinical and preclinical cancer research, thereby providing a more comprehensive representation of Jordan's oncology research landscape.

Eligibility criteria

The search was restricted to records containing at least one author affiliated with a Jordanian institution to ensure that the retrieved publications reflected Jordan's contribution to cancer research. Only original peer-reviewed journal articles were included in the analysis. Reviews, conference proceedings, book chapters, editorials, notes, letters, and other non-original publication types were excluded. In addition, only English-language publications were considered because English is the primary language of international scientific communication. These eligibility criteria ensured that the analysis focused exclusively on original cancer research output originating from Jordan.

Data retrieval and preparation

All eligible records were exported from the Scopus database in comma-separated values (CSV) format. The retrieved dataset underwent a detailed manual review to remove duplicate records, resolve inconsistencies in bibliographic information, and eliminate ambiguous or irrelevant entries. A final verification step was performed through independent examination of article titles and abstracts to confirm the relevance of each publication to cancer research. Studies that were not directly related to cancer research were excluded from further analysis.

This manual screening process enhanced dataset quality and relevance and provided an additional level of methodological rigor compared with fully automated bibliometric approaches. The final curated dataset served as the basis for subsequent thematic mapping and visualization analyses.

Keyword analysis and visualization

Keyword analysis and visualization were conducted using VOSviewer version 1.6.20 [17]. The software was used to perform scientific mapping and keyword co-occurrence analysis to characterize the intellectual structure of cancer research in Jordan and to identify dominant thematic areas and their temporal evolution.

To improve the quality and interpretability of the visual outputs, a custom thesaurus file (Table S1) was developed to standardize synonymous terms and consolidate keyword variations. Singular and plural forms were merged, and semantically similar expressions, such as "nanoparticle," "nanoparticles," and "nanomedicine," were unified into common categories [18]. This standardization process reduced fragmentation and improved clustering accuracy.

Keywords were included in the analysis only if they appeared at least 30 times within the dataset. This threshold was selected to minimize noise from infrequently occurring terms while ensuring the inclusion of keywords representing major research themes. The selected threshold provided an appropriate balance between sensitivity and specificity, allowing the identification of robust thematic patterns while maintaining visualization clarity. Consequently, the generated keyword maps and thematic clusters provided a comprehensive evidence-based overview of the evolution and thematic organization of cancer research conducted in Jordan over the past five decades.

RESULTS

Analysis of author keywords and thematic research trends

A total of 5,073 articles were initially retrieved based on the predefined search criteria. Following manual screening and removal of unrelated records, 4,567 articles met the eligibility criteria and were included in the final analysis. Author-keyword co-occurrence analysis was performed using VOSviewer to identify major research themes, trends, and priorities within Jordanian cancer research. A custom thesaurus file was applied to standardize keyword variations and improve dataset consistency. Only keywords appearing at least 30 times were included in the final analysis, resulting in 33 high-frequency keywords.

VOSviewer analysis identified five major thematic clusters within Jordanian cancer research (Figure 1, Table S2). The first cluster (red) comprised keywords including breast cancer, colon cancer, lung cancer, cervical cancer,

COVID-19, immunohistochemistry (IHC), and machine learning. This cluster highlights a strong research focus on the epidemiology, diagnosis, and molecular characterization of common malignancies, as well as the growing use of computational approaches for diagnostic and prognostic modeling.

The second cluster (green) included chemotherapy, radiotherapy, metastasis, prognosis, survival, bladder cancer, retinoblastoma, and children, reflecting substantial research activity in clinical oncology, therapeutic outcomes, survival analysis, and pediatric cancer management.

The third cluster (blue) encompassed anticancer activity, apoptosis, cytotoxicity, antioxidant activity, molecular docking, and quantitative structure–activity relationship (QSAR) studies. This cluster primarily represents mechanistic investigations focused on the induction of apoptosis, cytotoxic effects, and structure–activity relationships of potential anticancer compounds.

The fourth cluster (yellow), comprising palliative care, quality-of-life, and cancer-related terms, reflects a growing emphasis on patient-centered research and highlights increasing attention to the psychosocial, supportive, and survivorship aspects of cancer management.

The fifth cluster (purple) was characterized by nanoparticles, doxorubicin, and drug delivery, representing the emerging field of nanotechnology-based therapeutics. Research within this cluster focuses on improving drug delivery efficiency, enhancing therapeutic efficacy, and reducing systemic toxicity through targeted treatment approaches.

Collectively, the interconnected clusters illustrate a dynamic and evolving cancer research landscape in Jordan. The thematic structure demonstrates a gradual transition from predominantly descriptive and clinically oriented studies toward increasingly mechanistic, translational, computational, and technology-driven research that aligns with contemporary global oncology trends.

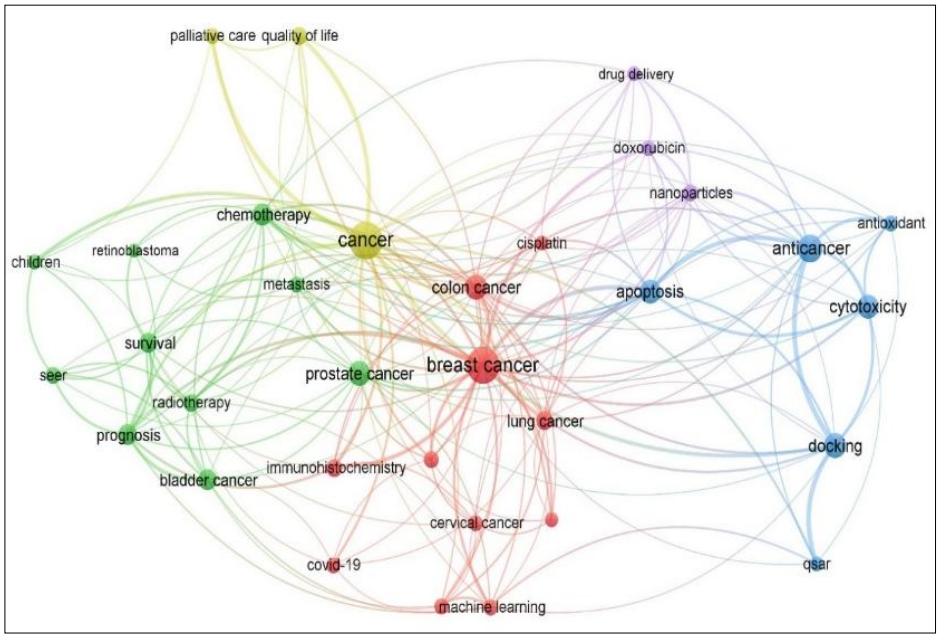

Figure 1: Network visualization map generated using VOSviewer, illustrating the co-occurrence relationships among the most frequent author keywords (≥30 occurrences) in Jordanian cancer research (1974–2024). Node size reflects keyword frequency, whereas line thickness represents the strength of co-occurrence links between keywords. Colors indicate thematic clusters identified by the software.

Temporal evolution of author keywords

To examine the temporal development of research themes, two bibliometric overlay visualizations were generated using VOSviewer (Figure 2). Figure 2A presents the temporal overlay map, in which the color gradient ranges from blue (earlier average publication years) to yellow (more recent average publication years).

Earlier research predominantly focused on traditional and clinically relevant topics, including cancer, breast cancer, and colon cancer, which are represented by blue and green shades, indicating their long-standing presence within the literature. Keywords of intermediate temporal prominence, such as apoptosis, chemotherapy, and prognosis, demonstrated sustained relevance across multiple decades.

In contrast, more recently emerging research areas, including COVID-19, nanoparticles, machine learning, and molecular docking, are represented by bright yellow colors, indicating their recent emergence and increasing

prominence within the scientific literature. These findings demonstrate a progressive diversification of Jordanian cancer research toward computational, molecular, and nanotechnology-driven domains that mirror current global research priorities.

Citation impact of author keywords

Figure 2B illustrates the normalized citation overlay map, providing insight into the relative citation performance of keywords within the research network. In this visualization, node size corresponds to keyword frequency, whereas the color gradient from blue to yellow reflects normalized citation impact, with yellow indicating higher relative citation influence.

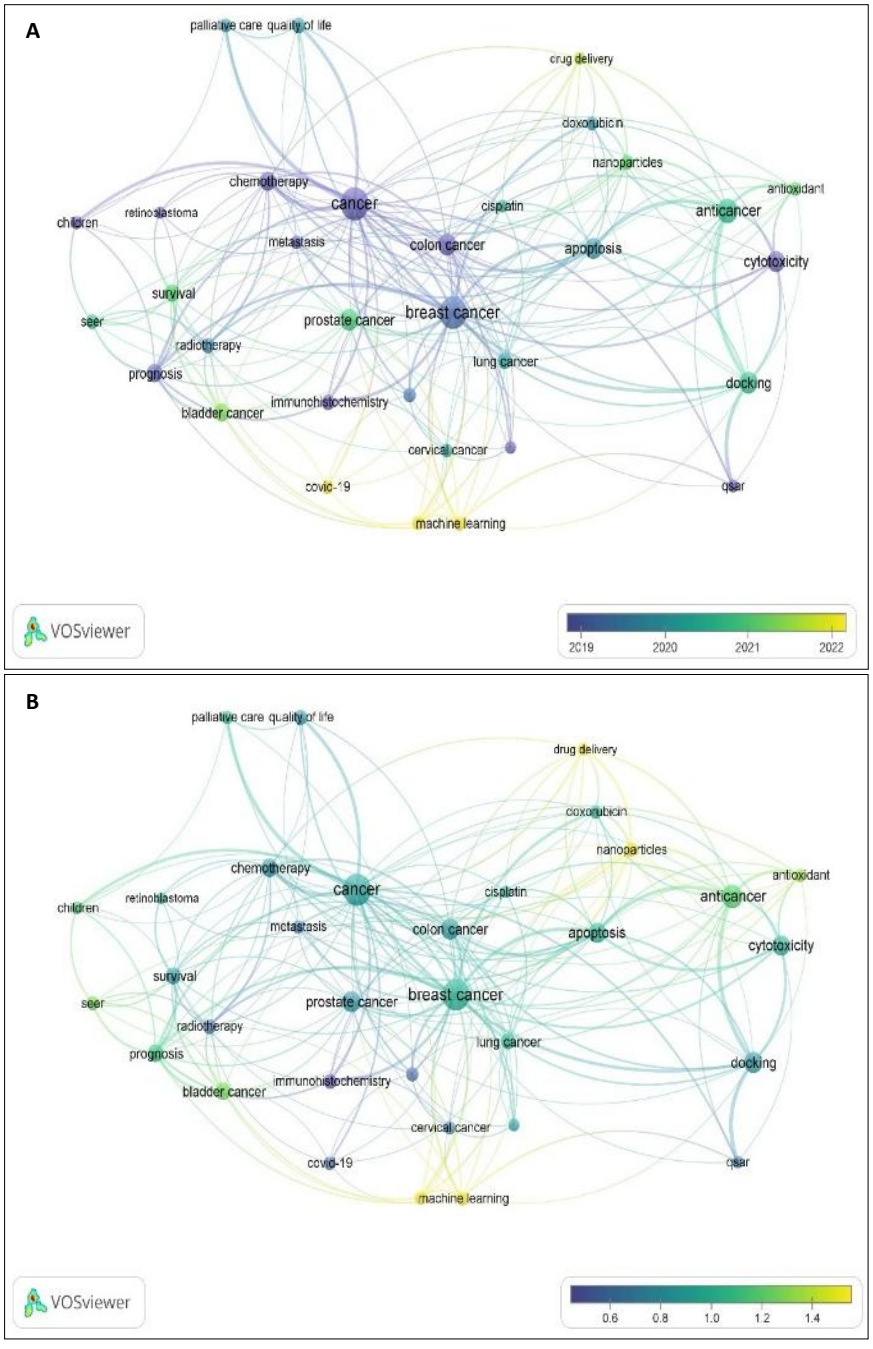

Figure 2: (A) Overlay visualization of author keywords showing keyword frequency and average publication year, with colors ranging from blue (earlier themes) to yellow (more recent themes). (B) Overlay visualization of the normalized citation impact of author keywords, with colors indicating relative citation influence across thematic areas in Jordanian cancer research.

Established clinical themes, including cancer, breast cancer, and colon cancer, exhibited strong normalized citation impact, reflecting their enduring scientific relevance and sustained influence within the literature. Conversely, emerging technological domains such as nanomedicine and machine learning demonstrated rapid increases in keyword frequency but comparatively lower citation accumulation, likely reflecting their more recent introduction into the research landscape.

These findings indicate the presence of a maturing oncology research ecosystem in Jordan, in which traditional clinical and epidemiological studies continue to exert substantial scholarly influence while newer technological disciplines are experiencing rapid expansion. The overlay visualization further demonstrates that keywords associated with clinical outcomes, including chemotherapy, radiotherapy, metastasis, prognosis, and survival, emerged earlier and constitute the foundation of the research network.

Nanomedicine-related terms, including nanoparticles, doxorubicin, and drug delivery, displayed intermediate green-to-yellow coloration, indicating their emergence as an important translational research frontier. Cross-cluster connectivity revealed strong interactions between nanotechnology-related keywords and mechanistic research terms, particularly cytotoxicity and apoptosis, highlighting increasing interdisciplinary integration between experimental oncology and advanced drug delivery research.

Machine learning and COVID-19 occupied more recent positions within the network and exhibited close associations with major tumor types and IHC-related investigations, illustrating the growing integration of computational methodologies and digital-health approaches into cancer research. Similarly, pediatric oncology and cancer-registry-related research, including studies involving retinoblastoma, children, and the Surveillance, Epidemiology, and End Results (SEER) database, formed smaller but consistent thematic components within the overall network.

Overall, the temporal and citation overlay analyses demonstrate that Jordanian cancer research has evolved from a predominantly clinic-centered and pathology-focused discipline toward a more diversified research environment incorporating molecular screening, computational technologies, artificial intelligence, and nanotechnology-based therapeutic strategies while maintaining strong connections to major cancer types and clinically relevant outcomes.

DISCUSSION

This study provides a comprehensive thematic mapping of cancer research conducted in Jordan over the past five decades. Through author-keyword clustering and temporal overlay analyses, the findings reveal how the field has evolved and diversified over time. Five major thematic domains were identified (Figure 1): epidemiology and diagnostics of major cancers with increasing computational integration; clinical management, therapeutic outcomes, and pediatric oncology; mechanistic and experimental investigations, including molecular docking and QSAR studies; palliative care and quality-of-life research; and nanotechnology-based drug delivery systems. Collectively, these themes demonstrate that Jordanian cancer research has progressed from a predominantly clinical and descriptive discipline toward a more translational, mechanistic, and technology-driven research environment.

Jordan's cancer research trajectory is particularly noteworthy within the Arab region. The country has built a strong clinical and epidemiological foundation through institutions such as KHCC and national cancer control initiatives while simultaneously adopting emerging technologies, including machine learning, nanomedicine, and *in silico* modeling. Compared with many regional oncology research programs, which remain largely focused on descriptive epidemiology and clinical outcomes, Jordan has demonstrated increasing integration of translational and computational approaches.

The temporal and citation overlay analyses (Figure 2) further highlight the evolution and diversification of Jordanian cancer research. The persistent prominence of high-frequency clinical keywords such as breast cancer, colon cancer, and chemotherapy reflects the continued importance of major public health priorities and therapeutic challenges. In contrast, the increasing emergence of machine learning, nanoparticles, and molecular docking illustrates a transition toward innovation, interdisciplinarity, and translational applications. The strong citation performance of established clinical and patient-centered themes suggests sustained international relevance and scholarly impact, whereas the comparatively lower citation intensity of newer computational and molecular research areas likely reflects their more recent emergence and developmental nature. Together, these findings indicate that Jordanian oncology research is transitioning from traditional descriptive and clinical frameworks toward integrated precision medicine and technology-oriented approaches.

Theme 1: epidemiology, diagnostics, and technological integration in major cancers

Cancer remains a major public health concern in Jordan, where increasing incidence rates and demographic transitions continue to shape healthcare priorities and research agendas. The national epidemiological landscape is dominated by breast, colorectal, lung, and cervical cancers, reflecting global trends while exhibiting distinct regional characteristics [5, 19]. Breast cancer accounts for approximately one-third of all cancers among Jordanian

women, with a median age at diagnosis nearly a decade younger than that reported in many high-income countries [20]. Lung cancer remains the most common malignancy among men, largely attributable to persistent tobacco consumption [21], whereas colorectal cancer ranks among the most common cancers affecting both sexes and has been linked to changing dietary and lifestyle patterns [22]. Although cervical cancer remains relatively uncommon, increasing attention has been directed toward prevention through expanded human papillomavirus vaccination programs and awareness campaigns [23]. These epidemiological trends have stimulated extensive research efforts to identify risk factors, improve early detection, and strengthen diagnostic capabilities [2, 3].

Population-based studies have consistently emphasized the importance of awareness and screening programs. Multiple knowledge, attitude, and practices studies have documented persistent deficiencies in public understanding of cancer risk factors and screening practices, particularly for breast and colorectal cancers [24–26]. Cultural stigma, socioeconomic barriers, and fear of diagnosis continue to hinder screening uptake and contribute to delayed presentation [27]. In response, Jordan established organized screening initiatives, including the JBCP, which have contributed to increased awareness and improved early detection rates [20]. Nevertheless, participation rates among women aged 40–69 years remain suboptimal, underscoring the need for sustained public health engagement and culturally tailored educational interventions [28]. Similar challenges exist in colorectal cancer screening, particularly among rural and underserved populations [22]. These observations collectively demonstrate the complex interactions among knowledge, health-seeking behavior, and access to preventive services.

Research on diagnostics and biomarkers has expanded considerably with the increasing use of IHC and molecular profiling techniques. Investigations have evaluated the expression of key biomarkers in breast, lung, and colorectal cancers, including estrogen receptor, progesterone receptor, Human epidermal growth factor receptor 2 (HER2), Ki-67, tumor protein p53 (p53), and Kirsten rat sarcoma viral oncogene homolog (KRAS) [29–31]. These studies have improved understanding of tumor heterogeneity, identified aggressive phenotypes such as triple-negative breast cancer, and contributed to the development of personalized treatment strategies [32, 33]. Likewise, studies involving lung cancer have enhanced histopathological classification and identified smoking-associated molecular signatures [31]. Research examining the cytotoxic effects of chemotherapeutic agents such as cisplatin has further contributed to the understanding of treatment response and resistance mechanisms in local patient populations [34–36].

Recent years have witnessed substantial growth in computational oncology. Machine learning and deep learning approaches have increasingly been applied to risk prediction, image analysis, and diagnostic support systems [37–39]. Jordanian researchers have successfully implemented machine learning algorithms to predict colorectal cancer risk using non-invasive clinical variables, demonstrating considerable potential for scalable screening programs [40]. Similarly, deep learning-based histopathological image analysis has shown promise for the automated identification of malignant features in breast and colorectal tissues [41, 42]. Although artificial intelligence remains an emerging field within Jordanian oncology, its potential to improve diagnostic accuracy, efficiency, and accessibility is increasingly recognized [43–45].

The COVID-19 pandemic further accelerated interest in digital-health technologies and computational healthcare solutions. Studies reported significant disruptions to screening programs, chemotherapy administration, and surgical services during lockdown periods [46, 47]. Consequently, artificial intelligence-assisted triage systems and telemedicine platforms were increasingly adopted to maintain continuity of care [48]. These developments reinforced the importance of technology-driven healthcare systems and highlighted opportunities for future digital transformation within oncology practice.

The predominance of epidemiological and clinical themes reflects Jordan's major cancer burden and continuing challenges related to delayed diagnosis and limited screening uptake. However, comparatively few studies have focused on disparities in cancer care among underserved populations, including refugees and displaced communities. This represents an important knowledge gap and an area requiring greater research and policy attention [49–51].

Theme 2: clinical management, prognosis, and survival outcomes in Jordanian cancer patients

A major component of Jordanian cancer research has focused on improving clinical management and understanding prognostic outcomes among adult and pediatric cancer patients. This thematic domain encompasses investigations of prostate cancer, bladder cancer, retinoblastoma, metastasis, survival, and

treatment response. Collectively, these studies illustrate substantial advances in evidence-based oncology practice driven by institutional development, national initiatives, and collaborative research efforts.

Prostate and bladder cancers are among the most common malignancies affecting Jordanian men. Research has primarily focused on early diagnosis, treatment optimization, and outcome assessment. The high incidence of bladder cancer has been linked to smoking and occupational exposures, consistent with patterns reported elsewhere in the region [21]. Studies have demonstrated improved progression-free survival among patients receiving multimodal therapeutic strategies that combine chemotherapy and radiotherapy for muscle-invasive disease [52]. Similarly, investigations of prostate cancer have identified prognostic markers such as p53 and Ki-67, which are associated with tumor aggressiveness and metastatic potential [53, 54]. These findings have improved patient stratification and facilitated more individualized treatment planning.

Jordan has also established a strong regional reputation in pediatric oncology, particularly in retinoblastoma management [10, 27, 55]. The expertise developed at KHCC has contributed substantially to advances in diagnosis, genetic testing, and multidisciplinary care [56]. Research demonstrates a gradual shift from traditional enucleation toward vision-preserving therapies and targeted intra-arterial chemotherapy, resulting in improved survival and quality-of-life outcomes [57]. These achievements have strengthened Jordan's contributions to pediatric oncology both regionally and internationally.

Studies addressing metastasis and survival have expanded considerably during recent decades. Analyses using national cancer registry data and the SEER framework have provided valuable insights into disease progression, recurrence patterns, and long-term outcomes [58, 59]. These investigations consistently indicate that a substantial proportion of patients continue to present with advanced-stage disease, which remains a major determinant of poor prognosis. Research involving breast and colorectal cancer cohorts has demonstrated markedly lower survival rates among patients diagnosed at advanced stages, highlighting the importance of earlier detection and improved access to treatment [20, 22, 60]. Multivariate analyses have further identified tumor stage, histological grade, and treatment adherence as critical prognostic determinants [20, 40, 61].

The development of modern radiotherapy and chemotherapy techniques has further strengthened cancer care in Jordan. Expansion of advanced radiotherapy technologies, including intensity-modulated radiotherapy and stereotactic radiotherapy, has improved local tumor control while reducing treatment-related toxicity [61]. Multiple studies have demonstrated improved outcomes among patients receiving combination or sequential systemic therapies [32, 62]. Furthermore, palliative chemotherapy protocols have improved both survival and quality-of-life among patients with advanced and metastatic disease [63–65]. These advances illustrate the growing emphasis on evidence-based clinical practice and continuous improvement of oncology services throughout the country.

Beyond traditional survival metrics, recent research has increasingly recognized the importance of broader patient-centered outcomes. Prognosis and survival are now viewed not only as biological endpoints but also as indicators of healthcare accessibility, socioeconomic factors, and quality of care [53, 58, 66, 67]. The integration of psychosocial and palliative services into cancer care represents a significant advancement in survivorship management within Jordan [67, 68]. Studies exploring patient experiences, psychological distress, treatment satisfaction, and supportive care needs have provided important evidence to inform the development of more comprehensive survivorship programs and healthcare policies [63, 69].

Theme 3: experimental therapeutics, cytotoxic screening, animal models, and mechanistic modeling in cancer research

Jordanian cancer research demonstrates a strong foundation in experimental therapeutics, encompassing investigations of anticancer activity, cytotoxicity, and apoptosis-related mechanisms. This area of research has been supported by active pharmaceutical and natural-product research sectors, which have generated a continuous pipeline of bioactive compounds derived from native medicinal plants and synthetic molecules [70, 71]. Over the past two decades, numerous studies have systematically evaluated extracts from *Salvia*, *Artemisia*, *Psoralea*, *Lavandula*, and *Juniperus* species, reporting significant antioxidant and cytotoxic activities against a variety of human cancer cell lines, including breast, colorectal, and lung cancer models [72–78]. These findings underscore the importance of both anticancer efficacy and antioxidant activity, reflecting the recognized role of oxidative stress in cancer development and therapeutic response.

Mechanistic investigations of apoptosis represent a major component of experimental oncology research in Jordan. Cell-based studies have demonstrated that exposure to plant-derived fractions and synthetic analogs

induces characteristic apoptotic responses, including DNA fragmentation, caspase activation, and mitochondrial depolarization, thereby confirming programmed cell death as a principal mechanism underlying anticancer activity. Research has examined the regulation of proapoptotic and antiapoptotic proteins, including Bax (B-cell lymphoma 2 associated X protein), Bcl-2 (B-cell lymphoma 2) and caspase-3, to determine how locally derived compounds shift cellular signaling toward tumor suppression [79–81]. Furthermore, several studies have linked the induction of apoptosis to the generation of reactive oxygen species, highlighting the close relationship between antioxidant modulation and cytotoxic signaling pathways [82]. Collectively, these findings demonstrate the increasing sophistication of experimental oncology research in Jordan, which now combines conventional biochemical assays with molecular endpoints to validate therapeutic potential.

Cytotoxicity screening remains a critical component of preclinical drug discovery. Jordanian laboratories have established standardized *in vitro* models utilizing MTT (3-(4,5-Dimethylthiazol-2-yl)-2,5-Diphenyltetrazolium Bromide) and sulforhodamine B assays to evaluate the viability of cancer cell lines exposed to natural and synthetic compounds [83]. These studies reported half-maximal inhibitory concentration values and examined associations between cytotoxic activity, phenolic composition, antioxidant capacity, and structural characteristics of the tested compounds. Comparative analyses involving normal and malignant cell lines have highlighted selective toxicity, a key requirement for advancing candidate compounds to *in vivo* evaluation [84, 85]. Several promising extracts have subsequently progressed to animal studies, where they demonstrated measurable tumor regression and minimal systemic toxicity, illustrating successful translation from laboratory discovery to preclinical validation [76, 84].

Jordanian researchers have increasingly incorporated computational chemistry and *in silico* modeling approaches, including molecular docking and QSAR analyses, into experimental oncology workflows. Molecular docking simulations have been used to predict interactions between phytochemicals or synthetic molecules and cancer-related targets, including kinases, DNA-processing enzymes, and apoptosis-regulating proteins, thereby facilitating more efficient drug discovery [86]. These computational approaches provide mechanistic insight into cytotoxic and apoptotic activities at the molecular level and enable the prioritization of compounds with favorable theoretical binding affinities and pharmacodynamic properties prior to synthesis and biological testing. Similarly, QSAR modeling has strengthened predictive drug discovery frameworks by identifying structural features, including lipophilicity, electronic distribution, and hydrogen-bonding capacity, that correlate with anticancer activity [87–90]. Together, these approaches provide a cost-effective bridge between natural-product chemistry and rational drug design, positioning Jordanian researchers at the interface of traditional pharmacognosy and modern computational pharmacology. The integration of anticancer, antioxidant, and *in silico* methodologies has established a distinctive research profile within the regional oncology landscape [91, 92].

Animal models constitute a critical component of translational cancer research in Jordan by bridging the gap between *in vitro* discoveries and potential clinical applications. Experimental investigations employing animal models, particularly murine systems, have been instrumental in evaluating the chemopreventive and therapeutic potential of dietary compounds, natural products, and newly synthesized molecules. For example, dietary lentils (*Lens culinaris* L.) demonstrated significant chemopreventive activity in an azoxymethane-induced colorectal cancer rat model, where lentil-enriched diets reduced aberrant crypt foci formation and enhanced hepatic glutathione-S-transferase activity, suggesting improved detoxification and protection against early carcinogenesis [93].

Similarly, bioactive phytochemicals such as mangiferin have been investigated in chemically induced colorectal cancer models, where they reduced tumor burden and improved histopathological outcomes [94]. Additional studies have evaluated thymoquinone and various medicinal plant extracts, demonstrating inhibition of tumor growth, induction of apoptosis, and suppression of angiogenesis in murine tumor models [95, 96].

Complementing natural-product research, medicinal chemistry investigations have assessed newly synthesized anticancer compounds, including thienopyrimidine and indole derivatives, in murine tumor models following promising *in vitro* cytotoxicity findings [97]. Likewise, antiangiogenic and antiproliferative extracts have been examined in animal models to provide mechanistic insight into tumor progression and therapeutic targeting [98–101].

These animal studies complement cellular investigations by enabling assessment of pharmacological efficacy, toxicity, and molecular mechanisms under physiologically relevant conditions. Increasingly, Jordanian cancer research has adopted animal models within comparative oncology frameworks that benefit both human

and veterinary medicine. Consistent with One Health principles, these investigations emphasize shared disease mechanisms across species and provide valuable insights into therapeutic development and disease management.

Despite growing utilization, animal-based cancer research remains relatively limited in Jordan. High costs, logistical constraints, infrastructure requirements, and ethical considerations associated with animal welfare continue to restrict wider implementation. Nevertheless, animal models remain indispensable for evaluating the efficacy and safety of candidate therapies before clinical translation. Expansion of ethically conducted animal research will be essential for generating more robust preclinical evidence, strengthening interdisciplinary collaborations, and supporting One Health initiatives that advance both human and veterinary oncology.

Theme 4: palliative care and quality-of-life in Jordanian cancer research

A distinct thematic cluster within Jordanian cancer research focuses on palliative care and quality-of-life, reflecting increasing recognition of the importance of holistic patient well-being in comprehensive cancer management. As cancer survival rates improve and treatment accessibility expands, researchers and clinicians have devoted greater attention to understanding the physical, psychological, emotional, and social needs of patients throughout the disease trajectory [65, 69].

Research indicates that palliative care in Jordan has evolved from a service primarily associated with end-of-life management into an integral component of comprehensive oncology care [65, 66, 69]. Studies conducted at institutions such as KHCC have evaluated early palliative care intervention models and demonstrated benefits in symptom control, emotional support, communication, and patient satisfaction [69, 102]. At the same time, surveys of healthcare professionals have identified persistent gaps in training, workforce capacity, and access to specialized palliative care resources, highlighting the need for continued professional development and institutional support [66, 103].

Parallel investigations focusing on quality-of-life have generated valuable insights into the lived experiences of cancer patients in Jordan. Studies evaluating pain, fatigue, depression, emotional distress, and functional capacity have demonstrated significant variations according to disease stage, treatment modality, and socioeconomic status [63, 67, 104, 105]. These findings emphasize that successful cancer management extends beyond tumor control and requires consideration of broader psychosocial and functional outcomes.

Patient-centered approaches are particularly important in the sociocultural context of the Middle East, where family structures, cultural beliefs, and social stigma substantially influence healthcare experiences and decision-making. Consequently, there is a growing need for culturally adapted assessment instruments, counseling services, and supportive care programs capable of addressing these unique challenges. Strengthening these resources may help reduce disparities in care and improve the overall quality-of-life of cancer patients and survivors within Jordan.

Theme 5: nanotechnology and targeted drug delivery in Jordanian cancer research

The fifth thematic cluster centers on nanoparticles, drug delivery, and doxorubicin, highlighting Jordan's growing contribution to nanotechnology-based oncology research. This research direction aligns closely with global precision medicine initiatives aimed at enhancing drug selectivity, reducing systemic toxicity, and overcoming treatment resistance associated with conventional chemotherapy. Jordanian researchers have increasingly employed nanotechnology to reformulate established anticancer agents, particularly doxorubicin, and to develop innovative delivery platforms that improve therapeutic performance and patient safety [106, 107].

An especially distinctive aspect of Jordanian nanomedicine research is the development of environmentally sustainable, plant-mediated nanoparticle synthesis approaches. Using local biodiversity, investigators have successfully produced biocompatible silver, gold, zinc oxide, and polymeric nanoparticles using plant extracts as reducing and stabilizing agents [108, 109]. This strategy not only leverages indigenous natural resources but also offers a cost-effective, environmentally friendly platform for large-scale nanoparticle production, making it particularly relevant for LMICs. These nanoparticles have demonstrated substantial cytotoxic and proapoptotic effects against breast, lung, and colorectal cancer cell lines through mechanisms involving enhanced oxidative stress and targeted intracellular delivery [110–115].

In addition to their anticancer activity, several studies have investigated the dual antimicrobial and anticancer properties of nanoparticle systems [116, 117]. This dual functionality may be particularly valuable for immunocompromised cancer patients, who face increased susceptibility to opportunistic infections during treatment.

Among conventional chemotherapeutic agents, doxorubicin has emerged as a principal model compound

for nanoformulation research. Jordanian investigators have developed nanoparticle-conjugated and liposomal formulations designed to increase tumor-site accumulation while minimizing cardiotoxicity, one of the most significant adverse effects associated with free doxorubicin [118, 119]. Experimental findings demonstrate enhanced cellular uptake, sustained drug-release profiles, and improved cytotoxic efficacy compared with conventional formulations. These achievements highlight Jordan's ability to integrate materials science, pharmaceutical technology, and oncology research to address long-standing therapeutic challenges.

Current drug delivery research in Jordan increasingly emphasizes innovation, safety, and translational potential. Investigators continue to optimize nanoparticle size, surface charge, ligand functionalization, and release kinetics to improve targeting specificity and therapeutic efficacy [120]. Concurrently, computational modeling approaches are being employed to predict nanoparticle–cell interactions, biodistribution patterns, and pharmacokinetic behavior, thereby facilitating more rational formulation design and accelerating translational development [121, 122].

Collectively, these advances demonstrate the growing maturity of Jordanian nanomedicine research and its potential to contribute to next-generation cancer therapeutics by integrating nanotechnology, computational modeling, and translational oncology.

Interdisciplinary advances in Jordanian cancer research: bridging computational, experimental, and clinical frontiers

Jordan's cancer research landscape has evolved from a predominantly clinical and epidemiological foundation into a more translational, technology-driven, and interdisciplinary ecosystem integrating computational methodologies, experimental models, and nanotechnology-based approaches. Supported by robust national infrastructure, particularly KHCC and JBCP, this transformation has accelerated the adoption of innovative research strategies and may serve as a valuable model for other middle-income countries seeking to strengthen oncology research capacity and translational outcomes.

The development of this research ecosystem has facilitated the integration of computational technologies into both experimental and clinical oncology. Machine learning, in particular, has emerged as an important bridge between experimental screening studies (Theme 3) and clinical applications (Theme 2). Studies have demonstrated the utility of machine learning algorithms in improving risk prediction, diagnostic accuracy, and early detection, particularly for colorectal cancer, using scalable, non-invasive approaches [40]. These advances illustrate how computational methods can enhance clinical decision-making while simultaneously supporting population-level screening initiatives.

Nanotechnology has similarly emerged as a critical driver of translational oncology research. As discussed in Theme 5, nanoparticle-based delivery systems have enabled the reformulation of conventional chemotherapeutic agents such as doxorubicin to improve therapeutic targeting and reduce systemic toxicity [106]. These developments align closely with global precision medicine initiatives aimed at maximizing efficacy while minimizing adverse effects. Furthermore, the integration of nanomedicine with molecular docking and QSAR methodologies has strengthened drug discovery pipelines by facilitating rational compound design, target identification, and pharmacodynamic evaluation [92, 123, 124]. The convergence of computational modeling and nanotechnology, therefore, represents a powerful framework for accelerating translational research and therapeutic innovation.

Experimental models have also played a central role in linking laboratory discoveries to clinical applications. Animal studies and other preclinical models have provided critical evidence on efficacy, safety, pharmacological activity, and mechanistic pathways prior to clinical translation. These investigations support the broader One Health framework by generating comparative oncology knowledge that is relevant to both human and veterinary medicine [93, 94]. Such studies contribute to a deeper understanding of disease mechanisms and may facilitate the development of novel therapeutic strategies applicable across species.

In parallel, palliative care research has expanded the scope of oncology beyond traditional clinical outcomes by emphasizing patient-centered care and survivorship. As highlighted in Theme 4, increasing attention has been devoted to psychosocial well-being, symptom management, quality-of-life, family support systems, and sociocultural influences on healthcare experiences [65, 69]. This shift reflects a more comprehensive understanding of cancer care that addresses not only biological outcomes but also the psychological, social, and functional dimensions of patient health.

Collectively, these interconnected themes demonstrate Jordan's transition toward an integrated oncology

research framework in which computational, experimental, translational, and clinical disciplines increasingly converge. This interdisciplinary synergy enhances innovation, strengthens research capacity, and positions Jordan to make meaningful contributions to both regional and global cancer research while supporting advances in human and veterinary oncology within a One Health context.

Implications for policy, training, and infrastructure

The thematic analysis identified several strategic priorities that could further strengthen Jordan's cancer research ecosystem and support implementation of the National Cancer Control Plan (2023–2030).

First, the development of a comprehensive national oncology data infrastructure should be prioritized. Integration of cancer registries, pathology databases, molecular profiling resources, biobanks, imaging repositories, and patient-reported outcome systems under FAIR (Findable, Accessible, Interoperable, and Reusable) data principles would improve data harmonization, facilitate multicenter collaboration, and accelerate translational research. Establishing a dedicated One Health Oncology Platform that connects KHCC, academic institutions, veterinary medicine faculties, computational research centers, and public health stakeholders could further promote interdisciplinary collaboration and comparative oncology research.

Second, workforce development should focus on strengthening competencies in bioinformatics, artificial intelligence, data science, translational research methodologies, and advanced laboratory techniques. Training initiatives should emphasize computational oncology, assay validation, regulatory science, good practice standards, nanoparticle characterization, molecular diagnostics, and digital pathology. Enhancing expertise in these areas would enable researchers and clinicians to effectively utilize emerging technologies and facilitate integration of Jordan's strong clinical infrastructure with contemporary precision-oncology approaches.

Third, continued investment in research infrastructure is essential to support innovation and translation. Shared national core facilities dedicated to digital pathology, molecular diagnostics, radiotherapy planning, small-animal imaging, advanced microscopy, bioinformatics, high-performance computing, and nanoparticle characterization would improve research efficiency and reduce duplication of resources. In addition, the development of standardized frameworks for artificial intelligence model validation, reproducibility assessment, and clinical implementation would support responsible adoption of emerging computational technologies.

Finally, greater emphasis should be placed on underrepresented research areas identified through thematic mapping, including healthcare disparities, cancer care among refugee and underserved populations, survivorship research, implementation science, and comparative oncology. Addressing these gaps would enhance the comprehensiveness of Jordan's cancer research portfolio and generate evidence directly relevant to national healthcare priorities.

Together, these strategic initiatives have the potential to strengthen interdisciplinary collaboration, enhance translational capacity, and consolidate Jordan's position as a regional leader in oncology research. By integrating advances in computational science, experimental therapeutics, clinical oncology, and One Health research, Jordan is well positioned to contribute to the development of innovative and sustainable solutions for cancer prevention, diagnosis, treatment, and survivorship.

Strengths and limitations

This study provides the most comprehensive long-term thematic assessment of cancer research conducted in Jordan, spanning 50 years (1974–2024). To our knowledge, it represents the longest country-specific thematic evolution analysis of cancer research in Jordan and one of the most extensive studies of its kind in the Arab region. A major strength of this work is the integration of clinical, epidemiological, experimental, computational, and nanotechnology-related research domains within a single analytical framework. Furthermore, the inclusion of translational and comparative oncology perspectives underscores the growing relevance of One Health concepts in Jordanian cancer research.

Methodologically, the study combines author-keyword co-occurrence analysis with temporal and normalized citation overlay mapping, providing a multidimensional perspective on thematic evolution, scholarly influence, and emerging research priorities. This integrated approach enables identification of both mature research domains and rapidly developing fields, thereby offering insights beyond conventional publication-count and citation-based bibliometric assessments. The use of a custom thesaurus file and extensive manual screening further enhanced data quality by minimizing synonym fragmentation, standardizing terminology, and removing irrelevant records. Consequently, the findings provide a robust evidence base that may assist policymakers, funding agencies, academic institutions, and researchers in prioritizing future investments, capacity building

initiatives, and collaborative research programs.

Despite these strengths, several limitations should be acknowledged. First, the analysis was restricted to Scopus-indexed English-language journal articles. Although Scopus provides extensive multidisciplinary coverage and substantial overlap with major databases such as PubMed and Web of Science, this restriction may have resulted in underrepresentation of Arabic-language publications, regional journals, conference proceedings, institutional reports, policy documents, and other forms of gray literature. Consequently, some locally relevant research activities may not have been fully captured.

Second, thematic mapping was based primarily on author-assigned keywords and predefined occurrence thresholds. Although keyword-based analyses provide valuable insight into author intent, conceptual focus, and emerging trends, they remain dependent on the consistency and completeness of keyword selection by individual authors. Variability in the use of terminology may influence cluster formation and thematic representation despite the application of thesaurus-based standardization procedures.

Third, sensitivity analyses using alternative databases, different keyword-occurrence thresholds, or alternative clustering approaches were not performed. Therefore, the stability of some thematic structures and citation relationships under different analytical conditions could not be formally evaluated. Similarly, quantitative cluster-validation metrics, such as silhouette scores, modularity indices, or network-stability assessments, were not calculated. Although thematic interpretations were supported through manual review, temporal overlays, and citation overlay visualization, the absence of formal validation metrics may influence the reproducibility of certain thematic patterns.

Finally, normalized citation analyses are inherently influenced by differences in publication age, citation practices across disciplines, and field-specific citation behaviors. Consequently, citation performance should be interpreted as a relative indicator of scholarly influence rather than a direct measure of scientific quality or societal impact.

Notwithstanding these limitations, the study provides a rigorous and evidence-based assessment of the evolution of cancer research in Jordan. The findings demonstrate substantial interdisciplinary growth, increasing technological sophistication, and strong alignment with contemporary global oncology trends, thereby offering a valuable framework for future research planning and policy development.

Future perspectives

The thematic evolution identified in this study highlights several promising directions for future cancer research in Jordan. Given the continuing burden of breast, colorectal, lung, and cervical cancers, future investigations should increasingly adopt multi-omics approaches that integrate genomics, transcriptomics, proteomics, metabolomics, and epigenomics to improve risk stratification, biomarker discovery, and precision medicine applications. The establishment of longitudinal biospecimen repositories linked to clinical, pathological, and imaging data would further strengthen translational oncology research and facilitate personalized therapeutic strategies.

The growing convergence of artificial intelligence, computational biology, and nanomedicine presents substantial opportunities for innovation. Future studies should focus on developing integrated diagnostic and therapeutic platforms that combine advanced imaging, molecular profiling, machine learning, and nanoparticle-based delivery systems. Such hybrid approaches may improve diagnostic accuracy, optimize treatment selection, and enhance therapeutic efficacy while reducing treatment-related toxicity.

Comparative oncology and One Health research also represent important future directions. Expansion of animal-based cancer models and comparative investigations of naturally occurring cancers in companion animals may provide valuable insights into disease mechanisms, biomarker development, and therapeutic responses relevant to both human and veterinary medicine. Strengthening collaborations among oncologists, veterinarians, molecular biologists, and computational scientists could accelerate progress in this emerging interdisciplinary field.

To support sustainable research growth, Jordan should consider developing dynamic research-monitoring systems, including real-time bibliometric dashboards and national oncology intelligence platforms that track research productivity, collaboration networks, emerging themes, and translational outcomes. Such initiatives would position Jordan as a regional leader in evidence-driven research evaluation and strategic planning.

Future translational oncology programs should increasingly emphasize mechanism-based research that integrates molecular profiling, pathology, imaging, and computational analytics, rather than relying solely on single-assay screening approaches. Artificial intelligence applications, including triage systems, histopathology

support tools, radiomics, toxicity prediction models, and clinical decision-support platforms, should undergo rigorous external validation with particular attention to calibration, fairness, transparency, and clinical utility.

Similarly, advances in nanomedicine and rational drug design should continue to integrate molecular docking, QSAR modeling, pharmacology, and experimental validation to demonstrate target engagement, optimize pharmacokinetic properties, and improve translational potential. Expanding collaboration among pharmaceutical scientists, computational researchers, and clinical oncologists will be critical for transforming laboratory discoveries into clinically meaningful interventions.

By building on these emerging strengths and addressing identified research gaps, Jordan has the opportunity to establish high-impact, sustainable, and globally relevant oncology research programs that advance cancer prevention, diagnosis, treatment, survivorship, and precision medicine.

CONCLUSION

This bibliometric thematic mapping study provides the first comprehensive assessment of the thematic evolution of cancer research in Jordan over a 50-year period (1974–2024). Analysis of 4,567 eligible publications identified five major and interconnected research domains: (i) epidemiology, diagnostics, and technological integration in major cancers; (ii) clinical management, prognosis, and survival outcomes; (iii) experimental therapeutics, cytotoxic screening, and mechanistic investigations; (iv) palliative care and quality-of-life research; and (v) nanotechnology-based drug delivery and targeted therapeutics. Temporal and citation overlay analyses demonstrated a clear progression from predominantly clinical and epidemiological investigations toward increasingly translational, computational, molecular, and nanotechnology-driven research approaches.

The findings highlight the growing integration of machine learning, *in silico* modeling, experimental therapeutics, and nanomedicine within Jordan's oncology research ecosystem, reflecting strong alignment with contemporary global research priorities. At the same time, established clinical themes, including breast, colorectal, and lung cancers, continue to exert substantial scientific influence and remain central to national cancer control efforts. The emergence of interdisciplinary collaborations linking computational science, experimental oncology, clinical practice, and One Health research further illustrates the maturation of Jordan's cancer research landscape.

From a practical perspective, the study provides evidence to support strategic research planning, capacity building, infrastructure development, funding prioritization, and the implementation of the National Cancer Control Plan (2023–2030). The identification of emerging research hotspots, including artificial intelligence, nanomedicine, comparative oncology, and precision medicine, offers valuable guidance for future investment and interdisciplinary collaboration.

A major strength of this study is its long-term temporal coverage and integration of multiple bibliometric visualization approaches, enabling a multidimensional understanding of thematic development and scientific impact. However, the findings should be interpreted in light of certain limitations, including reliance on Scopus-indexed English-language publications, dependence on author-assigned keywords, and the absence of sensitivity analyses and formal cluster-validation metrics.

Future research should focus on strengthening multi-omics investigations, precision-oncology initiatives, artificial intelligence applications, translational nanomedicine, and comparative oncology studies within a One Health framework. Greater emphasis should also be placed on healthcare disparities, survivorship research, implementation science, and underrepresented populations to ensure equitable advances in cancer prevention and care.

Overall, cancer research in Jordan has evolved into a dynamic, interdisciplinary, and increasingly technology-driven field characterized by strong clinical foundations and growing translational capacity. Continued investment in collaborative research infrastructure, advanced analytical technologies, and One Health-oriented innovation will further strengthen Jordan's contribution to regional and global oncology research and support the development of more effective strategies for cancer prevention, diagnosis, treatment, and survivorship.

DATA AVAILABILITY

The supplementary data can be made available from the corresponding author upon request.

GENERATIVE AI DECLARATION

The authors declare that QuillBot and ChatGPT were used solely to improve language, grammar, and

readability during manuscript preparation. All scientific content, data analysis, interpretation of results, and conclusions were developed and verified by the authors. The authors take full responsibility for the accuracy, integrity, and originality of the work presented, and no AI tool was listed as an author. No figures or images were generated or modified using AI tools.

AUTHORS' CONTRIBUTIONS

YB: Conceptualization, methodology, data curation, formal analysis, visualization, and original draft preparation. AAH, JT, SMA, RD, AYA, MAM, IH, KAR, WEH, EAG, and MHS: Data interpretation, manuscript review, and editing. YB, JT, SMA, WEH, EAG, and MHS: Supervision and project administration. All authors have read and approved the final version of the manuscript.

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COMPETING INTERESTS

The authors declare that they have no competing interests.

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