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A survey of the cytotoxicity of some medicinal plant extracts in Ghana against breast and prostate cancer cells

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Abstract

Cancer remains a global health challenge, with breast and prostate cancers being significant contributory factors to morbidity and mortality. Current treatments are limited by high costs, resistance, and adverse effects hence prompting the exploration of alternative therapies. This study evaluated the anticancer potential of crude extracts of ten medicinal plants commonly found in Ghana: *Azadirachta indica*, *Vernonia amygdalina*, *Launaea taraxacifolia*, *Dissotis rotundifolia*, *Chromolaena odorata*, *Heliotropium indicum*, *Zingiber officinale*, *Carica papaya* (leaves and seeds), and *Solanum melongena*, in breast (MCF-7) and prostate (PC-3) cancer cell lines. The plants were collected, authenticated, and processed for ethanolic extraction. Phytochemical analysis identified bioactive compounds including alkaloids, flavonoids, phenols, tannins, saponins, terpenoids, and glycosides. The cytotoxicity assays revealed a dose-dependent reduction in cell viability, with greater effects observed at higher concentrations than at lower concentrations. The extracts were found to be very effective even after 24 h hours, indicating their highly potent nature for these plants. Notably, extracts from *Heliotropium indicum*, *Vernonia amygdalina*, and *Azadirachta indica* showed significant activity, which could be attributed to their alkaloids and terpenoids, which induce apoptosis and inhibit proliferation. These findings highlight the therapeutic potential of plant-derived compounds as promising candidates for anticancer drug development. These results also highlight the importance of biodiversity conservation and the integration of traditional knowledge into modern research to combat the global cancer burden. Future studies should focus on optimizing the use of these bioactive compounds, both individually and in combination, to develop more effective cancer treatments.

Keywords Phytochemicals, Cytotoxicity, Medicinal plants, Breast cancer, Prostate cancer, Anticancer activity

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Background

Cancer remains one of the most significant global health challenges and is characterized by uncontrolled proliferation of abnormal cells with the potential to invade and metastasize [1]. According to the International Agency for Research on Cancer, in 2022, there were an estimated 20 million new cancer cases and 10 million cancer-related deaths worldwide, with approximately one in five individuals developing cancer during their lifetime, and one in nine men and one in 12 women succumbing to the disease. Breast and prostate cancers account for 11.6% and 7.3% of all cancer cases, respectively by 2022 [2]. Despite advances in diagnostics, the survival rates of breast and prostate cancer patients remain suboptimal [3]. Current treatment options, including chemotherapy, radiation therapy, and hormone therapy, are often associated with significant limitations, such as drug resistance, high costs, and severe side effects including nausea, hair loss, fertility issues, and skin reactions [4–7]. These challenges highlight the urgent need for alternative therapeutic strategies that are both effective and accessible.

Natural products derived from plants have long been recognized as valuable sources of bioactive compounds with medicinal properties. More than 60% of anticancer drugs currently available originate from natural products [8, 9]. Plants possess an exceptional diversity of secondary metabolites including alkaloids, flavonoids, terpenoids, phenolic acids, and saponins, many of which exhibit potent cytotoxic effects against cancer cells. These compounds can disrupt critical cellular processes such as proliferation, apoptosis, angiogenesis, and metastasis, making them attractive candidates for drug discovery and development. Plants in Ghana represent a largely untapped reservoir of potentially valuable phytochemicals. Ethnobotanical knowledge, passed down through generations, has provided insights into the medicinal uses of many of these local plants; however, their potential to treat specific diseases, such as cancer, remains underexplored. The exploration of local plants not only offers the possibility of identifying novel anticancer agents but also aligns with sustainable drug discovery efforts, leveraging readily available and culturally significant resources.

Several medicinal plants used in Ghanaian traditional medicine are recognized for their roles in managing tumors, swellings, and chronic inflammatory conditions, with emerging evidence supporting their anticancer potential. For example, *Azadirachta indica* and *Vernonia amygdalina* are among the most cited for cancer treatment by herbalists, demonstrating apoptotic and anti-proliferative activity in cancer cells [10, 11]. Although *Launaea taraxacifolia*, *Solanum melongena*, and *Zingiber officinale* are not traditionally labeled as anticancer remedies, studies reveal their extracts suppress tumor growth via antioxidant and cell cycle

regulation pathways [12–14]. Likewise, *Dissotis rotundifolia*, *Chromolaena odorata*, and *Heliotropium indicum* are used for swellings and sores, and their extracts exhibit cytotoxicity induction [15–17]. *Carica papaya* seeds and leaves, traditionally used for internal cleansing, have shown potent antitumor effects, supporting anecdotal claims [18]. Moreover, extracts from *Carica papaya* seed, *Heliotropium indicum*, *Vernonia amygdalina*, *Launaea taraxacifolia*, *Dissotis rotundifolia*, *Chromolaena odorata*, *Solanum melongena*, *Zingiber officinale*, *Azadirachta indica* have been recognized for their wide range of biological activities, including antimicrobial, antitumor, anti-inflammatory, and wound healing properties [19–21]. *Chromolaena odorata*, *Dissotis rotundifolia*, and *Heliotropium indicum* have shown selectivity inhibition for some cancer cells [22–24]. *Azadirachta indica* and *Zingiber officinale* inhibit cancer-related pathways such as NK-kB [25–27]. *Vernonia amygdalina*, *Solanum melongena*, *Carica papaya* seed, and *Solanum melongena* have also been shown to induce cell cycle arrest in some cancer cells [28–30]. Toxicological studies have also demonstrated that *Launaea taraxacifolia* extracts did not induce any signs of toxicity or mortality in Wistar rats after 28 days of treatment. The therapeutic potential of these plants is attributed to their rich phytochemical composition, including alkaloids, tannins, saponins, flavonoids, cyanogenic glycosides, and steroids [31–33]. Despite their wide availability in Ghana and broader use in Ghana and other regions, the medicinal applications of these plants, there is still a paucity of information on the cytotoxicity of some of these plants in prevalent cancers such as breast and prostate cancer cells. With increasing drug resistance and the need for effective treatment, plant extracts could offer an alternative solution.

This study explored the cytotoxic effects of crude extracts of local plants on breast and prostate cancer cell lines. By systematically evaluating their efficacy, this study identified promising candidates for further investigation and development as anticancer agents. Moreover, this study highlights the importance of preserving biodiversity and integrating traditional knowledge with scientific research to address the growing global burden of cancer.

Method

Plant sample collection, authentication and processing

Plant samples were collected from various locations in Ghana. The specific plant parts used were as follows: leaves of *Azadirachta indica*, *Vernonia amygdalina*, *Launaea taraxacifolia*, *Dissotis rotundifolia*, *Chromolaena odorata*, *Heliotropium indicum*, and *Solanum melongena*; rhizomes of *Zingiber officinale*; and both seeds and leaves of *Carica papaya*. The collected plant samples were authenticated at the Herbarium of the School of

Biological Sciences, University of Cape Coast. Authentication ensured the correct identification of the species before further processing. The samples were cleaned by washing under running water for approximately 30 min to remove any debris. Afterward, they were air-dried under shade for three weeks to retain their phytochemical integrity, except for *Zingiber officinale* and *Carica papaya* seeds, which took five and four weeks, respectively. Once dried, the plant leaves, *Carica papaya* seeds, and *Zingiber officinale* were milled into fine powders. The powdered samples were stored in tightly sealed labeled bottles and kept at room temperature in a cool, dry place.

Extraction of crude plant extracts for phytochemical analyses

Powdered plant samples were treated at a 10:1 sample-to-solvent ratio. Powdered leaf samples (50 g) of each plant were weighed into a 1-liter volumetric flask using a PG 203 electronic balance (Pyrex, England). Then, 500 ml of 70% ethanol was added to the sample in the flask and labeled. The use of 70% ethanol was selected based on its broad-spectrum extraction capability for a wide range of phytochemicals. It balances polarity to ensure efficient extraction of both hydrophilic and moderately lipophilic compounds and is commonly used in phytochemical studies because of its low toxicity and suitability for biological assays. Other solvents were not used in this preliminary screening to maintain consistency across samples.

The samples extracted in the volumetric flask were corked with nonabsorbent cotton wool and wrapped with aluminum foil. The flasks were placed on a multi-purpose shaker (Stuart Scientific, Germany) for 72 h at room temperature to facilitate the extraction of bioactive compounds. After the extraction period, the mixture was filtered through Whatman filter paper to separate the liquid extract from plant debris. The filtrate was then transferred to an evaporating dish and allowed to stand at room temperature to evaporate the solvent until a concentrated crude extract was obtained. The crude extracts were stored in a desiccator containing activated silica gel for two days before qualitative and cytotoxic analyses.

Qualitative analysis of phytochemicals

Flavonoids, phenols, tannins, saponins, terpenoids, alkaloids, steroids, glycosides, and cardiac glycosides were qualitatively analyzed in the crude extracts of all samples using methods described by Sofowara (1993), Trease and Evans (1989) and Harborne (1973) [34–35]. These methods utilize color changes and precipitate formation to detect major groups, such as alkaloids, flavonoids, tannins, phenols, saponins, glycosides, and terpenoids. Advanced analytical techniques, such as GC-MS or

HPLC, were not employed in this study, as the aim was preliminary profiling of phytochemical presence.

Cell culture and treatment

Breast cancer (MCF7) and prostate cancer (PC3) cell lines (American Type Culture Collection(ATCC), USA) were propagated and maintained in Dulbecco's modified Eagle's medium (DMEM) (Biowhittaker/Lonza, Walkersville, MD, USA) supplemented with 10% Fetal Bovine Serum (PAA Laboratories, Austria) and incubated in a 5% CO₂ incubator at 37°C (Sanyo, Japan). These lines were chosen because they represent two of the most prevalent and clinically relevant cancers, globally and within the Ghanaian population. 1 × 10⁴/well of MCF-7 and PC-3 cells were seeded in 96 well plates and treated each with sterile water (0 µg/µL; negative control), 2 µg/µL, 4 µg/µL, 6 µg/µL, 8 µg/µL and 10 µg/µL of crude extracts of *Heliotropium indicum*, *Vernonia amygdalina*, *Lau-naea taraxacifolia*, *Dissotis rotundifolia*, *Chromolaena odorata*, *Solanum melongena*, *Zingiber officinale*, *Azadirachta indica*, *Carica papaya* seed and leaves for 24 h and 48 h.

Cell viability assessment

The MTT (3-(4, 5-Dimethylthiazol-2-yl)-2, 5-diphenyl-tetrazolium bromide) assay (Sigma-Aldrich, USA) was used to evaluate the proliferative activity of the MCF-7 and PC-3 cells. 25 µL of the MTT working stock (2.5 mg/ml) was added onto the 96 well plate containing the treated cells and incubated at 37°C for four hours. Next, 100 µL acidified isopropanol was added to each well and incubated at 37 °C for 30 min. Absorbance was measured spectrophotometrically using a microplate reader (VERS-Amax tunable microplate reader, Molecular Devices, USA). The percentage of cell viability was calculated from the absorbance values. The experiments were performed in triplicate.

Statistical analysis

All results are expressed as mean ± SD from three independent experiments normalized to the untreated control and expressed as a percentage. GraphPad was used to determine the IC₅₀ values.

Results

Qualitative analysis of phytochemicals

Phytochemical screening of various plant samples revealed a diverse composition of bioactive compounds, such as alkaloids, flavonoids, tannins, phenols, steroids, terpenoids, glycosides, and saponins (Table 1). To understand the possible relationship between the phytochemical composition and cytotoxic effects, we categorized the plant extracts into four groups according to their shared bioactive constituents. Broad-Spectrum Phytochemical

Table 1 Qualitative phytochemical analysis of crude extracts. The table shows the results of the qualitative analysis of the ethanol extracts of ten (10) different plant species

Plant Samples	Phytochemicals							
	Alkaloids	Flavonoids	Tannins	Phenol	Steroids	Terpenoids	Glycoside	Saponin
<i>Azadirachta indica</i>	+	+	+	+	-	+	+	+
<i>Vernonia amygdalina</i>	+	+	+	+	-	-	-	+
<i>Heliotropium indicum</i>	+	+	+	+	-	-	+	+
<i>Chromolaena odorata</i>	+	+	+	+	-	-	-	+
<i>Dissotis rotundifolia</i>	+	+	+	+	-	-	+	+
<i>C.papaya leaves</i>	+	+	+	+	-	+	+	+
<i>C.papaya seeds</i>	+	+		+		+	-	+
<i>Solanum melongena</i>	+	+	+	+	+	+	-	-
<i>Launaea taraxacifolia</i>	+	+	+	+	+	+	-	-
<i>Zingiber officinale</i>	+	+	-	+	+	-	-	-

Legend: The (+) sign indicates the presence of a phytochemical and the (-) sign indicates the absence of phytochemicals

extracts, including *Heliotropium indicum*, *Vernonia amygdalina*, and *Dissotis rotundifolia*. These plants contain alkaloids, flavonoids, phenols, tannins and saponins. These are referred to as broad-spectrum phytochemical extracts due to the presence of five or more distinct classes of bioactive compounds out of the eight tested, which suggests a chemically diverse composition that may contribute to varied biological activities. The other group is the terpenoid-and flavonoid-rich extracts, which are composed of *Azadirachta indica*, *Carica papaya* (leaves), *Solanum melongena*, and *Launaea taraxacifolia*, all of which contain terpenoids, flavonoids, phenols, and glycosides. The combination of these phytochemicals suggests the potential mechanisms associated with terpenoid-mediated activity. Polyphenol-dominant extracts, characterized by the presence of flavonoids and phenols, but lacking terpenoids, were added as another group. These included *Chromolaena odorata*, *Vernonia amygdalina*, and *Dissotis rotundifolia*. This profile suggests a more selective range of phytochemicals that are commonly associated with antioxidant and anti-inflammatory properties. Extracts that exhibited relatively limited phytochemical profiles were classified as Minimally Diverse extracts. This included *Zingiber officinale* and *Carica papaya* (seeds), both of which exhibited relatively limited phytochemical profiles. *Z. officinale* lacked glycosides and saponins, while *C. papaya* seeds were devoid of tannins and glycosides, reflecting unique chemical characteristics that distinguish them from the other groups. These findings highlight the diverse chemical profiles among plant species and plant parts.

Dose-response of extracts on MCF-7 cell lines post-treatment

The results demonstrated the cytotoxic effects of various plant extracts on cell viability over two-time points, 24 and 48 h. Across all graphs, a clear negative correlation was observed between the extract concentration

and cell viability, indicating that higher concentrations resulted in greater reductions in viability (Fig. 1). This effect was more pronounced at 48 h than at 24 h, highlighting the time-dependent increase in cytotoxicity. The plant extracts studied include *Azadirachta indica*, *Carica papaya leaves and seeds*, *Chromolaena odorata*, *Launaea taraxacifolia*, *Heliotropium indicum*, *Zingiber officinale*, *Solanum melongena*, *Dissotis rotundifolia*, and *Vernonia amygdalina*. While all extracts showed a general trend of reduced viability with increasing concentrations, the viability between 24 and 48 h varied, suggesting differences in potency among the extracts with time. The IC₅₀ values for the extract on MCF7 cells indicate that most plant extracts exhibit greater cytotoxicity at 48 h compared to 24 h (Table 2). Some extracts, such as *Chromolaena odorata* and *Solanum melongena*, showed minimal changes over time, suggesting a less time-dependent effect. The broad-spectrum phytochemical group exhibited strong cytotoxicity, with *Heliotropium indicum* and *Vernonia amygdalina* showing lower IC₅₀ values at 48 h (2.94 ± 0.27 µg/µL and 3.19 ± 0.13 µg/µL, respectively) compared to *Dissotis rotundifolia* (3.52 ± 0.05 µg/µL). Among the terpenoid-and flavonoid-rich extracts, *Carica papaya* seeds displayed the highest potency (2.68 ± 0.21 µg/µL), followed by *Launaea taraxacifolia* (3.52 ± 0.22 µg/µL), *Azadirachta indica* (3.72 ± 0.68 µg/µL), and *Carica papaya* leaves (4.07 ± 0.30 µg/µL). *Solanum melongena*, which shares a similar profile, showed a slightly higher IC₅₀ of 3.81 ± 0.35 µg/µL. In the polyphenol-dominant group, *Chromolaena odorata* had an IC₅₀ of 3.81 ± 0.35 µg/µL. Within the minimally diverse group, *Zingiber officinale* exhibited one of the highest IC₅₀ values (4.07 ± 0.28 µg/µL), whereas *Carica papaya* seeds, despite limited phytochemical diversity, remained among the most potent.

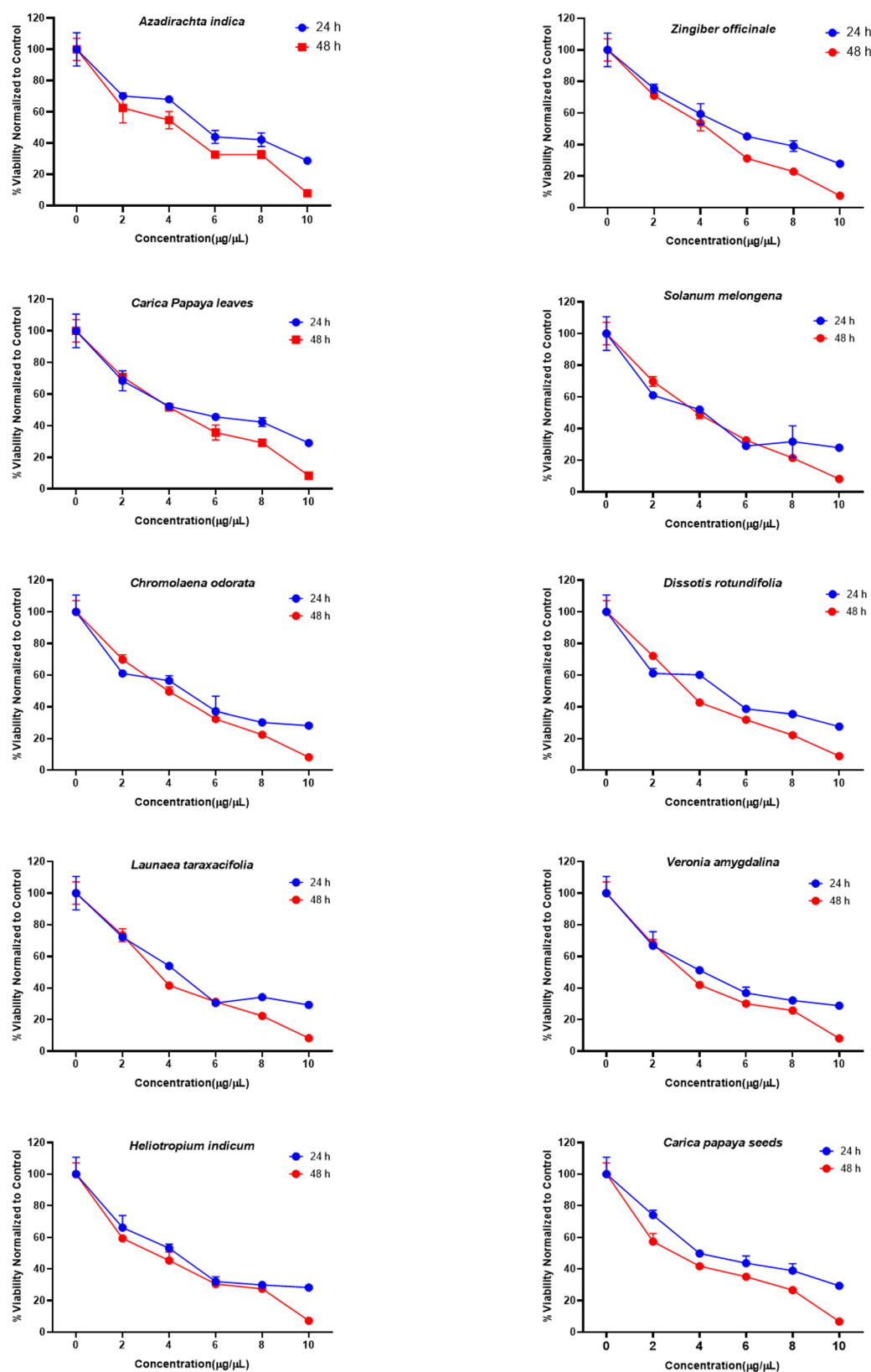


Fig. 1 Dose-response and cytotoxicity of plant extracts at 0 µg/µL, 2 µg/µL, 4 µg/µL, 6 µg/µL, 8 µg/µL, and 10 µg/µL on MCF-7 cancer cell lines for 24 h and 48 h. All extracts demonstrated a dose-dependent inhibition of MCF7 cell proliferation. Data are expressed as mean ± S.D

Table 2 IC₅₀ of plant extracts for 24 h and 48 h treatment of MCF-7 breast cancer cells. The most potent extracts at 48 h were *Heliotropium indicum* (2.94 µg/µL), *Vernonia amygdalina* (3.19 µg/µL), and *Carica Papaya seeds* (2.68 µg/µL), with all extracts exhibiting increased cytotoxicity over time. These data suggested that different plant extracts have varying levels of efficacy against breast cancer cells. The variation in IC₅₀ values over time highlights the potential for both immediate and sustained effects of these natural products

Plant Samples	IC ₅₀ (µg/µL) – MCF7	
	24 h	48 h
<i>Azadirachta indica</i>	5.97 ± 0.45	3.72 ± 0.68
<i>Veronia amygdalina</i>	3.73 ± 0.41	3.19 ± 0.13
<i>Heliotropium indicum</i>	3.77 ± 0.35	2.94 ± 0.27
<i>Chromolaena odorata</i>	3.94 ± 0.50	3.81 ± 0.35
<i>Dissotis rotundifolia</i>	4.19 ± 0.07	3.52 ± 0.05
<i>Carica papaya leaves</i>	4.42 ± 0.77	4.07 ± 0.30
<i>Carica papaya seeds</i>	4.29 ± 0.28	2.68 ± 0.21
<i>Solanum melongena</i>	3.40 ± 0.21	3.81 ± 0.35
<i>Launaea taraxacifolia</i>	4.09 ± 0.16	3.52 ± 0.22
<i>Zingiber officinale</i>	5.37 ± 0.36	4.07 ± 0.28

Dose-response of extracts on PC-3 cell lines post-treatment
PC3 cell lines showed a concentration-dependent decrease in relative cell viability after different treatments (Fig. 2). Both 24-hour and 48-hour treatments exhibit similar trends, with viability decreasing as the concentration increased. The 48-hour treatment generally resulted in slightly lower viability, suggesting a time-dependent cytotoxic effect. Some treatments showed a steeper decline, indicating higher potency, whereas others exhibited a more gradual response. The IC₅₀ values for PC3 cell lines showed a general decrease from 24 to 48 h across all plant extracts, indicating increased cytotoxicity over time (Table 3). This trend suggests time-dependent efficacy for all plant extracts, with stronger inhibition at 48 h. Extracts from the broad-spectrum phytochemical group showed strong cytotoxic effects, with *Heliotropium indicum* and *Vernonia amygdalina* exhibiting the lowest IC₅₀ values at 48 h (2.59 ± 0.08 µg/µL and 2.86 ± 0.17 µg/µL, respectively), followed by *Dissotis rotundifolia* (3.05 ± 0.10 µg/µL). Within the terpenoid-and flavonoid-rich group, *Launaea taraxacifolia* displayed greater potency (2.76 ± 0.22 µg/µL) compared to *Azadirachta indica* (3.71 ± 0.20 µg/µL), *Carica papaya leaves* (3.63 ± 0.15 µg/µL), and *Solanum melongena* (3.25 ± 0.30 µg/µL). The polyphenol-dominant extract, *Chromolaena odorata*, showed moderate activity (3.32 ± 0.15 µg/µL). Among the minimally diverse extracts, *Carica papaya seeds* exhibited moderate cytotoxicity (3.08 ± 0.07 µg/µL), whereas *Zingiber officinale* had the highest IC₅₀ value (4.23 ± 0.26 µg/µL), indicating the least potency in this group.

Discussion

The findings from this study highlight the cytotoxic potential of crude extracts of selected medicinal plants on breast (MCF-7) and prostate (PC-3) cancer cell lines. The results demonstrated a clear dose-dependent and time-dependent reduction in cell viability, confirming the potential of these plant extracts as promising candidates for alternative cancer treatments. Notably, a sharp increase in cytotoxicity was observed at lower concentrations at all time points. However, the difference in cytotoxicity was more pronounced at 48 h, with all extracts showing greater effects on breast and prostate cancer cell lines compared to 24-hour exposure. This suggests that prolonged exposure enhances the activity of the active compounds in the extracts, possibly because of either cumulative damage over time or delayed activation of cytotoxic mechanisms. These trends underscore the potential of these extracts as specific therapeutic agents and open new avenues for understanding the bioactivity of plant-based compounds.

Based on these findings, the bioactive compounds identified in the extracts were alkaloids, flavonoids, tannins, phenols, steroids, glycosides, cardiac glycosides, and saponins. However, the anticancer properties of these compounds remain to be explored. For example, *Heliotropium indicum* contains a pyrrolizidine alkaloid that exhibits anticancer, anti-inflammatory, and antioxidant effects. Pyrrolizidine alkaloid induces apoptosis in cancer cells and cytotoxicity, aligning with the cytotoxicity observed in this study [3636–39]. Pyrrolizidine alkaloid has been shown to inhibit breast, prostate, and cervical cancer proliferation by inducing DNA damage and inhibiting the polymerization of tubulin [36]. Hence, the presence of alkaloids could contribute to the increased cytotoxicity of the *Heliotropium indicum* extract in breast and prostate cancer cells. The therapeutic potential of alkaloids in *H. indicum* highlights the value of this plant in traditional and modern medicine, warranting further research to harness its benefits while mitigating toxicity concerns.

Similarly, *Vernonia amygdalina* has demonstrated direct antiproliferative effects, likely due to flavonoids such as luteolin, and steroid glycosides [40–42]. Our findings are consistent with those of previous studies that demonstrated that *V. amygdalina* inhibits breast cancer cell proliferation [41, 43, 44]. Studies have indicated that *V. amygdalina* inhibits DNA synthesis and proliferation in MCF-7 breast cancer cells. This effect is achieved through the regulation of key signaling pathways, including the suppression of extracellular signal-regulated kinases (ERKs), which are involved in cell survival and proliferation [44]. Furthermore, *V. amygdalina* induces apoptosis by downregulating transcription factors, such as NF-κB, which is associated with anti-apoptotic and

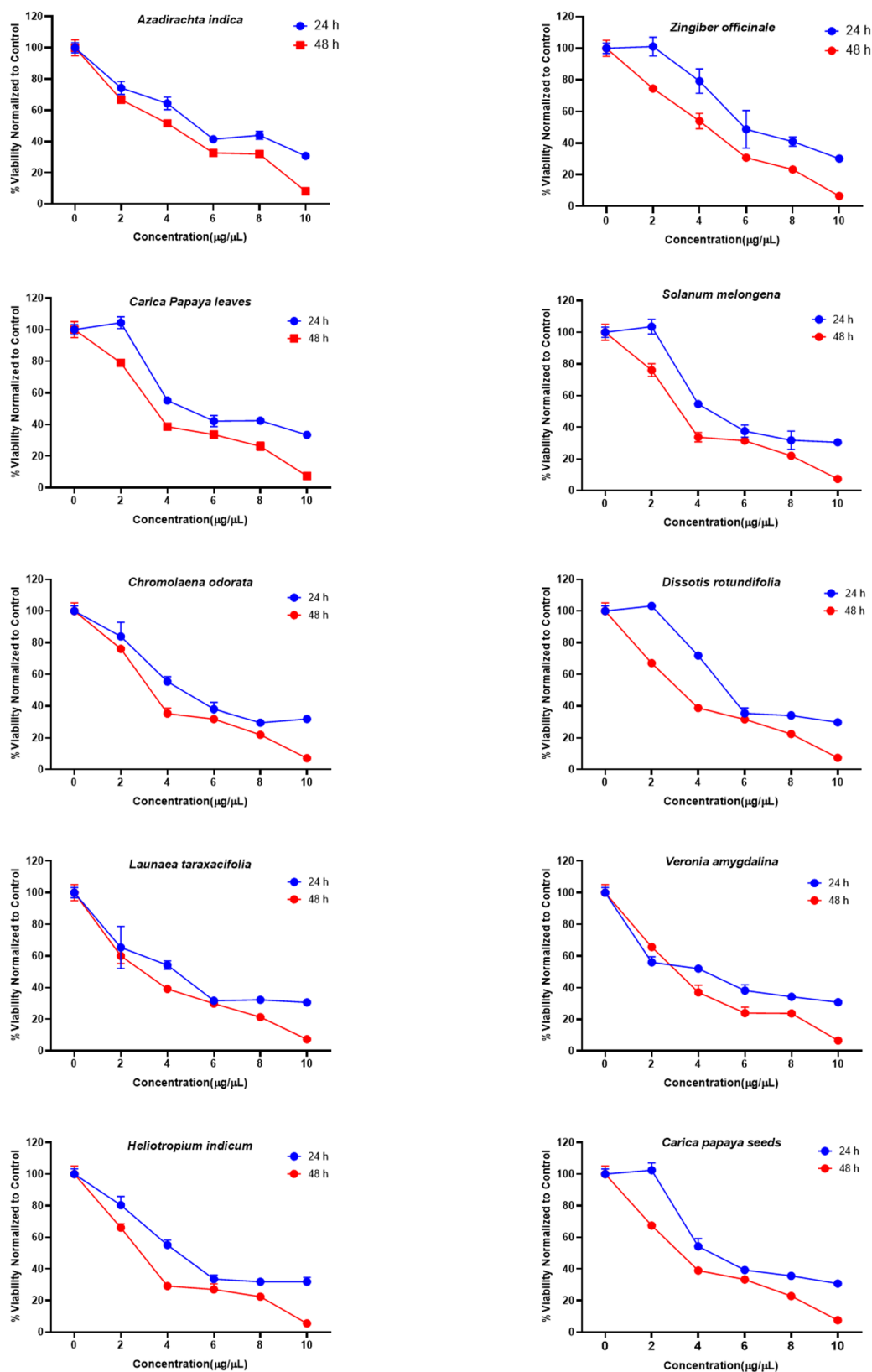


Fig. 2 Dose-response of PC-3 cell lines to plant extracts at 24 h and 48 h post-treatment. A dose-response graph of each plant extract treatment and their controls in PC-3 cancer cell lines is presented in the chart. Data represent the mean $\pm$ S.E.M of three independent experiments at 0 $\mu\text{g}/\mu\text{L}$, 2 $\mu\text{g}/\mu\text{L}$, 4 $\mu\text{g}/\mu\text{L}$, 6 $\mu\text{g}/\mu\text{L}$, 8 $\mu\text{g}/\mu\text{L}$ and 10 $\mu\text{g}/\mu\text{L}$ concentrations on PC-3 cancer cell lines for 24 h and 48 h

Table 3 IC₅₀ of plant extracts for 24 h and 48 h treatment of PC-3 prostate cancer cells. The IC₅₀ results in PC3 prostate cancer cells also indicated that the plant extracts exhibited varying degrees of cytotoxicity. The most potent extracts at 48 h were *Heliotropium indicum* (2.59 µg/µL), *Vernonia amygdalina* (2.86 µg/µL), and *Launaea Taraxacifolia* (2.76 µg/µL). All the extracts showed time-dependent cytotoxicity, with lower IC₅₀ values at 48 h than at 24 h

Plant Sample	IC ₅₀ (µg/µL) – PC3	
	24 h	48 h
<i>Azadirachta indica</i>	5.56 ± 0.24	3.71 ± 0.20
<i>Veronia amygdalina</i>	3.21 ± 0.21	2.86 ± 0.17
<i>Heliotropium indicum</i>	4.49 ± 0.14	2.59 ± 0.08
<i>Chromolaena odorata</i>	4.68 ± 0.30	3.32 ± 0.15
<i>Dissotis rotundifolia</i>	5.46 ± 0.10	3.05 ± 0.10
<i>Carica papaya leaves</i>	5.47 ± 0.16	3.63 ± 0.15
<i>Carica papaya seeds</i>	5.16 ± 0.19	3.08 ± 0.07
<i>Solanum melongena</i>	5.10 ± 0.19	3.25 ± 0.30
<i>Launaea taraxacifolia</i>	3.73 ± 0.48	2.76 ± 0.22
<i>Zingiber officinale</i>	6.30 ± 0.57	4.23 ± 0.26

pro-metastatic processes [45]. Moreover, its ability to enhance chemotherapy sensitivity [46] presents a compelling case for its integration into conventional treatment regimens.

Azadirachta indica, commonly known as neem, also exhibits significant anticancer potential. *Azadirachta indica* contains terpenoids, alkaloids, tannins, saponins, and flavonoids, which is consistent with our findings [47]. *Azadirachta indica* contains major terpenoids, such as nimbolide, azadirachtin, and alkaloids, which have been demonstrated to inhibit cancer cell proliferation by reducing the expression of proliferating cell nuclear antigen (PCNA) and modulating cytokeratin expression, which collectively suppresses tumor growth and promote cell differentiation [48–51]. Neem also induces apoptosis, a programmed cell death mechanism, through the increased expression of pro-apoptotic factors such as Bim, Bax, Apaf-1, and caspase 3, while simultaneously suppressing anti-apoptotic proteins such as Bcl-2 [52]. *Azadirachta indica* extract has significantly reduced tumor burden, pre-neoplastic lesions, and oxidative stress, whereas its nimbolide compound has been shown to inhibit the NF-κB and PI3K/Akt signaling pathways which are key regulators of cancer cell survival and proliferation [52–54]. These multifaceted mechanisms warrant further exploration to establish neem's therapeutic potential more comprehensively.

Launaea taraxacifolia also displayed noteworthy anticancer activity, attributed to its rich composition of alkaloids, flavonoids, and phenols [55]. The anticancer activity demonstrated by *Launaea taraxacifolia* might be a result of the presence of these bioactive compounds. Studies have shown that *L. taraxacifolia* has a significant growth inhibitory effect on WHC01 cancer

cells. Cell cycle analysis showed G0-G1 cell cycle arrest in WHC01 cells in the presence of the *L. taraxacifolia* extract, accompanied by morphological changes. *L. taraxacifolia* extract treatment resulted in the down-regulation of CYP1A2, ICAM-1, and VCAM-1 involved in cancer metastasis [56, 57]. These findings emphasize the need for further mechanistic studies to fully understand their therapeutic scope. In addition, *Chromolaena odorata* and *Dissotis rotundifolia* exhibited significant cytotoxic effects. *Chromolaena odorata* and *Dissotis rotundifolia* also showed significant cytotoxic effects, further supporting the potential of plant-based compounds as sources of bioactive agents. *Chromolaena odorata* and *Dissotis rotundifolia* have been shown to contain bioactive compounds such as alkaloids, flavonoids, tannins, and phenol [58, 59]. *C. odorata* was particularly effective against breast cancer cells through mechanisms such as apoptosis induction and Bcl-2 inhibition [60, 61].

Additionally, studies have explored the combination of *C. odorata* leaf extract and its flavonoid components with doxorubicin in 4T1 triple-negative breast cancer (TNBC) cells. This combination exhibited synergistic cytotoxic effects, enhancing the efficacy of doxorubicin and suggesting the potential of *C. odorata* as a co-chemotherapeutic agent [62]. Although these findings are promising for breast cancer treatment, research specifically targeting prostate cancer is limited. However, limited research on its effects against prostate cancer highlights the need for additional studies to fully elucidate its anticancer spectrum and underlying mechanisms. Similarly, *D. rotundifolia* displays anticancer properties against breast and prostate cancer cells, although its specific mechanisms of action require further investigation [24]. This study represents one of the few studies to elucidate the anticancer activity of *D. rotundifolia* in the breast and prostate. Although the plant exhibits general anticancer properties, its mechanisms of action against prostate and breast cancer cells remain to be determined. Further studies are necessary to explore this potential.

In our study, *Carica papaya* leaves and seeds also emerged as potent cytotoxic agents. These extracts contain alkaloids, flavonoids, and terpenoids, which collectively inhibit cell proliferation through mechanisms such as cell cycle arrest and BCL-2 downregulation. These findings are consistent with previous studies demonstrating *C. papaya*'s ability to stabilize the p53 tumor suppressor pathway, further supporting its role in cancer therapy [28, 63, 64]. Although there are few anticancer mechanistic studies on *Carica papaya* leaf extract it has been demonstrated to have anticancer activity [65]. The bioactive compounds in *Solanum melongena* include alkaloids such as solasonine and solamargine, which contribute to its anticancer effects by inducing apoptosis and causing cell cycle arrest [66]. Although most studies have focused

on liver cancer [67], these mechanisms are likely to be applicable to breast and prostate cancers, thereby presenting opportunities for broader applications. *Zingiber officinale* has demonstrated significant anticancer properties, particularly inducing cytotoxicity in prostate and breast cancer cells. Studies have shown that ginger extract can inhibit the growth and progression of prostate cancer cells by approximately 56%, primarily through mechanisms such as cell-cycle arrest and induction of apoptosis [68]. In breast cancer research, compounds such as 6-shogaol, a major phenolic constituent of ginger, have been found to induce cell cycle arrest and apoptosis in triple-negative breast cancer cells [69]. Additionally, ginger-derived nanovesicles have been reported to inhibit breast cancer cell proliferation by inducing apoptosis [70]. These findings support the potential of ginger as a natural therapeutic agent for cancer treatment, offering a complementary approach to conventional therapies.

Overall, the cytotoxic effects of the plant extracts on MCF-7 breast and PC-3 prostate cancer cells were generally aligned with their phytochemical groupings, although some differences were observed. Extracts of the broad-spectrum phytochemical group consistently demonstrated strong activity in both cell lines, particularly *Vernonia amygdalina* and *Heliotropium indicum*, supporting the synergistic role of alkaloids, flavonoids, and saponins. However, *Dissotis rotundifolia* showed slightly reduced potency in PC-3 cells compared to MCF-7 cells. Within the terpenoid- and flavonoid-rich groups, *Launaea taraxacifolia* showed relatively stronger activity in PC-3 cells than in MCF-7 cells, whereas *Solanum melongena* was more effective against breast cancer cells. In the polyphenol-dominant group, *Chromolaena odorata* exhibited limited activity in both cell lines, suggesting that the absence of terpenoids may restrict its cytotoxic potential. Notably, the minimally diverse group displayed divergent responses: *Carica papaya* seeds were highly active against MCF-7 cells but showed only moderate potency in PC-3 cells, whereas *Zingiber officinale* remained the least effective in both models. These findings underscore both shared and cell type-specific responses to phytochemical classes, highlighting the importance of compound composition and cancer cell context in mediating extract efficacy.

Although the crude extracts in these plants exhibit significant anticancer properties, their fractions and combined synergistic effects may hold the key to overcoming challenges such as chemoresistance and improving therapeutic efficacy. Although the observed cytotoxic effects are promising, this study represents an initial step in evaluating the anticancer potential of these plant extracts. Although qualitative phytochemical screening was not performed, future studies should incorporate UPLC-MS profiling of each extract to identify and quantify the

specific bioactive constituents that contribute to cytotoxicity. Future studies should focus on bioactivity-guided fractionation and compound isolation to identify the active compounds within the most potent extracts. The study is also limited by the lack of mechanistic studies, and future studies should include protein and gene expression analyses to clarify the apoptotic and anti-proliferative pathways involved. Investigating the potential synergy between plant extracts and conventional chemotherapeutics could provide insights into their utility as adjuvants in cancer treatment in the future.

Conclusion

This study highlights a dose- and time-dependent reduction in cell viability, with *Azadirachta indica*, *Carica papaya* leaves and seeds, *Chromolaena odorata*, *Launaea taraxacifolia*, *Heliotropium indicum*, *Zingiber officinale*, *Solanum melongena*, *Dissotis rotundifolia*, and *Vernonia amygdalina* seeds showing cytotoxic potential against breast (MCF-7) and prostate (PC-3) cancer cell lines. These findings suggest that the bioactive compounds in these plants, including alkaloids, flavonoids, and terpenoids, may contribute to their anticancer activity by inducing apoptosis and inhibiting proliferation pathways. This study underscores the therapeutic potential of plant-derived compounds and supports further research into their mechanisms of action, safety, and potential for drug development, both individually and in combination, for effective cancer treatment.

Acknowledgements

None.

Author contributions

Conceptualization: F.K., E.A., B.A., K.F. Methodology and Investigation: K.F., B.A., R.G., F.H., D.T., E.F., A.D.D., C.N., J.N., D.Y.S. Validation: E.A., B.A. and F.K. Supervision: K.F. Writing original draft: K.F., B.A., R.G. F.H. Reviewing and Editing: F.K., E.A.

Funding

None.

Data availability

No datasets were generated or analysed during the current study.

Declarations

Ethics approval and consent to participate

Not applicable.

Consent for publication

Not applicable.

Competing interests

The authors declare no competing interests.

Received: 17 February 2025 / Accepted: 14 August 2025

Published online: 22 August 2025

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