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Review Article

Alkaloids of Solanaceae in oncology: molecular and pharmacological aspects

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Abstract: Cancer remains a major global health challenge characterized by uncontrolled cellular proliferation and complex molecular dysregulation. Limitations associated with conventional therapies, including toxicity and resistance, have intensified the search for alternative and complementary therapeutic agents. Plant-derived secondary metabolites, particularly alkaloids, have emerged as promising candidates in the current time due to their structural diversity and versatile biological activities. Solanaceae family represents a significant reservoir of such bioactive compounds, containing a wide range of alkaloids including steroidal glycoalkaloids, tropane alkaloids and withanolides. These compounds exhibit diverse mechanisms of action, such as induction of apoptosis, cell cycle arrest, modulation of signaling pathways (e.g., PI3K/Akt, STAT3, NF-κB) and inhibition of metastasis and angiogenesis. Despite substantial *in vitro* evidence supporting their efficacy, challenges related to bioavailability, toxicity and limited clinical validation persist. Therefore, further *in vivo* studies, advanced drug delivery strategies and in depth investigations are essential to harness their full therapeutic potential. This review highlights the relevance of Solanaceae - derived alkaloids as a promising avenue for the development of novel anticancer agents.

Keywords: Alkaloids, anti-cancer agents, oncology, secondary metabolites, Solanaceae, *Solanum*, therapeutics

Introduction

Cancer is a multifaceted disease characterized by uncontrolled cell proliferation driven by genetic and epigenetic alterations (Brown et al., 2023). Despite advances in chemotherapy, radiotherapy and surgical interventions, the high cost, toxicity and side effects associated with these treatments, calls for the exploration of alternative therapeutic strategies (Zafar et al., 2025). Medicinal plants in this context, have gained renewed attention as valuable source of bioactive compounds with potential anticancer properties (Desai et al., 2008). Traditional systems of medicine, including Ayurveda, Unani and Siddha, have long utilized plant-based formulations and still today, a significant proportion of the global plant diversity is recognized for its medicinal potential (Vaidya and Devasagayam, 2007). Among plant-derived metabolites, alkaloids represent a structurally diverse class of nitrogen-containing compounds with significant pharmacological relevance (Heinrich et al., 2021). These secondary metabolites exhibit potent anticancer activities through multiple mechanisms, including inhibition of DNA replication enzymes, induction of apoptosis, modulation of signaling pathways and regulation of the cell cycle (Chidananda et al., 2025). Their multi-targeted mode of action makes them good prospects for the development of safer and more effective anticancer agents. The Solanaceae family, comprising over 3000 species, is a rich source of bioactive alkaloids and related compounds (Yadav and Koshi, 2022). Genera such as *Solanum* (plate 1), *Datura*, *Withania* and *Physalis* have been widely studied for their therapeutic potential both traditionally and pharmacologically (Manoharan et al., 2024). Alkaloids including solanine, solasonine, solanidine and withaferin A have showed significant anticancer activity across various experimental models, primarily through mechanisms such as cell cycle arrest, apoptosis induction and transcriptional regulation (Nkwe et al., 2021). These findings invite further exploration into how Solanaceae-derived alkaloids can be effectively translated from experimental promise into clinically viable anticancer therapies.

Methodology

The present study is based on an extensive survey of published literature related to family Solanaceae. Scientific databases, including Google Scholar, Scopus, PubMed and Web of Science, were consulted to retrieve peer-reviewed research articles, review papers, ethnobotanical surveys and pharmacological studies. Keywords including “Solanaceae,” “bioactive compounds,” “alkaloids,” “cancer treatment,” “Solanum”, “anticancer activity” and “apoptosis” were used to review relevant publications. Additionally, regional floras, theses, books and reports documenting traditional knowledge and distribution patterns were examined. Only studies containing verifiable scientific or ethnomedicinal data were considered. Information obtained was critically analyzed and systematically organized under thematic sections to ensure clarity and coherence (Kumar, 2025; Sahu et al., 2026).

Anticancer activity

Alkaloids derived from Solanaceae species exhibit diverse and multi-layered mechanisms of anticancer action, targeting key processes involved in tumor progression (Nkwe et al., 2021). In the Solanaceae family, major classes such as tropane, indole, pyridine, pyrrolidine, steroidal and

glycoalkaloids are commonly reported, typically occurring in 0.01-3% composition (Yadav and Koshi, 2022).

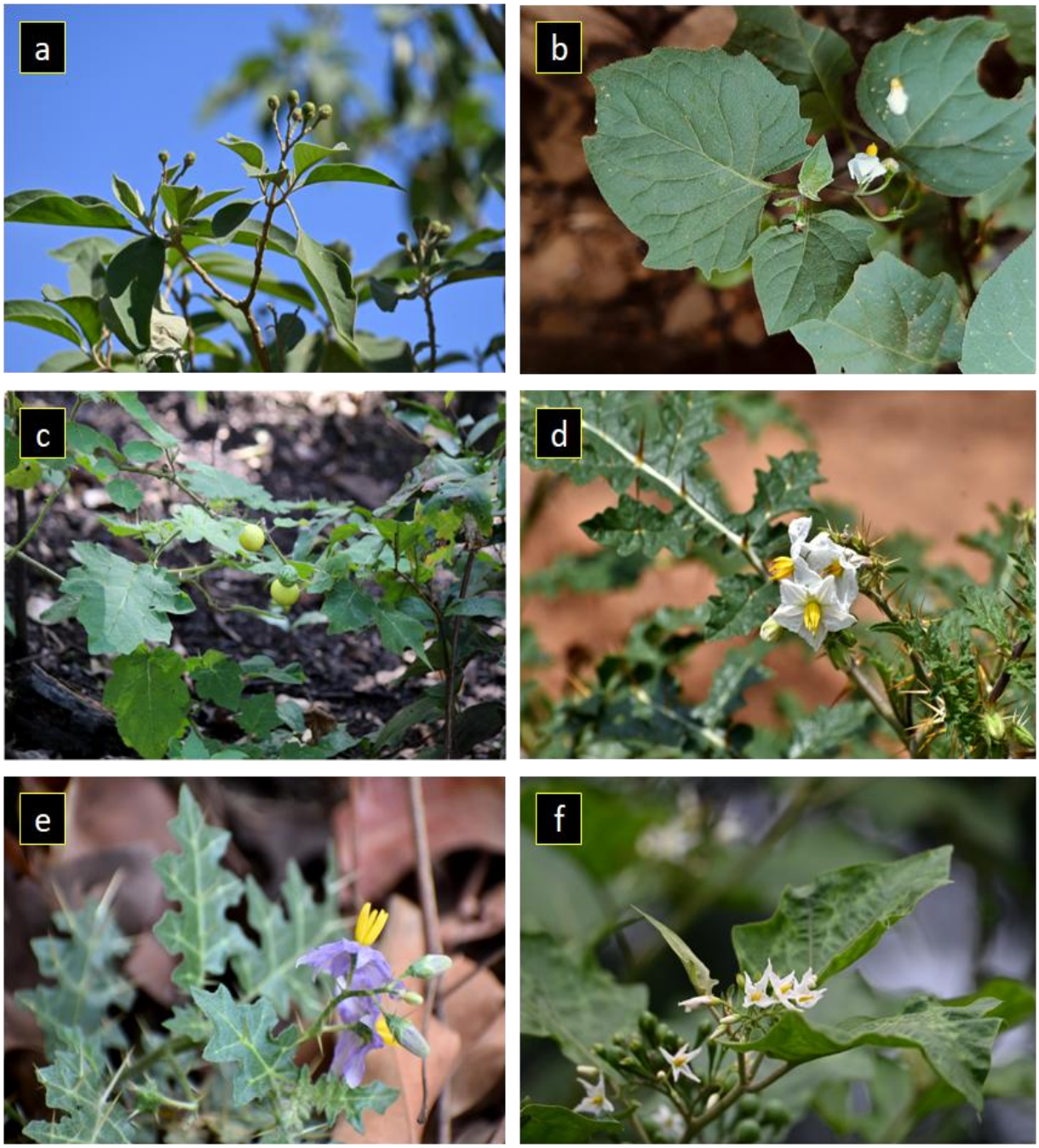

Plate 1: Members of family Solanaceae (a) *Solanum erianthum* (b) *Solanum nigrum* (c) *Solanum viarum* (d) *Solanum sisymbriifolium* (e) *Solanum virginianum* and (f) *Solanum torvum*

These compounds have been reported (Winkiel et al., 2022) to interfere with cell cycle progression at various checkpoints, inhibit critical signaling pathways such as PI3K/Akt, STAT3 and NF-κB and induce different forms of cell death, including apoptosis, necroptosis and autophagy (Table 1). Additionally, certain alkaloids demonstrate anti-metastatic and anti-angiogenic properties by modulating matrix metalloproteinases and vascular growth factors (Manoharan et al., 2024).

Table 1: Bioactive alkaloids from Solanaceae with reported anticancer activities and molecular targets

Plant source (Family: Solanaceae)	Alkaloids	Biological system evaluated	Primary antitumor effects	Molecular targets / pathways	Source(s)
Datura metel L.	Baimantuoluoamide A	In silico (CDK4: PDB 2W9Z, 1GII)	Cell cycle suppression	CDK4 inhibition	Nkwe et al., (2021)
	Baimantuoluoamide B				
	Daturametelindoles A–D	SGC-7901, HepG2, MCF-7	Cytotoxic activity (IC_{50}: 6.73-47.63 μM)	Not specified	Kowalczyk et al., (2022)
Solanum lycopersicum L.	Tomatine	HT-29, SKOV3, MCF-7, PC-3, melanoma	Anti-proliferative; apoptosis induction; autophagy inhibition	NF-κB, PI3K/Akt/mTOR, ERK pathway suppression	Winkiel et al., (2022)
		Melanoma, MCF-7	Anti-metastatic; anti-angiogenic	MMP-2, MMP-9 inhibition; ER/p-eIF2/VEGF modulation	
		HL-60, CT-26, CLC, SH-SY5Y	Necrosis and necroptosis induction	Cholesterol-mediated membrane disruption; AIF activation; JNK signaling	
Solanum aculeastrum Dunal	Solamargine + Solanine	SH-SY5Y	Cytotoxicity (IC_{50}: 10.72 μg/mL)	Not specified	Kowalczyk et al., (2022)

Solanum aculeastrum Dunal, *Solanum nigrum* L., *Solanum palinacanthum* Dunal, *Solanum lycocarpum* A.St.-Hil., *Solanum melongena* L.	Solamargine	HepG2, Huh-7; SH-SY5Y	Cell cycle arrest (S, G2/M phases)	Likely regulation of cell cycle checkpoints	Nkwe et al., (2021); Yadav and Koshi, (2022)
Solanum melongena L.	α-Solanine	Pancreatic cancer cell lines	Anti-proliferative; cell cycle arrest (S phase)	VEGF degradation; STAT3 inhibition; upregulation of HIF-1α and E-cadherin	Nkwe et al., (2021)
Solanum nigrum L. (Plate 1b)	Solanidine	A549; CAM xenograft model	Tumor growth inhibition; cell cycle arrest (S, G2/M)	Cell cycle regulatory pathways	Nkwe et al., (2021)
	Solasonine	Bcap-37; HepG2, Huh7	Cell cycle arrest (S phase)	Not clearly defined	
Withania somnifera (L.) Dunal	Withaferin A	HD11-C3-GFP1, HL60, QT6, 3T3-L1	Cell cycle arrest (G2/M); differentiation modulation	Inhibition of MYB and C/EBPβ transcription factors	
Solanum tuberosum L.	Chaconine	DAOY, RL95-2; *in vitro* & *in vivo*	Anti-proliferative; anti-inflammatory	Hedgehog (Smo) inhibition; PI3K/Akt and	Winkiel et al., (2022)

				ERα suppression	

Research gaps

Despite extensive *in vitro* evidence supporting the efficacy of Solanaceae derived alkaloids, the translation of these researches into clinical applications remain limited due to insufficient *in vivo* validation and lack of detailed insights for several compounds.

Future aspects

Variability in phytochemical composition and challenges in bioavailability require the development of advanced delivery systems, such as nanocarriers, to enhance therapeutic efficiency. Integrating traditional ethnopharmacological knowledge with modern molecular approaches may assist the identification of novel targets and accelerate the development of Solanaceae-derived alkaloids as viable anticancer therapeutics.

Conclusion

Researches show that, alkaloids derived from the Solanaceae family demonstrate significant anticancer potential through their ability to target multiple pathways involved in tumor initiation and progression. Their diverse mechanisms, including cell cycle regulation, apoptosis induction and signaling pathway modulation, position them as valuable plant sources for future drug development. However, the transition from experimental studies to clinical application remains limited due to gaps in *in vivo* validation, standardization, ethnopharmacological and pharmacokinetic understanding. Addressing these challenges through integrated research approaches, including molecular studies and advanced delivery systems, will be crucial. The continued exploration of Solanaceae bioactives not only reinforces the importance of plant-based therapeutics but also opens pathways toward more effective, accessible and sustainable cancer treatments.

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