Available online on 15.06.2025 at http://jddtonline.info

Journal of Drug Delivery and Therapeutics

Open Access to Pharmaceutical and Medical Research

Open Access Full Text Article

Research Article

TLC Profiling and Phytochemical Evaluation of *Kaempferia parviflora* Rhizome: A Rich Source of Bioactive Metabolites

Swati Pandey, Shubhrat Maheshwari, Jagat Pal Yadav, Amita Verma *

Bioorganic and Medicinal Chemistry Research Laboratory, Department of Pharmaceutical Sciences, Sam Higginbottom University of Agriculture, Technology and Sciences, Prayagraj, 211007, India

Article Info:

Article History:

Received 11 March 2025
Reviewed 23 April 2025
Accepted 21 May 2025
Published 15 June 2025

Cite this article as:

Pandey S, Maheshwari S, Yadav JP, Verma A, TLC Profiling and Phytochemical Evaluation of *Kaempferia parviflora* Rhizome: A Rich Source of Bioactive Metabolites, Journal of Drug Delivery and Therapeutics. 2025; 15(6):79-84
DOI:
http://dx.doi.org/10.22270/jddt.v15i6.7182

*Address for Correspondence:

Prof. (Dr.) Amita Verma (Professor and Head), Bioorganic and Medicinal Chemistry Research Laboratory, Department of Pharmaceutical Sciences, Sam Higginbottom University of Agriculture, Technology and Sciences, Prayagraj, 211007, India

Abstract

The present study investigates the phytochemical composition and chromatographic profiling of the hydroalcoholic extract of *Kaempferia parviflora* rhizome. Preliminary phytochemical screening revealed the presence of key secondary metabolites including alkaloids, flavonoids, tannins, phenolics, saponins, steroids, glycosides, terpenoids, and volatile oils, supporting the plant's ethnomedicinal significance. Thin Layer Chromatography (TLC) analysis was performed using four solvent systems of varying polarity to optimize the separation and visualization of constituent compounds. Distinct and well-resolved bands were observed under UV light (254 nm and 365 nm), with Rf values ranging from 0.08 to 0.97, indicating a rich diversity of polar and moderately polar phytochemicals. Derivatization with vanillin-sulfuric acid further confirmed the presence of compound classes such as flavonoids, phenolics, terpenoids, and glycosides. The comprehensive phytochemical and chromatographic profiles obtained in this study underscore the potential of *K. parviflora* as a valuable phytopharmaceutical candidate, laying the groundwork for further bioactivity-guided isolation and anticancer assessment.

Keywords: *Kaempferia parviflora*, Black ginger, Phytochemical analysis, TLC analysis, hydroalcoholic extract.

1. INTRODUCTION

Kaempferia parviflora Wall. ex Baker, commonly referred to as black ginger, is a medicinal plant belonging to the Zingiberaceae family. It is predominantly native to Southeast Asia, particularly Thailand, Myanmar, and Laos. Traditionally, the rhizomes of *K. parviflora* have been used in folk medicine to manage a variety of health conditions, including digestive disorders, inflammation, hypertension, and metabolic imbalances [1, 2]. In recent decades, the plant has attracted growing scientific interest due to its diverse therapeutic properties, especially its antioxidant and anticancer activities, aligning with the global resurgence in the use of ethnomedicines [3]. Globally, breast cancer remains the most commonly diagnosed cancer and the leading cause of cancer-related mortality among women (World Health Organization, 2023). Although significant advancements have been made in breast cancer treatment—spanning chemotherapy, hormonal therapy, immunotherapy, and radiotherapy—challenges such as adverse side effects, drug resistance, and recurrence continue to hinder clinical outcomes [4]. These limitations have spurred increased interest in identifying effective plant-based therapeutics that could serve as primary or adjunctive treatment options. Phytochemical studies of *K. parviflora* rhizomes have revealed the presence of valuable secondary metabolites, particularly polymethoxyflavones (PMFs) such as 5, 7-dimethoxyflavone and 5, 7, 4′-trimethoxyflavone, as well as the widely studied flavonoid kaempferol[5]. These compounds have demonstrated notable biological activities, including cytotoxic effects on cancer cells, along with antibacterial, anti-inflammatory, and antioxidant properties. The antioxidant activity of these metabolites is particularly significant, as oxidative stress is a major contributor to carcinogenesis and tumor progression. Oxidative stress arises from an imbalance between the generation of reactive oxygen species (ROS) and the body's antioxidant defense mechanisms, leading to cellular damage through lipid peroxidation, DNA mutations, and disruption of

intracellular signaling pathways[2, 6-7]. Analytical techniques such as phytochemical screening and thin layer chromatography (TLC) are essential tools in the identification, profiling, and standardization of bioactive compounds in medicinal plants. These methodologies not only facilitate the understanding of the chemical composition of plant extracts but also lay the groundwork for pharmacological exploration. Recent investigations have highlighted the cytotoxic potential of *K. parviflora* extracts against various cancer cell lines [8, 9]. The present study aims to evaluate the phytochemical constituents and antioxidant potential of *Kaempferia parviflora* rhizome extract, with a particular emphasis on its potential role in breast cancer treatment. The investigation includes qualitative phytochemical screening and TLC fingerprinting. By integrating phytochemical profiling with antioxidant assessment, this research contributes to the advancement of phytopharmaceutical development, highlighting *K. parviflora* as a promising natural candidate for supportive therapy in oxidative stress-related conditions, particularly breast cancer.

2. MATERIAL AND METHODS

2.1 Collection, Authentication and preparation of Plant Material

Fresh *Kaempferia parviflora* rhizomes were collected from a certified herbal farm and were carefully identified and authenticated. The taxonomic identity of the samples was confirmed by Mr. Vinay Ranjan, Scientist-E and Head of Office, Botanical Survey of India, Central Regional Centre, Allahabad. The authentication was further verified by a taxonomist from the Ministry of Environment, Forests, and Climate Change, Government of India. A voucher specimen (Reference No. SIP/2024-2025/534) was prepared and deposited for future reference[10]. The rhizomes were thoroughly washed with distilled water to remove any adhering soil or debris, sliced into thin sections, and shade-dried at ambient room temperature (25 ± 2 °C) for 7–10 days[7].

2.2. Preparation of hydroalcoholic Extract of *Kaempferia parviflora* Rhizome

The shade-dried rhizome slices were pulverized into a fine powder using a mechanical grinder and stored in airtight containers to prevent moisture absorption. Approximately 100 g of the powdered material was placed in a cellulose thimble and subjected to Soxhlet extraction using the mixture of 50% ethanol 50% water as the solvent. This solvent system was selected due to its proven efficiency in extracting a broad spectrum of phytochemicals, particularly polar and moderately non-polar compounds such as flavonoids, phenolics and terpenoids[11]. The thimble containing the rhizome powder was positioned in the main chamber of the Soxhlet apparatus and attached to a round-bottom flask containing solvent. A reflux condenser was mounted above the extractor, allowing continuous condensation of the solvent. The system was maintained on a heating mantle, and the extraction process was carried out for 6–8 hours at approximately 80-85°C, until the siphoning solvent became colorless, indicating exhaustive extraction. The extract was then filtered and concentrated under reduced pressure using a rotary evaporator to remove residual solvent shown in Figure 1. The concentrated extract was further dried in a vacuum desiccator to yield a solid mass. The crude hydroalcoholic extract was stored in an amber-colored container at 4°C until further use [12].

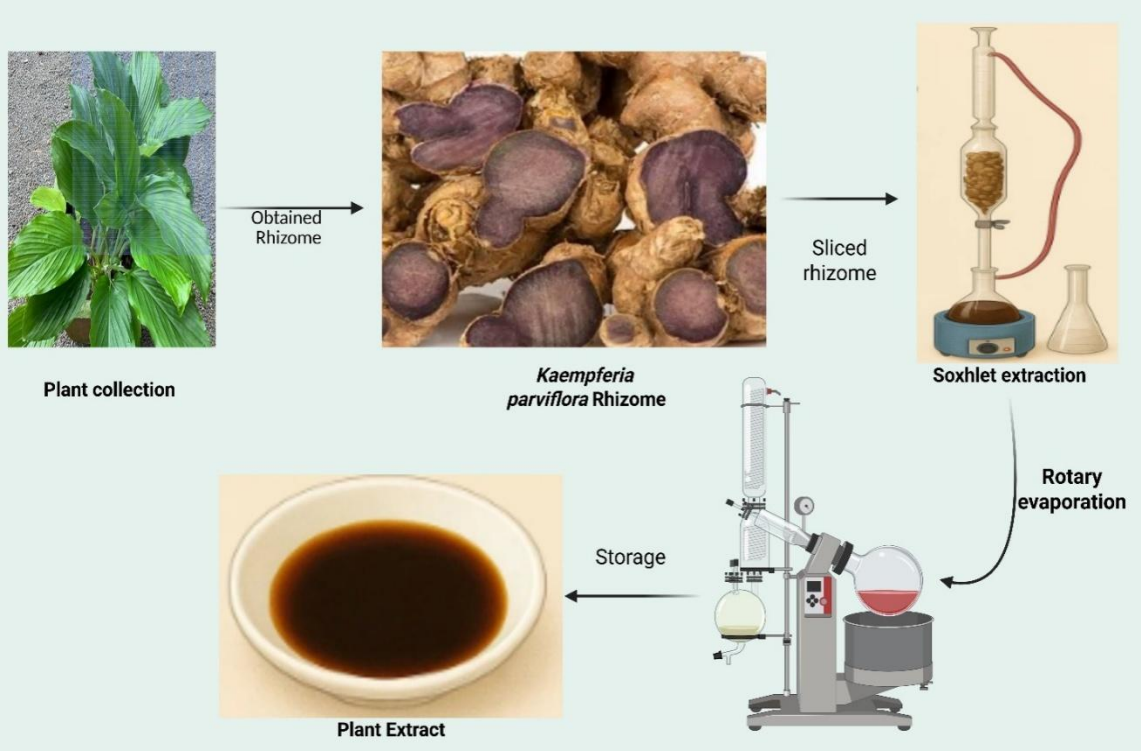

Figure 1. Extraction process of *Kaempferia parviflora* rhizome extract.

2.3 Preliminary Phytochemical Screening

The hydroalcoholic extract of *Kaempferia parviflora* rhizome was subjected to preliminary phytochemical screening to identify the presence of major classes of bioactive compounds. Standard qualitative methods were employed as described in authoritative pharmacognostic and botanical literature [13–19]. These tests were designed to detect various phytochemical groups, including alkaloids, flavonoids, phenolics, terpenoids, saponins, tannins, and glycosides.

2.4 Thin Layer Chromatography (TLC) Profiling of *Kaempferia parviflora* Extract

2.4.1 Preparation of TLC Plate

Thin layer chromatography (TLC) was employed to generate a phytochemical fingerprint of the hydroalcoholic extract. Pre-coated silica gel 60 TLC plates (Merck) served as the stationary phase. A small volume (1–2 µL) of the extract was applied to the plate using a fine glass capillary, ensuring that the spot was placed approximately 1 cm above the lower edge of the plate. Care was taken to maintain uniformity in spot size and spacing across all samples to ensure reproducibility and consistent migration [20, 21].

2.4.2 Solvent Systems

To achieve effective separation of various phytoconstituents, four solvent systems with differing polarities were selected: (1) toluene:ethyl acetate (2:8, v/v), (2) toluene:ethyl acetate (3:7, v/v), (3) toluene:ethyl acetate (7:3, v/v), and (4) methanol:ethyl acetate (2:8, v/v). These systems were specifically chosen to facilitate the separation of compounds such as flavonoids, phenolic acids, terpenoids, and glycosides based on their polarity.

2.4.3 Development of TLC Plates

Each mobile phase was freshly prepared using analytical-grade solvents. The prepared TLC plates were placed in glass developing chambers pre-saturated with the respective solvent systems. The development was allowed to proceed until the solvent front reached approximately 8 cm from the point of origin. After development, the plates were removed and air-dried at room temperature. Visualization of the separated spots was conducted under UV light at wavelengths of 254 nm and 365 nm. To further aid in compound detection, some plates were treated with vanillin-sulfuric acid reagent and gently heated at 110°C, which produced characteristic color reactions indicative of specific classes of phytochemicals [22]. The retention factor (Rf) for each observed spot was calculated using the formula:

Rf = (Distance traveled by the compound) / (Distance traveled by the solvent front)

3. RESULTS

3.1Phytochemical Screening

The preliminary phytochemical analysis of the hydroalcoholicextract of *Kaempferia parviflora* rhizome revealed the presence of a diverse range of bioactive compounds. The screening confirmed the presence of alkaloids, flavonoids, tannins, phenolics, terpenoids, saponins, steroids, glycosides, and volatile oils shown in Table 1. These phytochemical classes are widely recognized for their therapeutic significance, contributing to various biological activities including antioxidant, anti-inflammatory, anticancer, and antimicrobial effects. The detection of multiple classes of secondary metabolites aligns with the ethnopharmacological use of *K. parviflora* in traditional medicine and underscores its potential as a candidate for pharmacological and phytopharmaceutical development.

Table 1: Phytochemical constituents identified in *Kaempferia parviflora*hydroalcoholic extract.

S. No.	Phytochemical Class	Test Method	Result
1	Alkaloids	Dragendorff's Wagner's Test	+ve +ve
2	Flavonoids	Shinoda Test	+ve
3	Tannins	Ferric Chloride Test	+ve
5	Saponins	Foam Test	+ve
6	Phenolics	Ferric Chloride Test	+ve
7	Glycosides	Keller–Killiani Test	+ve
8	Terpenoids	Salkowski Test	+ve
9	Solublity Test	Volatile oil	+ve

3.2 Thin Layer Chromatography (TLC) Profiling

Thin Layer Chromatography (TLC) analysis of the hydroalcoholicextract of *Kaempferia parviflora* was carried out using four solvent systems of varying polarity to profile the phytochemical constituents. The TLC plates revealed multiple well-resolved bands under UV light (254 nm and 365 nm), indicating the presence of a wide array of phytochemicals. Visual detection after derivatization with vanillin-sulfuric acid also confirmed the occurrence of distinct compound classes such as flavonoids, phenolics, terpenoids, and glycosides[23].

3.2.1 Solvent System 1: Toluene: Ethyl Acetate (2:8) – Moderate Polarity

This polarity solvent system exhibited excellent resolving capacity with sharp, well-separated bands. Under 365 nm UV light, several bright fluorescent spots were observed, suggestive of the presence of flavonoids and terpenoids. A total of 12 spots with distinct Rf values ranging from 0.09 to 0.95 were recorded (Figure 2 and Table 2), indicating a diverse composition of moderately polar compounds. *Refer: Plate 1*

Table 2: ***Rf values of phytoconstituent spots observed on TLC Plate 1 using Toluene: Ethyl Acetate (2:8, v/v) solvent system.***

Spot No.	Distance Traveled by Compound (cm)	Rf Value
1	0.7	0.09
2	1.5	0.19
3	2.4	0.30
4	3.1	0.39
5	3.8	0.48
6	4.6	0.58
7	5.2	0.65
8	5.8	0.73
9	6.3	0.79
10	6.8	0.85
11	7.3	0.91
12	7.6	0.95

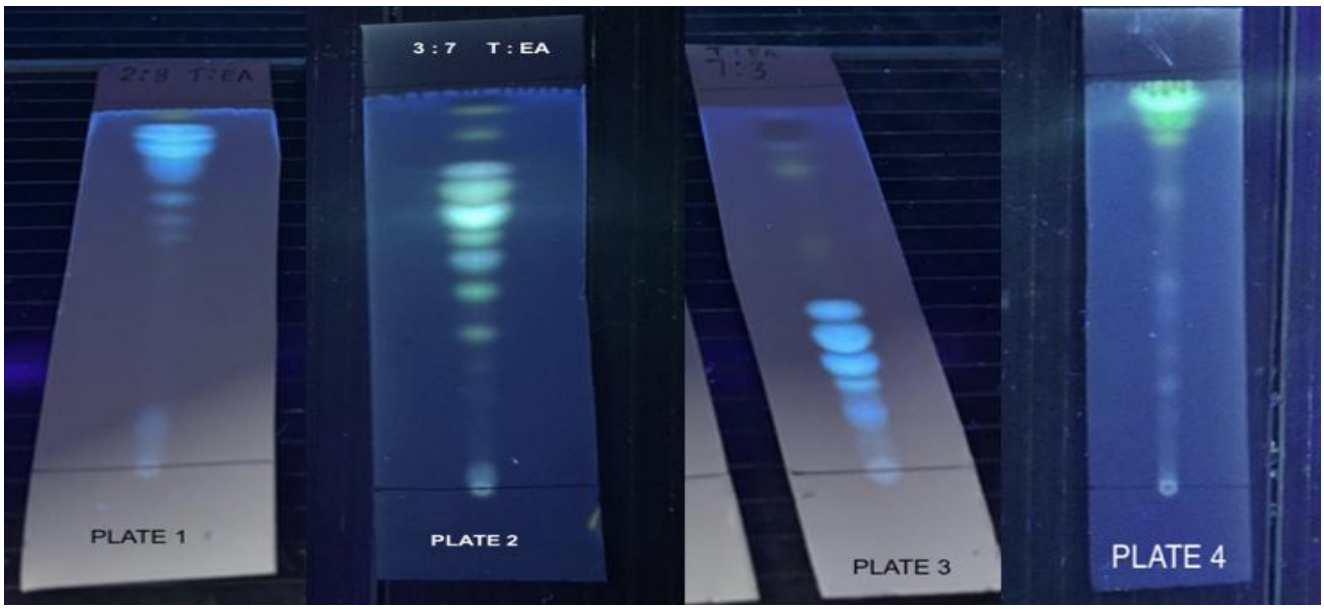

Figure 2: ***Thin Layer Chromatography (TLC) profiling of hydroalcoholicextract ofKaempferia parviflorarhizome using various solvent systems under UV light (365 nm).***Plate 1: Toluene: Ethyl Acetate (2:8, v/v) – Moderate polarity system showing multiple bright fluorescent bands indicating a diverse range of polar phytochemicals.Plate 2: Toluene: Ethyl Acetate (3:7, v/v) – Medium polarity system exhibiting strong resolution of mid-polar compounds with numerous distinct spots.Plate 3: Toluene: Ethyl Acetate (7:3, v/v) – Low polarity system resulting in fewer migrated polar compounds, with several spots clustered near the baseline.Plate 4: Methanol: Ethyl Acetate (2:8, v/v) – Highly polar system showing intense upper fluorescent bands, suggesting efficient separation of flavonoids, phenolics, and glycosides.

3.2.2 Solvent System 2: Toluene: Ethyl Acetate (3:7) – Medium Polarity

A slightly less polar mixture showed good migration of both mid-polar and some non-polar compounds. The resolution remained high, with 13 observable fluorescent spots (Rf values: 0.13–0.97), reflecting a broad phytochemical spectrum including potential phenolics and sterols (Table 3). *Refer: Plate 2*

Table 3: ***Rf values of phytochemical constituents observed on TLC Plate 2 developed using Toluene: Ethyl Acetate (3:7, v/v) under UV light (365 nm).***

Spot No.	Distance Traveled by Compound (cm)	Rf Value
1	1.0	0.13
2	1.8	0.23
3	2.4	0.30
4	3.0	0.38
5	3.5	0.44
6	4.0	0.50
7	4.5	0.56
8	5.0	0.63
9	5.5	0.69
10	6.1	0.76
11	7.0	0.87
12	7.6	0.95
13	7.8	0.97

3.2.3 Solvent System 3: Toluene: Ethyl Acetate (7:3) – Low Polarity

This relatively non-polar system displayed limited separation of polar compounds, as most spots appeared near the baseline. Thirteen spots with Rf values ranging from 0.11 to 0.96 were recorded, suggesting predominant retention of polar phytoconstituents (Table 4). *Refer: Plate 3*

Table 4: ***Rf values of phytochemical constituents observed on TLC Plate 3 developed using Toluene: Ethyl Acetate (7:3, v/v) under UV light (365 nm).***

Spot No.	Distance Traveled by Compound (cm)	Rf Value
1	0.9 cm	0.11
2	1.5 cm	0.19
3	2.2 cm	0.28
4	2.8 cm	0.35
5	3.4 cm	0.43
6	4.0 cm	0.50
7	4.5 cm	0.56
8	5.1 cm	0.64
9	5.6 cm	0.70
10	6.2 cm	0.78
11	6.7 cm	0.84
12	7.2 cm	0.90
13	7.7 cm	0.96

3.2.4 Solvent System 4: Methanol: Ethyl Acetate (2:8) – High Polarity (Hydrophilic Focus)

This polar system demonstrated efficient separation of hydrophilic compounds, with bright fluorescent spots suggestive of phenolic, flavonoids, and glycosides. Eleven distinct spots with Rf values from 0.08 to 0.91 were observed (Table 5), reflecting strong resolving power for polar phytochemicals. *Refer: Plate 4*

Table 5: ***Rf values of phytochemical constituents observed on TLC Plate 4 developed using Methanol: Ethyl Acetate (2:8, v/v) under UV light (365 nm).***

Spot No.	Distance Traveled by Compound (cm)	Rf Value
1	0.6	0.08
2	1.2	0.15
3	1.9	0.24
4	2.5	0.31
5	3.1	0.39
6	3.8	0.48
7	4.5	0.56
8	5.2	0.65
9	6.0	0.75
10	6.5	0.81
11	7.3	0.91

4. DISCUSSION

The present study provides substantial evidence supporting the rich phytochemical constitution and therapeutic potential of the hydroalcoholicextract of *Kaempferia parviflora* rhizome. The preliminary phytochemical screening revealed the presence of multiple classes of secondary metabolites, including flavonoids, alkaloids, tannins, terpenoids, phenolics, saponins, steroids, and glycosides. These findings are consistent with the documented ethnomedicinal use of *K. parviflora* across Southeast Asia and highlight its relevance in contemporary phytotherapeutic applications [23]. Among the identified constituents, flavonoids and phenolic compounds were particularly prominent. The Shinoda test confirmed the abundance of flavonoids, while the ferric chloride test indicated significant levels of phenolics and tannins. These compound classes are well-established for their antioxidant properties, which are primarily mediated through free radical scavenging and the attenuation of oxidative stress. Given the critical role of reactive oxygen species (ROS) in the initiation and progression of carcinogenesis, particularly in hormone-dependent malignancies such as breast cancer, the presence of such compounds suggests a potential chemo preventive role for *K. parviflora*[19].TLC analysis further substantiated the chemical complexity of the extract. Multiple solvent systems were employed to maximize the resolution of phytoconstituents with varying polarities. The Toluene: Ethyl Acetate (2:8, v/v) and Methanol: Ethyl Acetate (2:8, v/v) systems demonstrated the most effective separation of polar and mid-polar compounds, as evidenced by the appearance of distinct fluorescent bands under UV light (365 nm). The observed Rf values align closely with previously reported profiles of methoxylated flavonoids in *K. parviflora*, suggesting that such compounds may be among the major constituents responsible for its pharmacological activity [16]. The detection of alkaloids and terpenoids further strengthens the therapeutic profile of the extract. Alkaloids are known to exhibit cytotoxic properties through mechanisms such as microtubule disruption

and inhibition of DNA synthesis, while terpenoids have been reported to exert anti-proliferative, pro-apoptotic, and antiangiogenic effects [8, 11]. Collectively, the integration of phytochemical screening and TLC profiling in this study establishes a robust foundation for subsequent investigations.

5. CONCLUSION

The hydroalcoholic extract of *Kaempferia parviflora* rhizome demonstrated a broad spectrum of bioactive phytochemicals through both qualitative screening and TLC analysis. The presence of multiple secondary metabolites, particularly flavonoids, phenolics, and terpenoids, known for their pharmacological activities, highlights the therapeutic promise of this medicinal plant. The successful TLC profiling using various solvent systems provided a comprehensive fingerprint of the phytoconstituents, indicating significant chemical diversity and solvent-dependent mobility. These findings validate the traditional medicinal use of *K. parviflora* and support its continued investigation as a source of natural compounds for the development of anticancer agents. Further bioassay-guided fractionation and mechanistic studies are warranted to isolate specific constituents responsible for its anticancer activity.

Declaration of Competing Interest: The authors declare no competing interest.

Ethics approval and consent to participate: NA

Consent for publication: The publication of the material in print, online or other media formats as determined by publisher.

Availability of data and material: All data and materials related to this work are available in the manuscript.

Acknowledgements: The authors are thankful to Shalom Institute of Health and Allied Sciences, Sam Higginbottom University of Agriculture, Technology, Prayagraj, India, for providing the necessary facilities to execute this manuscript.

REFERENCES

1. Pham NK, Nguyen HT, Nguyen QB. A review on the ethnomedicinal uses, phytochemistry and pharmacology of plant species belonging to *Kaempferia* genus (Zingiberaceae). Pharm Sci Asia. 2021;48(1):1–24. https://doi.org/10.29090/psa.2021.01.19.070
2. Chew SC, Nyam KL. Black ginger (*Kaempferia parviflora*): A source of functional ingredient for food, nutraceutical and pharmaceutical applications. Food Chem Adv. 2025;7:100980. https://doi.org/10.1016/j.focha.2025.100980
3. Tan TYC, et al. Application of *Kaempferia parviflora*: A perspective review. Nat Prod Commun. 2024;19(10):1934578X241281615. https://doi.org/10.1177/1934578X241281615
4. Süntar I. Importance of ethnopharmacological studies in drug discovery: Role of medicinal plants. Phytochem Rev. 2020;19(5):1199–209. https://doi.org/10.1007/s11101-019-09629-9
5. Nguyen TVA, Nguyen TH, Nguyen TKO, Nguyen PN, Le HL. Novel findings on the bioactivities of black ginger of Vietnam and optimization of its extraction using response surface methodology. Chem Pap. 2024;78(9):5191–207. https://doi.org/10.1007/s11696-024-03458-7
6. Lee M, et al. Antiskin inflammatory activity of black ginger (*Kaempferia parviflora*) through antioxidative activity. Oxid Med Cell Longev. 2018;2018:5967150. https://doi.org/10.1155/2018/5967150
7. Sitthichai P, et al. *Kaempferia parviflora* rhizome extract as potential anti-acne ingredient. Molecules. 2022;27(14):4401. https://doi.org/10.3390/molecules27144401
8. Hairunisa I, Abu Bakar MF, Da'i M, Bakar FIA, Syamsul ES. Cytotoxic activity, anti-migration and in silico study of black ginger (*Kaempferia parviflora*) extract against breast cancer cell. Cancers. 2023;15(10):2785. https://doi.org/10.3390/cancers15102785
9. Hairunisa I, Abu Bakar MF, Da'i M. Pharmacological and anticancer potential of black ginger (*Kaempferia parviflora*) - Review article. Iraqi J Pharm Sci. 2024;33(4):30–48. https://doi.org/10.31351/vol33iss4pp30-48
10. Abubakar A, Haque M. Preparation of medicinal plants: Basic extraction and fractionation procedures for experimental purposes. J Pharm Bioallied Sci. 2020;12(1):1. https://doi.org/10.4103/jpbs.JPBS_175_19
11. Tangjitjaroenkun J, Yahayo W, Supabphol S, Supabphol R. Selective cytotoxicity of *Kaempferia parviflora* extracts in human cell lines. Asian Pac J Cancer Prev. 2021;22(S1):73–9. https://doi.org/10.31557/APJCP.2021.22.S1.73
12. Chaisuwan V, Dajanta K, Srikaeo K. Effects of extraction methods on antioxidants and methoxyflavones of *Kaempferiaparviflora*. Food Res. 2022;6(3):374–81. https://doi.org/10.26656/fr.2017.6(3).408
13. Cabral JPS. The impact of 16th century German botanical treatises on Garcia de Orta's*Coloquios dos Simples*. Adv Hist Stud. 2020;9(2):20–37. https://doi.org/10.4236/ahs.2020.92003
14. Evans WC, Evans D, Trease GE. *Trease and Evans Pharmacognosy*. 16th ed. Edinburgh: Saunders/Elsevier; 2009.
15. Khandelwal KR. *Practical Pharmacognosy: Techniques and Experiments*. Maharashtra: NiralPrakashan; 2008.
16. Huo C, et al. Methoxyflavones from black ginger (*Kaempferia parviflora* Wall. ex Baker) and their inhibitory effect on melanogenesis in B16F10 mouse melanoma cells. Plants. 2023;12(5):1183. https://doi.org/10.3390/plants12051183
17. Wongpia A, et al. Chemical composition analysis of essential oil from black gingers (*Kaempferia parviflora*) by gas chromatography–mass spectrometry (GC–MS). ActaHortic. 2022;1339:323–30. https://doi.org/10.17660/ActaHortic.2022.1339.40
18. Harborne JB. *Phytochemical Methods*. Dordrecht: Springer Netherlands; 1984. https://doi.org/10.1007/978-94-009-5570-7
19. Hoang TNN, Phan TT, Phan TKL, Nguyen NHV, Dao Dong TA, Le THA. Phytochemical screening, extraction, and determination of the bioactivities of the extract-enriched polyphenols and saponins from *Musa balbisiana* fruit. J Food Process Preserv. 2023;2023:1–16. https://doi.org/10.1155/2023/2581641
20. Dev M, Mukadam M. Phytochemical profiling and TLC analysis of indigenous plants. Int J InnovSci Res. 2025;3(1):6–10.
21. Danciu V, Hosu A, Cimpoiu C. Thin-layer chromatography in spices analysis. J LiqChromatogrRelat Technol. 2018;41(6):282–300. https://doi.org/10.1080/10826076.2018.1447895
22. Asante IK, Owusu E, Essilfie MK, Kwarteng M, Amuzuah O. Phytochemical investigation and thin layer chromatography of methanolic extracts of some selected grain legumes. J PharmacognPhytochem. 2016;5(3):240.
23. Kwon G-H, Kim MH, Han YS. Quality characteristics and antioxidant activity of yanggaeng added with black ginger (*Kaempferia parviflora*). J Korean Soc Food Nutr. 2021;50(7):715–24. https://doi.org/10.3746/jkfn.2021.50.7.715