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RESEARCH ARTICLE

CONVENTIONAL PRACTICES FOR GYNECOLOGICAL WELFARE AMONG INDIGENOUS IRULAR CLANS OF TAMIL NADU, INDIA

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Abstract

Ethnobotanical knowledge serves as a vital reservoir of culturally rooted health practices, especially among indigenous communities. This investigation explores the medicinal plant usage for gynecological disorders among the Irular tribal population of Anaikatty, Maruthamalai and Theethipalayam areas of Tamil Nadu. A total of 50 informants, primarily above the age of 50, were interviewed using semi-structured methods. The study recorded 31 medicinal plant species belonging to 24 families, predominantly sourced from forest ecosystems, indicating strong ecological dependence. The families Lamiaceae and Fabaceae were most frequently represented. Herbs were the dominant life form (15 species), and leaves were the most commonly used plant part. Decoction emerged as the principal preparation method. Quantitative ethnobotanical indices were calculated to assess the cultural importance of each plant. The informant consensus factor values ranged from 0.55 to 0.85, with *Achyranthes aspera* L. scoring the highest, indicating substantial agreement on its use for menstrual disorders. Relative frequency of citation values varied from 0.12 to 0.50, while use value ranged between 0.10 and 0.82. The findings reflect a well-preserved traditional pharmacopoeia, despite generational gaps in knowledge transmission. Rapid expansion of the economy, meanwhile, poses an urgent risk to traditional medicinal knowledge and medicinal plant species for numerous reasons. Therefore, it is essential to establish regulations and protocols to safeguard plant wealth and ancient traditions linked to them.

Keywords: Ethnobotany, Irular, Knowledge, Medicinal Plants, Quantitative Analysis

1. Introduction

Ethnobotany holds an infinite magnitude in safeguarding scientific research and cultures, as it draws a parallel paradigm with traditional knowledge systems and modern scientific routines, expediting the discovery of therapeutic compounds and pioneering treatments[1,2,3]. It portrays a fundamental responsibility in the recovery of biodiversity by authenticating the antiquated uses of plant species emphasizing their impact in local ecosystems[4,5,6,7]. Ethnobotanical explorations contribute to the indulgence of human-plant interactions, as it emboldens indigenous communities by acknowledging and substantiating their conventional wisdom and methods [8,9]. Tribal communities in India have a copious cultural heritage deeply interconnected with indigenous medicine. These communities have fostered excellent medicinal practices over generations, employing immediately available plants for alleviating various ailments[10,11].

The Irular, Paniyan, and Kurumba tribes are just a few of the prominent ethnic communities who have made Tamil Nadu as their home. Each of these groups have unique ancestral traditions and healthcare systems that are widely acknowledged for their capacity for healing a variety of illnesses [12]. The Irular tribal community of Tamil Nadu, known for their intricate perception of medicinal plant species and conventional healing practices, plays a crucial part in the region's ethnobotanical inheritance, contributing extensively to biodiversity conservation and posing valuable prospective for pharmaceutical progressions [13].

Gynecological syndromes comprehend a great extent of ailments affecting the female reproductive system, like menstrual disorders, polycystic ovarian syndrome (PCOS), and cervical cancer. These disorders are a chief public health conflict, contributing to obscure sickness and disadvantaged lifestyle, especially for females of all ages [14]. Irrespective of evolvement in the parental health care and cervical cancer deterrence, there is a severe disregard of Benign Gynecological Conditions (BGCs) that have pervasive consequences on overall physical and mental health [15]. In the current set-up, there is an exemplar shift of interest towards traditional medicine as there is a rising appeal in natural and holistic attitude to healthcare coupled with concerns regarding ramifications of modern pharmaceuticals. Therefore, the present investigation highlights the key medicinal plant species incorporated in Irular indigenous medicinal system for curing gynecological disorders.

2. Material and methods

2.1. Study area

Ethnobotanical findings for this research were methodically congregated from the tribal communities dwelling in three distinct localities within Coimbatore district, Tamil Nadu, India (Fig.1). Theethipalayam, situated at coordinates 10.9146° N latitude and 76.8844° E longitude, includes a scope of 1,339 hectares exemplified by a montage of dry deciduous and semi-evergreen woods. Maruthamalai Hills, located at 11.0333° N latitude and 76.8667° E longitude, ascend to an elevation of 4,406 feet Above Mean Sea Level (AMSL), signifying a prominent part of the Western Ghats with its notable dry deciduous forest cover. Anaikatty, situated at 11.1443° N latitude and 76.7569° E longitude, extend over a sector of 752.3 hectares and contrasts in elevation from 560 to 1,600 meters AMSL. These diverse environmental settings not only shelter rich biodiversity but also serve as receptacles of long-established ecological knowledge among the tribal inhabitants, providing instrumental cognizance for ethnobotanical investigations.

Fig. 1 Study area for data collection;
a. Maruthamalai hills; **b.** Anaikatty; **c.** Theethipalayam

2.2. Data collection

Partly structured interviews and group discussions were conducted to obtain data relevant to the present investigation from informants including senior tribal individuals and healthcare practitioners during the months of October and November, 2024 *via* recurrent visits (Fig. 2). A total of 50 individuals were approached for collection of primary data with the help of questionnaires and Participatory Rural Appraisal (PRA). Secondary data were collected from existing literatures. Plants were collected and photographed with the help of informants from these settlements. The vernacular names of the medicinally valuable species were confirmed and their method of utilization were catalogued with the help of experienced elders.

According to existing systems, the life forms of the documented plant species were separated [16]. The taxonomical description and scientific names of the recorded medicinal plant species were authenticated with the help of Flora of Madras Presidency [17].

Fig. 2 Interaction with tribals during data collection

2.3. Ethical issues

The motive of the research was delineated to the participants, and their prior informed authorization (oral) was obtained before participation. All participants voluntarily agreed to take part in the study and informed that they could withdraw from the interviews at any time.

2.4. Quantitative analysis

To evaluate the customary usage and magnitude of each therapeutic plant species within assorted disease classifications, three ethnobotanical indices were worked out; factor of informer consensus (F_{ic}), relative Frequency Of Citation (RFC) and Use Value (UV). The degree of consensus among the interviewees on the proper use of plants for particular illness classes was appraised using F_{ic} [18]. The frequency at which sources stated a specific species permitted RFC to calculate every single plant species' local prominence [19]. UV was applied to establish the relative worth of each species *via* taking into account the quantity and frequency of citations supplied by the informants [20].

3Results

3.1. Demographic scrutiny of the respondents

Throughout the course of investigation, interviews were carried out with 50 respondents (20 women and 30 men), about their apprehension on ethnomedicine. Informants over the age of fifty provided the majority of ethnobotanical data. Although most of the older participants were illiterate, age bias may have contributed an integral part in their better degree of medicinal knowledge. In contrast, the younger generation was found to be less motivated and novice regarding conventional healing practices, highlighting a challenge to the preservation of traditional wisdom.

3.2. Documented plant species and their associated data

A cumulative number of 31 curative plant varieties contained within 24 specific families were exercised for remedying gynecological illnesses among Irular tribal population, were documented in the current study. The entirety of the information on medicinal plants are depicted in Table 1, comprising their scientific and vernacular names, families, parts used, preparation methods, curative applications, F_{ic}, RFC and UV. Out of 31 plant species, 25 species were obtained from forested areas and 8 species were cultivated. Hence, this investigation underscores the fact that how Irulars rely on their natural habitat for ethnomedicine preparations.

The family Lamiaceae and Fabaceae accounted for the most used plant family with three species thereafter, the Acanthaceae, Amaranthaceae, and Euphorbiaceae families with about two species each (Fig. 3). Herbs, with 15 species, were the most common living form utilized to cure gynecological illnesses, followed by shrubs with 10 species and trees with 5 species (Fig. 4). The most commonly used plant part is leaf, represented by 9 species, which is subsequent to the use of entire plant with 8 species and root with 5 species (Fig. 5). Decoction was the mostly frequently implemented approach for medicine preparation (12 species). The other modes of formulations recurrently exercised are juice, powder (7 species each), and paste (5 species) (Fig. 6).

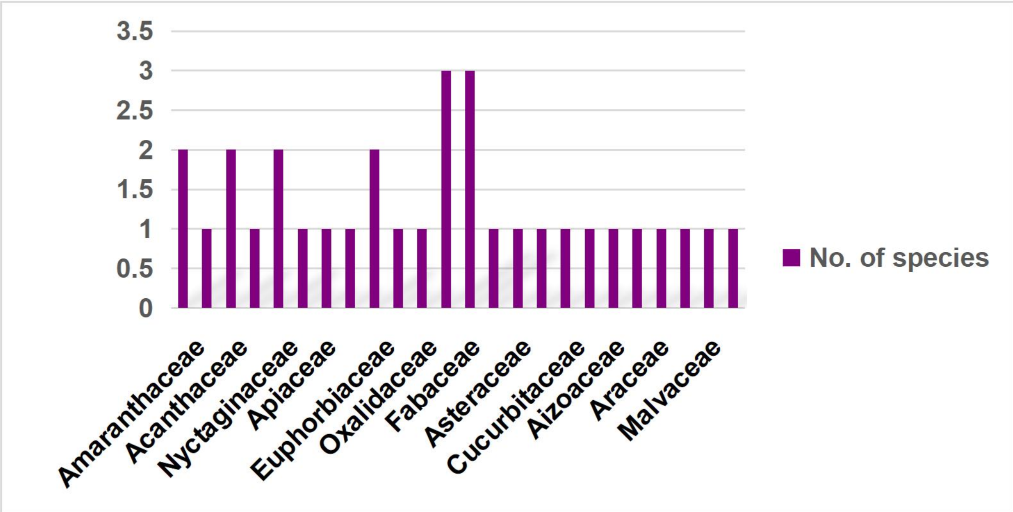

Fig. 3 Distribution of medicinal plant species by family

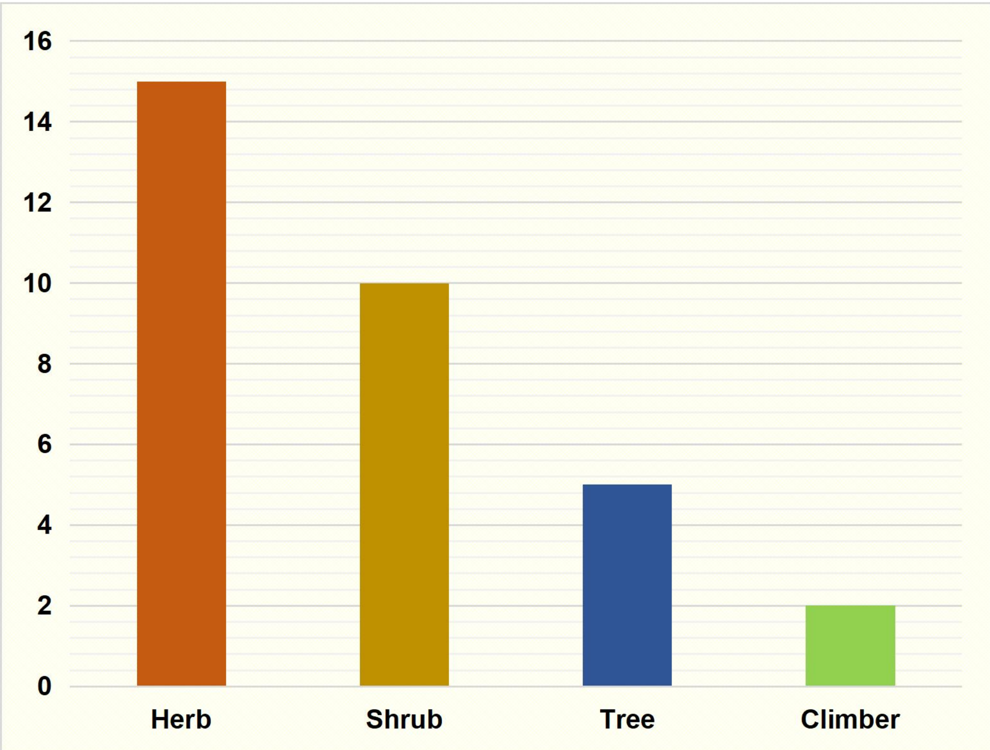

Fig. 4 Diversity of plant types in Irular ethnomedicine

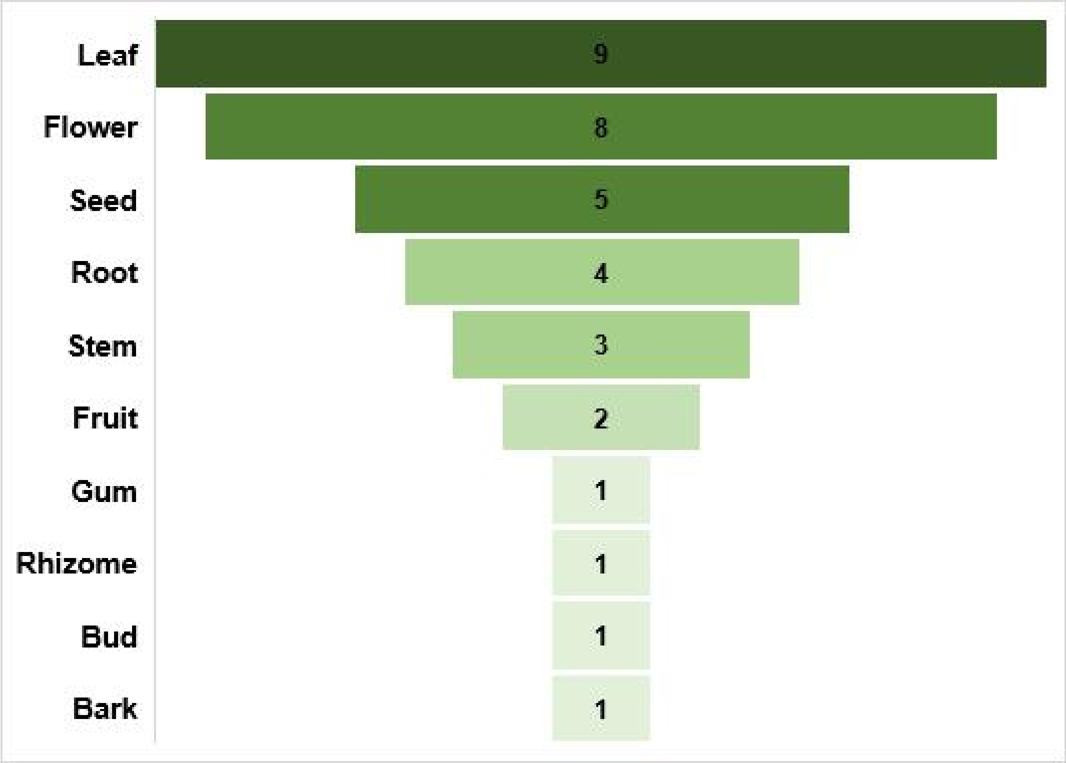

Fig. 5 Various plant parts used for preparation of medicine

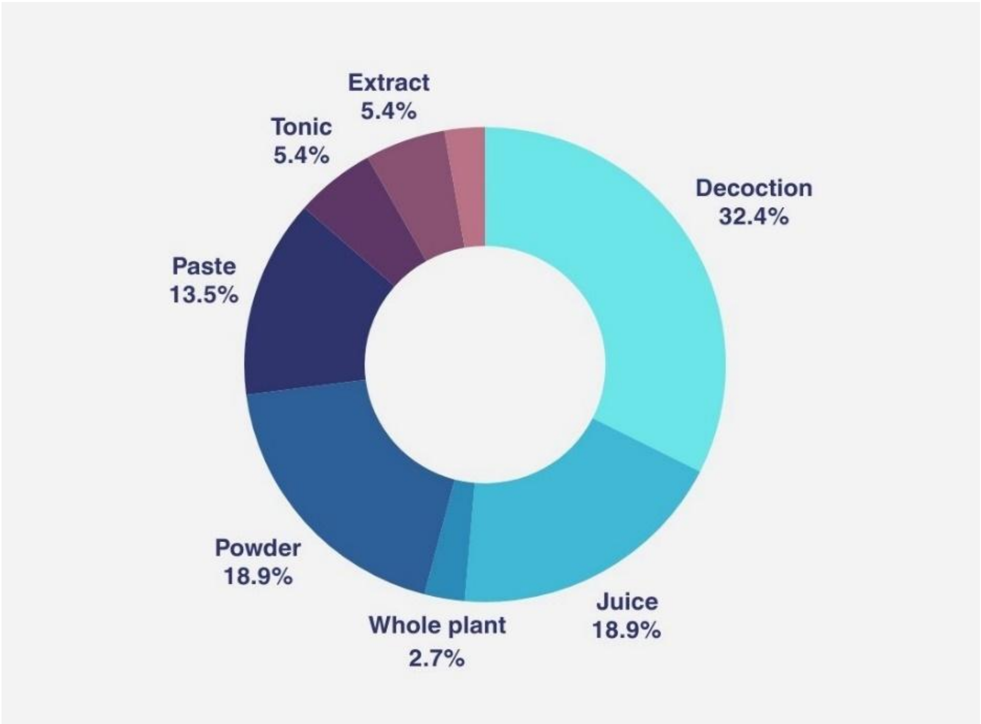

Fig. 6 Preparation methods of medicinal formulations by Irulars

Table 1 Medicinal plant species utilized by Irulars for the treatment of gynecological disorders

Scientific name	Verna-cular name	Family	Wild/ Culti-vated	Habit	Plant part used	Mode of pre Para-ion	Disease category	F_{ic}	R CF	U V
Amaranthus viridis L.	Mulai keerai	Amarantha-ceae	Wild	H	L, F	Juice	Menstrual disorders	0. 76	0. 34	0. 30
Achyranthes aspera L.	Naauruvi	Amarantha-ceae	Wild	H	WP	Juice	Menstrual disorders	0. 85	0. 45	0. 82
Andrographis paniculata (Burm. f.) Wall. ex Nees	Nilavembu	Acantha-ceae	Wild	H	WP	Deco-ction	Menstrual disorders, labor compliat-ions	0. 78	0. 48	0. 76
Aloe vera L.	Kaatralai	Liliaceae	Wild	H	R	Deco-ction	Labor complicatio ns	0. 65	0. 36	0. 40
Boerhavia diffusa L.	Punarvana	Nyctagina-ceae	Wild	H	Se	Deco-ction	Menstrual dis-orders	0. 82	0. 46	0. 79
Catharanthus r oseus (L.) G. Don	Nithyakalyani	Apocyna-ceae	Cultiv ated	H	Fr, Fl	Juice	Miscarriage	0. 70	0. 24	0. 18
Cuminum cyminum L.	Seeragam	Apiaceae	Cultiv ated	H	Fr	Juice	Labor complicat-ions	0. 81	0. 50	0. 80
Carica papaya L.	Papaya	Caricaceae	Cultiv ated	Sh	Fr	Juice	Menstrual disorders	0. 76	0. 30	0. 32
Euphorbia hirta L.	Amman pacharisi	Euphorbia-ceae	Wild	H	L	Fresh	Menstrual disorders	0. 77	0. 42	0. 74
Ficus carica L.	Athippazham	Moraceae	Wild	T	WP	Deco ction	Labor complicat-ions	0. 65	0. 38	0. 34
Oxalis corniculata L.	Puliyarai	Oxalidaceae	Wild	H	Se	Powd er	Miscarriage	0. 76	0. 20	0. 22
Ocimum tenuiflorum L.	Thulasi	Lamiaceae	Wild	H	WP	Powd er	Labor complicat-ions	0. 80	0. 45	0. 76
Ricinus communis L.	Amanakku	Euphorbia-ceae	Wild	Sh	L, Fl	Powd er, de cocti on	Menstrual disorders	0. 65	0. 14	0. 12
Mirabilis jalapa L.	Antimana-tharai	Nyctagina-ceae	Wild	H	L	Paste	Menstrual disorders	0. 70	0. 12	0. 10
Senna occidentalis (L.) Link	Thangarai	Fabaceae	Wild	Sh	WP	Juice, decoc tion	Menstrual disorders	0. 83	0. 49	0. 81
Leucas aspera (Willd.) Link	Thumbai	Lamiaceae	Wild	H	L	Paste	Menstrual disorders	0. 79	0. 43	0. 75
Phyllanthus emblica L.	Malanelli	Phyllanthac eae	Wild	T	St	Powd er, to nic	Vaginitis	0. 76	0. 26	0. 20
Sphagneticola trilobata (L.) Pruski	Mangal kodi Kari salai	Asteraceae	Wild	H	R	Deco ction	Labor complicatio ns	0. 82	0. 48	0. 79
Withania somn ifera (L.) Dunal	Manjalvettuva thalai	Solanaceae	Wild	Sh	R	Decoc tion, paste	Vaginitis	0. 55	0. 34	0. 24

Cucurbita pepo L.	Mangal pusan i	Cucurbita-ceae	Cultiv ated	Cr	L	Extra ct, pa ste	Vaginitis	0. 80	0. 47	0. 77
Curcuma longa L.	Mangal	Zingibera-ceae	Cultiv ated	H	WP	Juice	Urinary in continence	0. 78	0. 44	0. 75
Trianthema po rtulacastrum L.	Saranathi	Aizoaceae	Wild	H	R	Deco ction	Infertility	0. 68	0. 18	0. 22
Barleria casati ana Buscal. & Muschl.	Oothapo	Acantha-ceae	Wild	Sh	G	Tonic	Labor complicatio ns	0. 81	0. 50	0. 79
Phyla nodiflora (L.) Greene	Kodu thalai	Verbena-ceae	Wild	H	Rh	Powd er	Urinary in continence	0. 62	0. 32	0. 28
Acacia modesta Wall.	Thaerchavuk ku	Fabaceae	Wild	T	Fl	Powd er	Infertility	0. 68	0. 30	0. 26
Acorus calamus L.	Vasambu	Acoraceae	Wild	H	WP	Infusi on	Menstrual disorders	0. 76	0. 12	0. 14
Bauhinia variegata L.	Mandarai	Fabaceae	Wild	ST	B	Extra ct	Labor complica-tions	0. 68	0. 36	0. 30
Capsella bursa-pastoris (L.) Medik.	Varudanthi mooligai	Brassicacea e	Wild	H	L	Powd er	Menstrual disorders	0. 78	0. 42	0. 75
Grewia optiva J.R. Drumm. ex Burret	Biul	Malvaceae	Wild	T	R	Paste	Menstrual disorders	0. 77	0. 40	0. 74
*Mentha longifolia (*L.) L.	Puthina	Lamiaceae	Cultiv ated	H	L, Fl	Juice	Menstrual disorders	0. 83	0. 49	0. 81
Tinospora sinensis (Lour.) Merr.	Amudam	Menisperm aceae	Wild	Cl	WP	Juice	Menstrual disorders	0. 80	0. 46	0. 78

3.3. Quantitative analysis

To calculate F_{ic} values, the gynecological diseases noted down in the existing study were classified into six categories: menstrual disorders, labor complications, vaginitis, infertility, miscarriage, and urinary incontinence (Fig. 7). F_{ic} values fluctuated from 0.55 to 0.85. The peak F_{ic} value of 0.85 was perceived for *Achyranthes aspera* L., representing its sound accord among informers for its application in curing menstrual disorders. Contrarywise, *Withania somnifera* (L.) Dunal displayed the lowest F_{ic} value of 0.55, proposing lower consensus for its utilization in treatment for vaginitis. RCF values in these findings vary between 0.12 to 0.50. *Cuminum cyminum* L. and *Barleria casatiana* Buscal. & Muschal. have the maximum RCF values of 0.50 specifying that half of the informants quoted these plants for improving labor difficulties. Nevertheless, *Acorus calamus* L. had one of the lowest RCF values (0.12) implying it was less frequently mentioned by the informants. UV values in this examination ranged from 0.10 to 0.82. The peak UV was detected for *A. aspera* (0.82). In contrast, the lowest UV observed was for *Mirabilis jalapa* L. (0.10), alluding it as a less commonly used plant species. On the whole, the high Fic, RCF, and UV values specify that certain plants are greatly appreciated and extensively acclaimed for their medicinal properties, exposing a rich habitual understanding that is critical for the social health traditions of the Irular community.

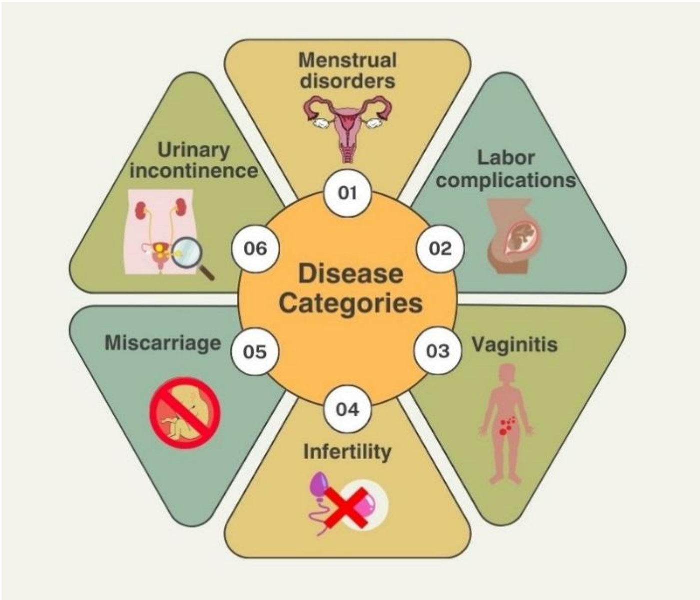

Fig. 7 Categories of gynecological disorders treated by Irulars

4. Discussion

With the goal to preserve indigenous knowledge, discover rich plant-based resources for food, medicine and cultural activities, and advance scientific understanding for sustained human well-being, ethnobotanical expeditions are indispensable[21,22]. Ethnobotany represents a dynamic scientific discipline that connects indigenous ecological know-how with methodical explorations thereby expediating evidence-based justification of traditional practices and their amalgamation into pharmacology, nutrition, and ecosystem management[23]. The systematic documentation of ethnobotanical knowledge strengthens biodiversity safeguarding, apprises sustainable resource consumption, and postulates a robust framework for bioprospecting and the discovery of novel bioactive compounds [21,22].

An individual's age has implications on the dissemination and perpetuation of traditional knowledge given that the older members of the community are inclined to have richer ethnobotanical knowledge that has been acquired over time[24]. Therefore, preserving and transmitting ancient customs to younger members of community necessitates acknowledging the wisdom that older generations acquire [25]. Similar patterns declared among the native inhabitants of Wolaita and Gondar (Ethiopia), and the Naama of Algeria further support the observation that older people endure significantly more ethnobotanical knowledge [26,27,28]. This finding also appears consistent with the findings among the Irular community. Around locations where access to standard medical care may be restricted, such as women's reproductive health, ethnobotanical knowledge provides crucial insights into plant-based treatments. Such knowledge systems symbolize generations of empirical inspections and cultural transmissions, replicating how communities acclimate local floristic reserves to tackle reproductive health challenges [23]. A number of investigations has been carried out globally to gauge the knowledge of medicinal plants that tribal groups possess in the treatment of gynecological disorders. These studies highlight not only the diversity of species employes but also the cultural specificity of plant selection, preparation, and administration, underscoring the role of ethnobotany in preserving reproductive health traditions across distinct ecological and social contexts [29,30,31].

Within ethnobotanical enquiries, Lamiaceae and Fabaceae are two angiosperm families that are viewed as cornerstones, owing to their extreme species diversity, phytochemical abundance, and broad spectrum of traditional usages spanning medicine, nutrition, and cultural practices [32,33,24,25]. The consistent mention of Lamiaceae and Fabaceae species in the traditional practices of the Maroon and Malayali tribes and ethnic groups of Ethiopia reinforces the fact that the prominence of these families in disease treatment is likely linked to their aromatic properties [32,33,24,25]. Herbs have been used as a medicine since ancient times across all cultures as they are abundant in the surroundings of tribal settlements [34]. The results reported for the Irular community in the present study were confirmed by investigations among indigenous groups of Mizoram, Cooch Behar (West Bengal), and Himachal Pradesh, which likewise found herbs to be the predominant growth type [35,36,37]. Since leaves are readily accessible, comprises of greater bioactive entities and sustainable when compared to other plant portions, they are often used in the preparation of medicine by the tribes and local healers [38,24,25].

Decoction is utilized extensively in medical traditions, as reflected by the fact that it was the most popular form of therapeutic preparation in this investigation [39]. As it can efficiently extract hydrophilic bioactive components, particularly from tough plant parts like roots, bark, and stems, decoction is often preferred [40]. Numerous ethnobotanical investigations have revealed similar results, with decoction continuing to be the most popular preparation technique because of its ease of use, effectiveness, and cultural acceptance amongst rural and indigenous groups [41,42].

A strong and culturally embedded knowledge system regarding the use of medicinal plants for gynecological ailments among the Irular community is indicated by the high F_{ic}, RFC, and UV observed in this study. The F_{ic} value of 0.85 for *Achyranthes aspera* L. in handling menstrual disorders reflects a high degree of agreement among informants, underscoring its perceived ethnomedicinal role. These results coincide with prior studies among tribal populations along the Pakistan-Afghan border, which found equivalent F_{ic} values (0.95 for menstrual problems, 0.94 for sexual and urinary issues) [43]. This points to a strong cultural consensus concerning the use of natural therapies to manage women's health. Conversely, the high UV for *Moringa oleifera* Lam. (2.588) reported by Vedarayanam Taluk residents for breastfeeding and reproductive problems reinforces the notion that versatile species with an assortment of therapeutic uses regularly control regional medical practices [30]. Parallel trends may also be seen in China, as *Scutellaria baicalensis* Georgi, received the highest UV (0.91), implying widespread usage of the species [44]. *A. aspera* also had the highest UV (0.82) in this investigation, verifying its crucial role in the local ethnopharmacopoeia. The particular usage of *Achyranthes aspera* by Irulars has been confirmed by previous accounts that it is used to treat menstruation and gynecological disorders [45,46]. These tendencies are further supported by RFC values, which show the key role of certain species in maternal health traditions. For example, *Cuminum cyminum* L. and *Barleria casatiana* Buscal. & Muschl. were commonly indicated for labor problems (RFC=0.50). Similar plant prominence has been documented in other regions, where *Withania somnifera* (L.) Dunal and *Foeniculum vulgare* Mill. were among the top species cited for gynecological and urinary disorders [43]. Ultimately, the study's robust quantitative indicators align with ethnobotanical trends recognized across geographically and culturally diverse societies.

5. Conclusion

The Irular community in Anaikatty, Maruthamalai Hills, and Theethipalayam, Tamil Nadu, employs 31 medicinal plant species to treat gynecological conditions; the most often used components and preparation techniques are leaves and decoctions. Quantitative indicators like UV (up to 0.82), RCF (up to 0.50), and Fic (up to 0.85) demonstrate the widespread agreement and dependence on certain species of medicinal plants. These results highlight the importance of conserving traditional knowledge in the face of diminishing intergenerational transmission and reflect the community's rich ethnobotanical heritage.

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Statements and declarations

Funding:

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Conflict of interest:

The authors have no conflicts of interest to declare.

Ethics approval:

The ethnobotanical field study was conducted in strict adherence to ethical standards with prior informed consent obtained from tribal elders and the local community before initiating the survey.

Consent to participate:

Not applicable

Consent for publication:

The authors have accepted responsibility for the entire content of this submitted manuscript and approved submission.

Availability of data and material:

Not applicable

Code availability:

Not applicable

Authors' contributions:

Conceptualization: TK, AP, MJ; Data curation: LS, AP, TK; Formal analysis: LS, AP; Funding acquisition: LS; Investigation: LS; Methodology: AP, TK; Project administration: TK, AP; Resources: LS; Software: AP; Supervision: TK, AP; Validation: TK, AP; Visualization: AP; Writing-original draft: AP; Writing-review and editing: AP, MJ, TK

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RESEARCH ARTICLE

EDIBLE FLOWERS OF KERALA AS FUNCTIONAL FOODS: NUTRITIONAL AND THERAPEUTIC PERSPECTIVES: A REVIEW

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Abstract

Edible flowers are an under-utilised reservoir of nutrients and bioactive phytochemicals that link culinary traditions to ethnomedicine. Edible flowers in Kerala represent a culturally embedded, nutritionally promising group of functional food ingredients. Integrating traditional knowledge with modern phytopharmacology can accelerate their transition from household recipes to evidence-based nutritional inventions and functional food products. This review synthesises nutritional, phytochemical, and pharmacological evidence for commonly consumed flowers in the region and frames them as functional food ingredients that confer health benefits beyond basic nutrition. This can be achieved by summarising the proximate composition, key micronutrients and documented bioactivities of selected edible flowers of Kerala. The review also evaluates value-added food preparational practices in Kerala and their nutraceutical benefits, as well as the importance of integrating ethnobotanical heritage with contemporary scientific inquiry to fully unlock the health-promoting potential of Kerala's floral diversity.

Keywords: Traditional cuisine, Bioactive compounds, Nutritional profile, Phytochemicals, Flora of Kerala, Therapeutic properties.

Introduction

Kerala's rich plant biodiversity and culinary traditions make floral ingredients a familiar element of local diets, from 'Vazhapoo' (Banana blossom) 'thoran' (a type of fry) to Moringa flower stir-fries. Flowers are not mere garnishes; many are nutrient-dense and contain concentrated phytochemicals, such as polyphenols, flavonoids, anthocyanins, and alkaloids, associated with antioxidant, anti-inflammatory, and other health-promoting benefits, which qualify them as functional foods under modern nutraceutical discourse [1,2]. *Moringa oleifera, Sebania grandiflora, Clitoria ternatea, Nelumbo nucifera, Musa paradisiaca, Hibiscus spp*, etc, are the most commonly used edible flowers of Kerala. For instance, the blossom of *M. oleifera* is widely recognised not only for its culinary versatility but also for traditional medicinal applications, and recent reviews noted its antioxidant, anti-inflammatory, hepatoprotective, and lipid-modulating potential [3].

Another widely used floral vegetable in Kerala is *Musa spp*. Mature banana flowers can be eaten as curry and stir-fry. It is recognised for being rich in fibres, minerals, proteins, and antioxidants [4]. Similarly, flowers of *Hibiscus spp.* are widely used in Kerala cuisine in the form of tea and chutneys. Nutritionally, *Hibiscus spp.* is rich in proteins, fibre, carbohydrate, β-carotene, and vitamin C [5]. Overall, edible flowers are far from being occasional delicacies; they constitute a culturally embedded, nutritionally promising group of functional-food ingredients. Their frequent use in daily cuisine aligns with traditional dietary practices. Emerging biochemical and pharmacological evidence underlines their potential role in nutraceutical diets, micronutrient supplementation and prevention of diseases to an extent. By systematically compiling the nutritional and pharmacological data, this review aims to underscore the value of common edible flowers used in Kerala as functional foods by advocating their scientific validation and promoting their integration into sustainable and culturally relevant food systems.

Materials and Methods

The present study reviews the literature available from the past ten years. A systematic review was carried out in public databases like Science Direct (www.Sciencedirect.com), Research Gate (www.Researchgate.com), and Springer (www.Springer.com).

Review of literature

1 Nutritional composition and proximate analysis

Fresh flowers typically consist of water, approximately 70-90% of their fresh weight and flowers like banana blossom, pumpkin flowers, and Sesbania flowers have high moisture, contributing to their soft texture and suitability in curries and fritters [6]. When dried or processed, edible flowers often supply an appreciable amount of dietary fibre, proteins, carbohydrates, and minerals, making them comparable to conventional vegetables rich in micronutrients. Protein content varies from 1-6% and edible flowers are generally low-fat foods (0.3-1.5%). Carbohydrates vary from 5-18% range depending on the species. [7]. For instance, in a proximate composition study of several underutilised edible floral species, Kerala's most commonly used *Musa paradisiaca* blossoms reported substantial fibre and carbohydrate content, along with notable protein and ash (mineral) content [8]. The edible parts, especially the floral parts of *Moringa oleifera,* were found to be rich in carbohydrates, glycosylated flavonoids, and especially α-tocopherol (a form of vitamin E) at appreciable levels of approximately 18mg/100g dry weight, highlighting their potential as nutrient-rich food items [9]. However, the proximate micronutrient profiles vary strongly with species, cultivar, and environmental conditions. This variability, combined with a low number of systematic differences across many edible flower species, highlights that standardised nutrient databases for edible flowers remain limited.

2 Phytochemical and pharmacological properties of some commonly used edible flowers

Edible flowers have long been a part of traditional food and medicinal heritage, valued not only for their sensory attributes but also for their rich phytochemical composition and diverse pharmacological activities. A global review of edible flowers identified that many species are rich in both primary and secondary metabolites, many of which are responsible for their colour, aroma, flavour, and medicinal values, such as phenolic acids, saponins, flavonoids, carotenoids, tocols, anthocyanins, essential oils, and other bioactive compounds. Such compounds confer antioxidant, anti-inflammatory, and other major bioactive effects; these bioactive compounds contribute significantly to the health-promoting potential of edible flowers, positioning them as promising candidates for functional foods and natural therapeutics [10].

Clitoria ternatea, also known as butterfly pea, is a widely used edible flower in Kerala, and in recent research, its flowers have shown high levels of anthocyanins, flavonoids, and other polyphenols. *In vitro* assays demonstrated significant antioxidant activity and protection against oxidative stress [11]. Similarly, studies on *Musa sapientum* (Banana blossom) reported that different floral parts like bract, floret, and young blossom contain phenolics, flavonoids, tannins, saponins, alkaloids and anthocyanins. Moreover, the banana-blossom extract manifested high total phenolic content (168.88 mg GAE/g) in the ethanolic extract of its floret and also demonstrated lipid peroxidation inhibition *in vitro*, suggesting its powerful antioxidant potential [12]. In a recent study on the ethanolic extracts of *Moringa oleifera* flowers inhibited lipid peroxidation, suppressed inflammatory NO production, and demonstrated enzyme inhibitory effects [13]. Several studies have reported that petals of *Hibiscus spp* are a rich source of polyphenols and anthocyanins, and exhibited significant radical scavenging effects [14]. Extracts of *Nelumbo nucifera*, commonly known as Lotus, demonstrated significant antioxidant and anti-inflammatory effects *in vitro* [15].

3 Culinary forms of Kerala and functional delivery

Kerala's cuisine already contains multiple routine routes for delivering edible flower nutrients in the form of 'thoran', coconut-based stir-fry, curries, deep fry/fritters, and floral infusions/tea and across the regions, edible flowers are incorporated into daily meals, festival dishes, functional beverages, and traditional-medicine-based cuisines. In Kerala, Banana blossom is typically prepared as 'thoran', which integrates the flower with oil and coconut lipids, improving the absorption of lipophilic micronutrients such as provitamin A carotenoids [16]. *Sesbania grandiflora* or Agathi flowers, which are rich in minerals and polyphenols, are also prepared and served as 'thoran' [17]. Moringa flowers are usually served as stir-fries, and also added to 'sambar' (a special mixed vegetable curry), and light curries, which are traditional Kerala recipes that emphasise short cooking to maintain texture and floral aroma. This mild cooking method helps to release bioactive compounds [18]. *Clitoria ternatea,* or butterfly pea petals, are most often used as tea or infusions and are also employed for visually striking rice dishes in Kerala. Pumpkin blossoms are rich in antioxidants and have established pharmacological significance, and other cucurbit flowers are a common part of Kerala's traditional cuisine. Usually served as slow-cooked stir-fries, and hence preserving nutrients and carotenoids [19].

Conclusion

Edible flowers represent a vibrant yet underexplored component of Kerala's traditional food system, contributing not only colour, aroma, and culinary diversity but also significant functional and therapeutic value. Their pharmacological benefits include antioxidant, anti-inflammatory, cardioprotective, antidiabetic, neuroprotective, and digestive benefits, reiterating the relevance of these traditional foods in addressing modern dietary and health challenges. Culinary practices in Kerala, such as 'thoran', curries, fritters, teas, and fermented preparations, not only enhance palatability but also influence the bioavailability of these key phytoconstituents. However, scientific evidence on optimal processing to preserve nutritional integrity remains limited, highlighting the need for systematic studies on preparation and phytochemical interactions. Furthermore, many edible flowers used in household or indigenous cuisines remain poorly documented despite their cultural permanence. Overall, documented edible flowers in Kerala represent a promising reservoir of culturally rooted functional foods with potential nutraceutical applications. Integrating these flowers into the contemporary diet can make a meaningful contribution to promoting nutritional security, enhancing wellness, and preserving Kerala's unique heritage. In addition, expanding research on underutilised floral species could therefore reveal novel bioactive compounds with therapeutic promise. Strengthening community-based documentation and ethnobotanical surveys can safeguard traditional knowledge for future generations.

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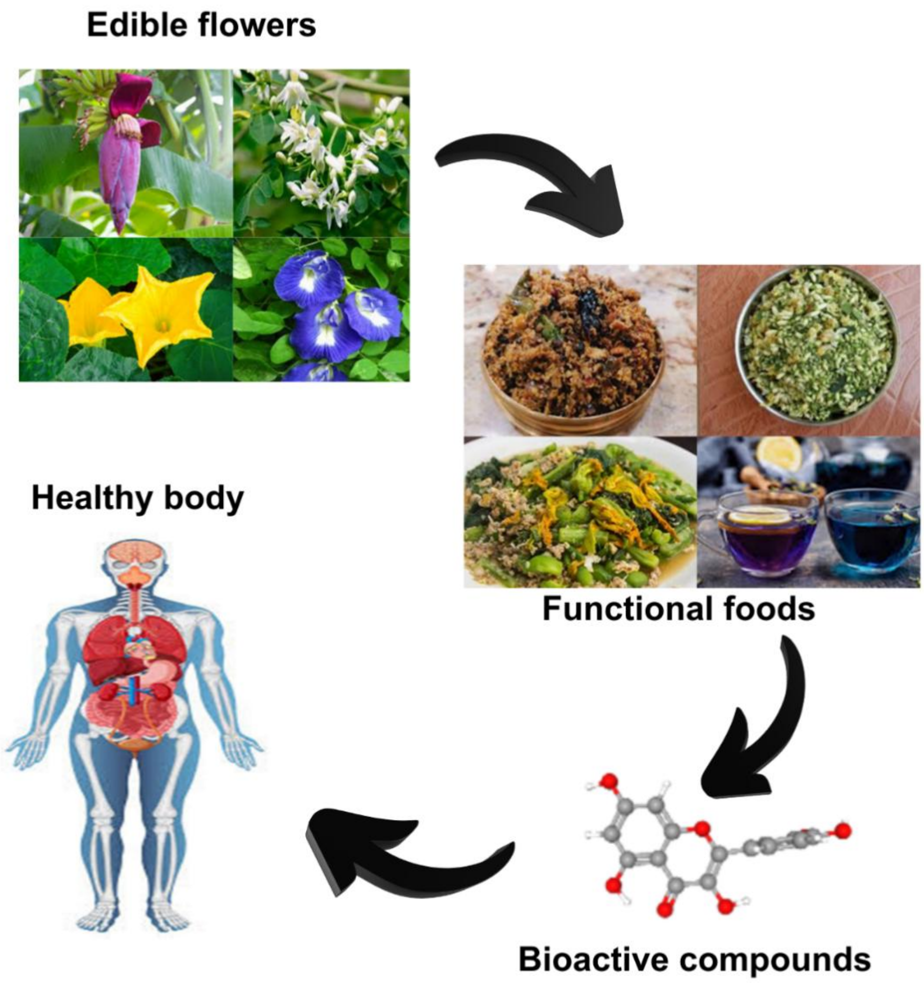

Figure 1: Conceptual illustration of edible flowers as functional foods

Table 1. Important edible flowers of Kerala used as functional foods

Sl.No	Scientific Name	Common name	Family	Culinary Use	Pharmacological Significance
	Moringa oleifera	Drumstick flower	Moringaceae	Stir-fries, curries, fritters	Nutrient-dense, antioxidant, anti-inflammatory, hepatoprotective, lipid-modulating
	Sesbania grandiflora	Hummingbird tree flower	Fabaceae	Stir-fries, curries, lentil mixes	Rich in vitamins and antioxidants.
	Clitoria ternatea	Butterfly pea	Fabaceae	Herbal tea/infusion, blue rice, salads	Anthocyanin-rich, antioxidant, neuroprotective
	Musa paradisiaca	Banana blossom	Musaceae	Stir-fries, cutlet,fritters	Antioxidant
	Hibiscus rosa-sinensis	Hibiscus	Malvaceae	Tea, chutney, salads	Antioxidant, cardioprotective, anti-inflammatory
	Cucurbita maxima	Pumpkin flower	Cucurbitaceae	Fried-fritters, stir-fries	Rich in carotenoids, Osteoprotective
	Legenaria siceraria	Bottle guard flower	Cucurbitaceae	Curries, stir-fries	Digestive health, detoxifying [20]
	Rosa spp.	Rose	Rosaceae	Jam, Squash	Antioxidant, anti-inflammatory [21]
	Carica papaya	Papaya flowers	Caricaceae	Stir-fries	Antihelminthic, digestive aid [22]
	Amaranthus spp.	Amaranth flower	Amaranthaceae	Curries, stir-fries	Antioxidant [23]

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RESEARCH ARTICLE

AN ANALYTICAL STUDY ON STOCK PRICE BEHAVIOUR USING TECHNICAL ANALYSIS: EVIDENCE FROM SELECTED SECTORS IN INDIA (2023–2025)

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Abstract

This research paper investigates the behavior of stock prices across three major sectors of the Indian economy pharmaceuticals, oil and energy, and banking using the tools of technical analysis. With the rise of algorithmic trading, the integration of predictive analytics and behavioral finance has transformed how investors assess risk and opportunity. The study employs simulated monthly data from 2023 to 2025 for selected companies, including Dr. Reddy's Laboratories, Sun Pharma, ONGC, Indian Oil Corporation, HDFC Bank, and ICICI Bank. Technical indicators such as Simple Moving Average (SMA), Beta, and Money Flow Index (MFI) are applied to identify market trends, volatility, and liquidity patterns. The findings reveal that pharmaceutical stocks demonstrate stable upward trends with lower volatility, oil stocks reflect sensitivity to global commodity prices, and banking stocks show cyclical movements influenced by policy rates and inflationary trends. This analysis underscores the significance of technical indicators as strategic tools for short-term trading and risk-adjusted investment decisions. It contributes to the growing literature on technical analysis in emerging markets, demonstrating how sectoral interdependencies can guide investor sentiment and capital allocation.

Keywords

Technical Analysis, Stock Market, NSE, Volatility, Moving Average, Money Flow Index, Beta Analysis.

1. Introduction

The stock market serves as a vital component of the global financial ecosystem, facilitating capital formation and liquidity. In India, the capital market has undergone significant transformation since liberalization in the early 1990s, driven by reforms, digital infrastructure, and increased investor participation. The Bombay Stock Exchange (BSE) and the National Stock Exchange (NSE) have emerged as key institutions fostering transparency and efficiency in securities trading. The volatility in the market, however, remains a defining feature, influenced by both macroeconomic factors and behavioral trends. Technical analysis has therefore gained prominence as a method of evaluating securities based on statistical trends derived from trading activity such as price movements and volume. Unlike fundamental analysis, which focuses on intrinsic value, technical analysis interprets market psychology through graphical patterns and quantitative indicators. This study aims to apply these techniques to selected industries pharmaceuticals, oil and energy, and banking to identify price behavior, market trends, and potential buy/sell signals in the context of the Indian stock market between 2023 and 2025.

2. Statement of the Problem

Stock market behavior in emerging economies like India is influenced by a combination of domestic policy decisions, global economic fluctuations, and investor sentiment. Predicting short-term price movements is complex due to dynamic market conditions, geopolitical factors, and liquidity constraints. The growing participation of retail investors post-pandemic has further amplified market volatility. Investors often rely on market trends rather than fundamental metrics, leading to irrational exuberance or pessimism. This study seeks to address this gap by using technical analysis to examine sectoral behavior and to identify consistent patterns that can help investors make data-driven decisions in the volatile environment of 2023–2025.

3. Objectives of the Study

- To evaluate stock price behavior across the pharmaceutical, oil, and banking sectors using technical analysis.
- To compute and interpret key indicators such as Simple Moving Average (SMA), Beta, and Money Flow Index (MFI).
- To examine the degree of volatility and identify buy/sell signals in selected companies.
- To provide actionable insights for portfolio diversification and investment timing in emerging markets.

4. Review of Literature

Technical analysis has long been recognized as a vital approach for forecasting market trends. Bernstein (1975) argued that psychological factors and collective investor behavior account for a significant portion of short-term price fluctuations. Fama's (1965) Efficient Market Hypothesis posits that stock prices incorporate all available information, implying that consistent outperformance is unlikely. However, later research in emerging markets contests this, revealing inefficiencies that allow technical strategies to yield abnormal returns. Balasubramaniam (1994) found that Indian stock returns do not follow a random walk, suggesting predictable market tendencies. Gupta (2022) demonstrated that indicators like SMA and MFI could successfully forecast trend reversals in high-volatility environments. In the international context, Chan and Chen (1991) studied the impact of firm structure on stock responses to economic news, concluding that small-cap firms show heightened sensitivity to market shocks. Collectively, these studies affirm the value of technical analysis as a decision-making framework, particularly in emerging and transitional economies.

5. Research Methodology

This research adopts a quantitative analytical framework using simulated monthly closing prices for six companies representing three sectors of the Indian economy: pharmaceuticals (Dr. Reddy's Laboratories, Sun Pharma), oil and energy (ONGC, Indian Oil Corporation), and banking (HDFC Bank, ICICI Bank). The data span from January 2023 to December 2025. The primary analytical tools applied include Simple Moving Average (SMA), which helps identify trend reversals; Beta, which measures systematic risk relative to the market; and Money Flow Index (MFI), an indicator of liquidity based on price and volume data. The analysis employs descriptive statistics, trend visualization, and interpretation of volatility patterns to deduce sectoral performance. The simulated data emulate realistic NSE price trends using probabilistic modeling to reflect post-pandemic economic recovery and sector-specific fluctuations. The results are presented through tables and charts for interpretive clarity.

Table 1: Selected Sectors and Companies

Sector	Companies
Pharmaceuticals	Dr. Reddy's Laboratories, Sun Pharma
Oil & Energy	ONGC, Indian Oil Corporation
Banking	HDFC Bank, ICICI Bank

6. Data Analysis and Interpretation

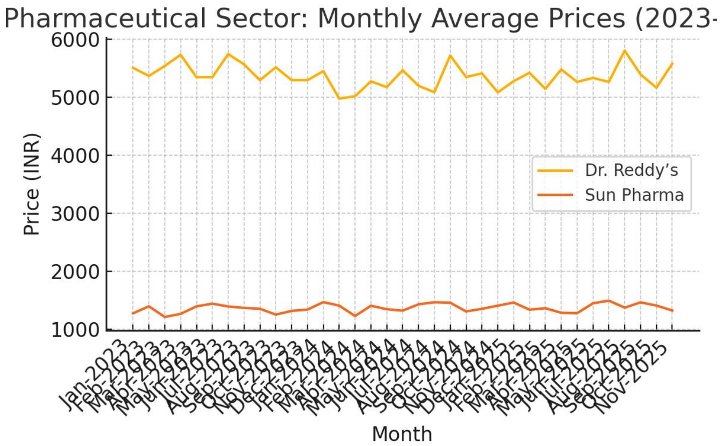

Figure 1: The pharmaceutical sector shows a stable growth pattern. Dr. Reddy's demonstrates consistent upward movement, indicating investor confidence in healthcare stocks post-COVID-19. Sun Pharma exhibits moderate volatility due to regulatory and global pricing pressures but remains on an upward trajectory.

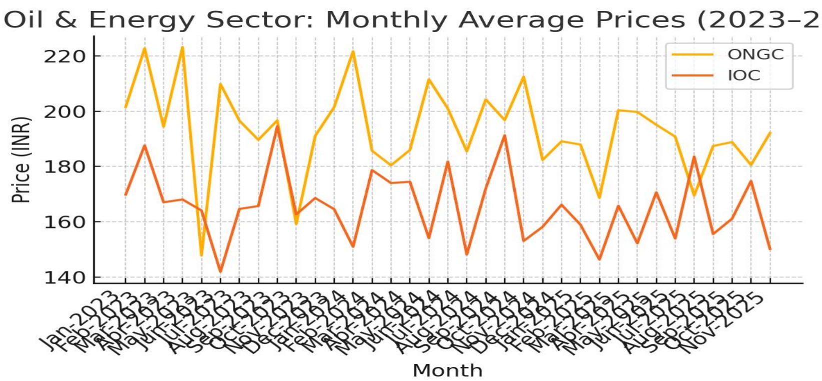

Figure 2: Oil and energy stocks such as ONGC and IOC reveal moderate fluctuations corresponding to global oil price changes. The trend lines indicate recovery phases aligned with energy demand post-pandemic, while seasonal dips correspond to crude supply corrections.

7. Findings and Suggestions

The study finds that:

- Pharmaceutical stocks are defensive assets offering stable returns and lower beta values (<1), implying lesser market sensitivity.
- Oil stocks provide moderate returns but remain vulnerable to international crude price volatility.
  • Banking stocks display cyclicality in response to monetary policy changes, interest rate adjustments, and credit growth.
- Simple Moving Average and Money Flow Index indicators proved effective for identifying short-term buy and sell signals.
- Investors are advised to diversify portfolios across defensive and cyclical sectors to minimize unsystematic risk and capitalize on sector rotation.
- Regulatory reforms and digital trading platforms have enhanced market transparency, further validating technical strategies for data-driven investing.

8. Conclusion

This study concludes that technical analysis remains an indispensable tool for understanding stock price behavior in emerging markets like India. The pharmaceutical sector emerged as a stable performer, while oil and banking sectors exhibited cyclical and externally driven volatility. Indicators such as SMA and MFI help investors interpret market psychology and improve decision timing. The findings underscore that technical indicators, when combined with macroeconomic awareness, can substantially enhance investment strategies. Future research may expand to include machine learning-based predictive modeling and a comparative study of global emerging markets to validate cross-market consistency.

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RESEARCH ARTICLE

HUMAN-WILDLIFE CONFLICT IN A CHANGING WORLD: PRECEDENTS, DRIVERS, AND TACTICS FOR SUSTAINABLE COEXISTENCE

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Abstract

Human-wildlife conflict (HWC) has appeared as one of the most persistent maintenance challenges worldwide, driven by quick habitat fragmentation, agricultural growth, and growing overlap between human settlements and wildlife ranges. This review combines key ecological and anthropogenic drivers motivating HWCs, concentrating on how land-use change, resource competition, and behavioural adaptation in wildlife deepen contacts with humans. Global patterns divulge region-specific disputes such as, elephant crop-raiding in Asia, carnivore-livestock predation in Africa, and primate invasions in urbanizing landscapes, stressing the socio-ecological dimensions of HWC. The ecological consequences spread beyond direct human and wildlife losses; they disturb trophic interactions, alter species dispersal, and endanger long-term ecosystem stability. Mitigation processes have grown from traditional deterrent-based approaches to more scientific, landscape-oriented strategies. Modern interventions include geofencing, early-warning systems, habitat restoration, and scientifically designed barriers, while traditional knowledge systems continue to provide context-specific solutions. Community-based preservation models and wildlife corridors have proven effective in reducing spatial clash by ensuring safe animal movement and improving human tolerance through inclusive decision-making. By integrating ecological understanding, local community participation, and adaptive management, this review emphasizes the need for holistic conflict mitigation.

Keywords: Anthropogenic Activities, Biodiversity, Crop Loss, Degradation, Habitat Fragmentation.

1. Introduction

Human-wildlife conflict (HWC) is scientifically defined as the negative interactions between human populations and wild animal species, leading to adverse consequences for social, cultural, or economic wellbeing, while simultaneously impacting wildlife populations and their habitats [1,2,3]. Such disputes emerge when humans and wildlife compete for limited and overlapping resources such as space, food, and water, especially in landscapes where natural areas are degraded due to agricultural expansion, industrial activity, urbanization, and infrastructural development [2,4]. Direct manifestations of HWC include crop raiding by herbivores, livestock predation by carnivores, damage to property and infrastructure, and, in severe instances, injury or loss of human life [3,5,6]. From the wildlife perspective, conflict situations often lead to vengeful killings, population decline, habitat disintegration, altered movement patterns, and disruption of natural behavior and genetic exchange [7,8]. Beyond immediate ecological impacts, HWC also erodes social tolerance toward wildlife, disproportionately affects rural and forest-dependent communities, exacerbates poverty, and threatens regional protection goals [5,9,10]. Thus, HWC represents not merely an ecological challenge, but a complex socio-ecological issue that demands integrated mitigation approaches involving ecological science, land-use planning, community participation, and supportive policy frameworks.

The frequency and severity of HWC are rapidly increasing worldwide, driven by expanding human populations (**Fig. 1**) [11,12]. As natural resources decline and anthropogenic pressures intensify, humans and wildlife are brought into closer and more frequent contact [13,14]. Climate change further alters territorial suitability and species movement patterns, creating new pressure points for confrontations [1,6,8]. In several regions, conservation efforts have also contributed to the recovery of certain wildlife populations, inadvertently increasing the likelihood of encounters in shared landscapes. Globally, HWC has emerged as a major barrier to biodiversity conservation and sustainable development, particularly in rural regions of Africa and Asia where high biodiversity intersects with dense agro-forestry-dependent human populations [15,16,17]. In these areas, the economic, nutritional, and emotional costs of conflict are profound, affecting food security, livelihoods, and human safety. Retaliatory responses often drive declines in threatened species, compound environmental degradation, and hinder long-term safeguarding outcomes [17].

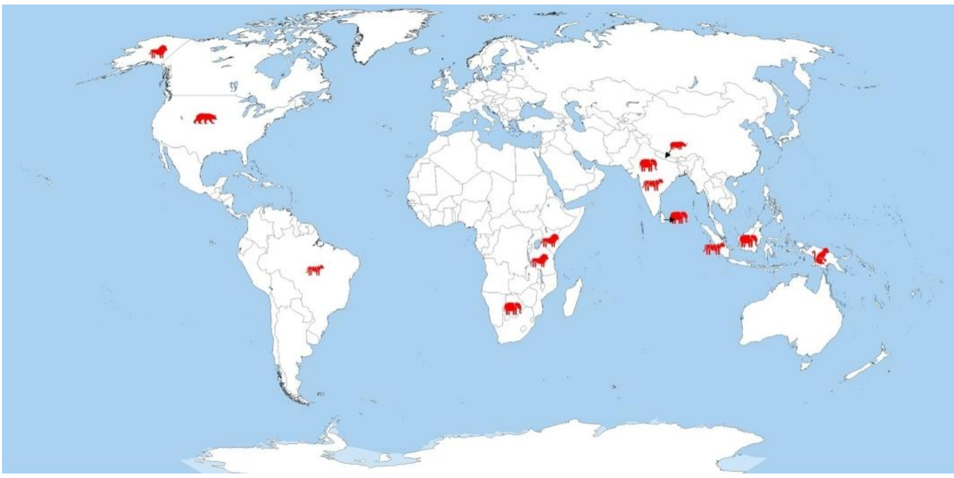

Fig. 1 Map depicting major HWC zones worldwide, highlighting species-specific conflict areas

In this context, the significance of mitigating HWC cannot be overstated. Contemporary conservation frameworks, including the Convention on Biological Diversity and the Sustainable Development Goals, prioritize coexistence-based approaches that balance ecological integrity with human wellbeing. Effective mitigation requires integrated, context-specific strategies such as landscape-level planning, early-warning systems, improved compensation mechanisms, and community-led rapid response teams. Strengthening local participation, promoting livelihood diversification, and implementing evidence-based policy frameworks are essential for fostering coexistence and enhancing both socio-economic and ecological resilience in human-dominated landscapes.

2. Key Ecological and Anthropogenic Drivers of HWCs

Major drivers of HWC are clearly illustrated by recent case studies that link specific land-use and climatic changes to documented incidents (**Fig. 2**). In Nepal, a landscape-scale analysis showed that deaths and injuries caused by tigers, leopards, rhinos, and elephants were concentrated in highly fragmented forest mosaics, where disaggregated patches and dense human settlements forced large mammals to move through villages and crop fields [18]. In eastern India's North Bengal, a two-year dataset of 380 crop-raiding events revealed that Asian elephants repeatedly targeted paddy and maize fields located along their traditional movement routes between forest blocks and tea estates, with risk increasing near forest edges and riverine corridors [19]. Across Assam, West Bengal, Odisha, and Chhattisgarh, news and conservation reports document annual cycles of elephant herds moving through tea gardens and paddy landscapes, causing extensive crop loss, house damage, and frequent human and elephant fatalities as migratory paths intersect expanding agriculture [20]. In the Western Ghats (Wayanad), compensation records and farmer interviews indicate that rising elephant numbers, fruiting jackfruit and mango in farm plots, and paddy cultivation near forest boundaries have shifted discord to peak seasons when elephants concentrate on these high-calorie crops, with over 90% of reported incidents involving crop depredation [21]. Climate-linked droughts and forest fires in India and East Africa are pushing elephants and large carnivores out of drying protected areas toward irrigated farms and village water sources, where tigers and elephants have been implicated in hundreds of human deaths and substantial crop losses over the past decade [22]. Beyond agriculture, a recent study from a coal-mining landscape in southern India showed that mining-induced land-cover change and associated monoculture plantations have altered rhesus macaque ranging, reducing crop damage but causing a shift toward frequent house-raiding in expanding built-up areas, directly tying extractive industry to new, highly localized conflict fronts [23].

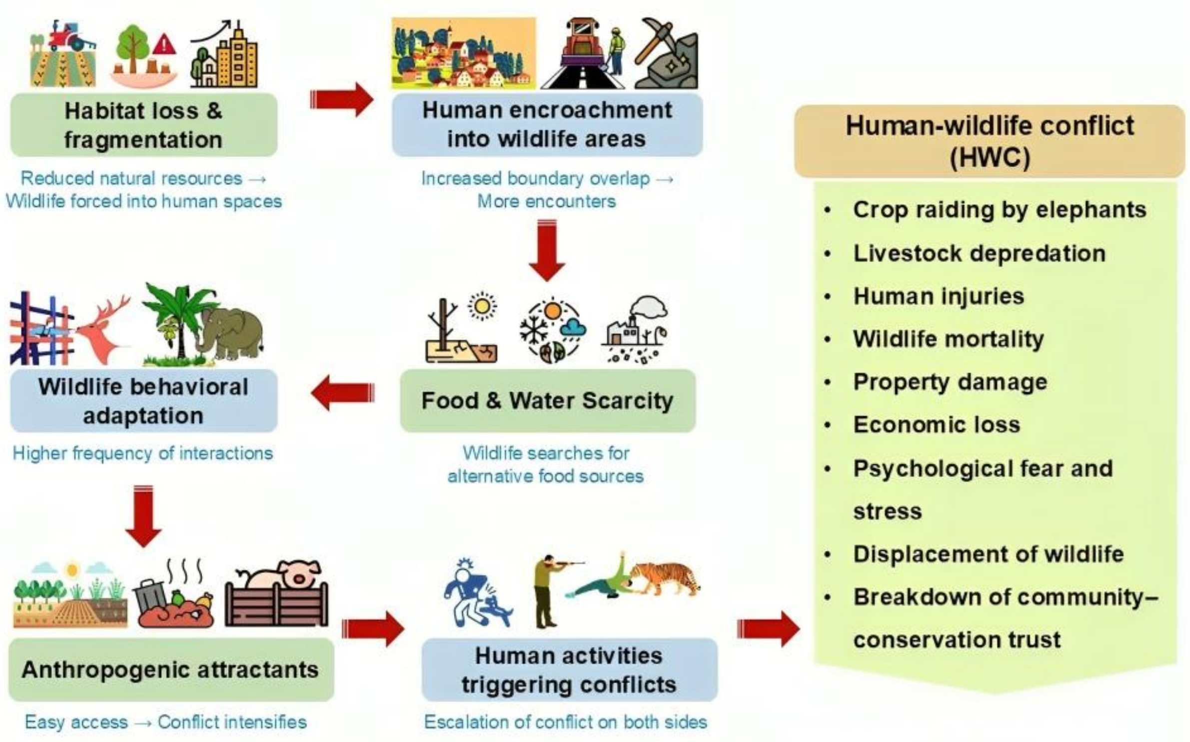

Fig. 2 Conceptual flowchart of the main drivers of HWC

3. Global patterns of major HWCs

HWCs varies globally with regionally distinct species driving most conflicts. These conflicts are often shaped by local ecological and socio-economic factors leading to diverse impact types such as livestock depredation, crop damage, or direct human injury. **Table 1** presents a concise overview of key species, associated issues, and geographic regions, illustrating how different continents face unique challenges and require tailored management approaches

.

Table 1 Overview of major HWC species, conflict types, and geographic distribution across global regions

Region/ Country	Key species	Dominant conflict issues
Kenya, Tanzania, Zimbabwe (Africa)	African lion, spotted hyena, African elephant	Livestock depredation, crop raiding, human injuries and deaths near protected areas [24,25,26]
Namibia, Botswana (Africa)	Hyena, elephant, leopard	Livestock kills, crop loss, retaliatory killings of predators [24,26]
India (Assam, West Bengal, Odisha, etc)	Asian elephant, tiger, leopard, wild boar	Crop raiding, livestock kills, human fatalities in forest fringe agriculture [27,28]
Sri Lanka	Asian elephant	Paddy and chena crop damage, high human-elephant mortality [29]
USA and Canada (North America)	Black bear, grizzly bear, gray wolf, coyote	Livestock depredation, bear encounters near urban areas, managed lethal control [30,31]
Australia (mainland and K'gari)	Kangaroo, dingo	Grazing competition, vehicle collisions, livestock predation, dingo attacks [32,33]
Brazil and Chile (South America)	Jaguar, puma, Andean bear	Livestock depredation, retaliation, habitat loss [34]
Indonesia and Malaysia (Southeast Asia)	Tigers, elephants, orangutans	Crop raiding, livestock loss, habitat encroachment [35]
Nepal	Tigers, rhinos, elephants	Livestock predation, crop damage, human injury and fatalities [19]

4. Ecological consequences

HWC can induce rapid behavioral shifts, with many species increasing nocturnality, shortening activity periods, and avoiding nearby settlements, which alters movement ecology and space use at population scales [4]. Reliance on anthropogenic food sources such as crops, garbage, or livestock carcasses restructures feeding niches and diet breadth in carnivores and omnivores, often increasing body condition for a subset of individuals while elevating disease risks and changing interspecific competition dynamics [6,36]. Fragmented landscapes and road networks create strong barriers to dispersal, reduce effective population size, and enhance inbreeding, with genetic studies showing reduced gene flow and emerging population structure in struggle-prone carnivores, elephants, and ungulates that must cross high-risk human-dominated matrices [4,37]. Because large carnivores and megaherbivores often act as keystone species, their local decline or extirpation through conflict-driven mortality can trigger trophic cascades, including mesopredator release, herbivore overabundance, vegetation degradation, and associated losses of ecosystem services such as carbon storage and natural pest control [36,38].

5. Mitigation strategies: Traditional and scientific approaches

Traditional HWC mitigation employs community-based strategies such as watch towers, fire torches, ditches, community patrols, and crop selection of non-palatable species, which leverage local knowledge and social structures to reduce wildlife incursions effectively at low cost [39,40]. Scientific and modern technological approaches have increasingly augmented these, including camera trapping and early warning systems that improve real-time monitoring of wildlife movement; innovative fencing techniques like solar electric, trench, and bio-fencing that create physical and psychological barriers; as well as acoustic and olfactory deterrents that exploit animal sensory sensitivities to prevent crop-raiding and livestock predation [41,42]. Drone-based monitoring and GIS remote sensing facilitate large-scale landscape analysis to identify hotspot areas and inform targeted interventions, while compensation schemes and insurance models offer economic incentives to communities, reducing retaliatory killings and fostering coexistence [43,44]. Central to all effective mitigation is the meaningful involvement of local communities and eco-development committees, which ensure culturally adapted, sustainable, and participatory struggle management strategies that align protection goals with human livelihoods (**Table 2**).

Table 2 Overview of major mitigation approaches for HWCs

Traditional/ community based approaches	Scientific/ Modern approaches
Watchtowers for crop monitoring	Solar-powered electric fencing
Drumming, shouting & fire torches to chase wildlife away	Early-warning systems (SMS alerts, sensor alarms)
Cowbells / noise-making devices	Camera trapping & GPS collaring for animal movement tracking
Living fences (agave, cactus, thorny hedges)	Drone-based monitoring of conflict-prone areas
Chili rope / chili smoke deterrents	Landscape planning & corridor restoration
Beehive fencing (effective against elephants)	Compensation schemes using verified digital evidence
Communal guarding of fields	Geofencing & virtual boundaries
Sacred groves and cultural restrictions limiting disturbance	Biological control of crop attractants
Use of guard animals (dogs, local cattle breeds)	Improved livestock enclosures (predator-proof sheds)
Traditional seasonal cropping to avoid peak movement periods	Waste management protocols to eliminate attractants

6. Community-based conservancy and corridor approaches

India's Wildlife Protection Act (1972) and its buffer zone policies form a cornerstone of the country's preservation framework by legally safeguarding wildlife and habitats through the creation of sanctuaries, national parks, and ecologically sensitive zones (buffer zones) that act as transitional spaces minimizing anthropogenic impacts on core protected areas [45,46]. However, enforcement challenges persist, including variable buffer zone notification and clearance processes that impact conservation efficacy. In Africa, conservancy models, community-led land stewardship programs integrating sustainable resource use and wildlife maintenance, have become prominent for addressing HWCs by empowering local communities and creating incentives for coexistence [47]. North American strategies emphasize the establishment and maintenance of wildlife corridors and landscape connectivity to facilitate safe animal movement across fragmented ecosystems, supported by legal protection under legislation such as the Endangered Species Act and State recovery plans, thus mitigating conflict arising from habitat encroachment [48]. At the international scale, frameworks such as the Convention on Biological Diversity (CBD) and IUCN guidelines integrate HWC mitigation into biodiversity conservation and sustainable development goals, promoting cross-border cooperation, policy harmonization, and the use of science-based management strategies globally [49]. Together, these policies establish a multilevel governance approach critical for balancing human needs with wildlife protection.

7. Conclusion

HWC represents a complex interplay of ecological pressures, human expansion, and shared resource use. This review highlights that effective mitigation cannot rely on isolated interventions but must integrate scientific tools, habitat connectivity, traditional knowledge, and active community participation. Strengthening coexistence requires long-term ecological planning, improved governance, and inclusive, locally adapted strategies. By promoting landscape-level conservation and empowering communities, sustainable solutions to HWCs can be achieved, ensuring both biodiversity protection and human well-being.

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