Nature's Rhythm

Nature's Rhythm:

The Impact of Seasonal Variations on Herbal Medicine

By

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*To the **keepers of ancient wisdom**, whose reverence for nature's cycles laid the foundation for traditional medicine, and to the **scientists and healers of today**, who continue to explore the harmony between the earth's rhythms and human well-being. May this work serve as a bridge between tradition and science and as a tribute to the enduring intelligence of plants and the seasons that guide them.*

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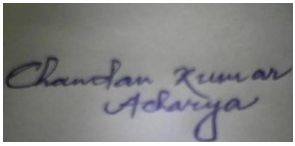
FOREWORD

The natural world has long been a rich source of medicinal compounds, with plants playing a pivotal role in traditional and modern medicine. However, the biosynthesis and accumulation of these vital compounds are intricately tied to environmental factors, particularly seasonal variations.

This groundbreaking research sheds light on the complex relationships between seasonal changes and medicinally important plant metabolites. By exploring the impact of temperature, light, water availability, and photoperiodism on plant secondary metabolism, this study provides critical insights into the optimal cultivation and harvesting strategies for maximizing bioactive compound yields. This research addresses a critical knowledge gap in the field of pharmacognosy and plant biotechnology, providing valuable insights into the dynamic relationships between environmental factors, plant secondary metabolism, and bioactive compound production. By elucidating the impact of seasonal variations on medicinally important plant metabolites, this study enhances understanding of plant-based medicine quality and efficacy. This study also informs evidence-based cultivation and harvesting practices. Also supports climate-resilient agricultural strategies and contributes to the development of standardized quality control measures. Moreover, the findings presented here have far-reaching implications for:

1. Medicinal plant cultivation and crop management.
2. Quality control and standardization of plant-based medicines.
3. Climate change mitigation and adaptation strategies.
4. Human health and wellbeing.

I commend the authors for their meticulous research and commitment to advancing our understanding of the intricate relationships between plants, environment, and human health.



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PREFACE

Plants have long served as vital components of traditional medicine, offering a rich source of bioactive compounds essential for human health. However, the biosynthesis and accumulation of these medicinally important plant secondary metabolites (PSMs) are significantly influenced by environmental factors, particularly seasonal variations. Fluctuations in temperature, light intensity, water availability, and photoperiodism affect plant growth, development, and metabolic pathways, leading to changes in the concentration and composition of bioactive compounds. These shifts can impact the efficacy, safety, and therapeutic value of plant-based remedies. PSMs play a crucial role in plant defense against pests, pathogens, and environmental stress, and are increasingly utilized in pharmaceuticals and functional foods due to their therapeutic potential. Their commercial value has spurred growing interest in enhancing metabolite production through advanced cultivation and tissue culture techniques. As climate change continues to alter environmental conditions, it also poses challenges to the stability and quality of medicinal plants. This book explores the complex relationship between seasonal dynamics and the biosynthesis of PSMs, aiming to deepen our understanding of the mechanisms that drive metabolite production. It discusses optimal harvesting periods, improved crop management strategies, and the potential consequences of climate change on plant-derived medicines. Drawing on current research and case studies of species like *Artemisia annua, Camellia sinensis, and Hypericum perforatum*, the book offers practical insights and future directions. Designed for researchers, academics, and professionals in plant science and pharmacognosy, it highlights the intricate connections between plants, environmental conditions, and human health in a rapidly changing world. Key objectives include identifying optimal harvesting times, improving crop management practices, and assessing the implications of climate variability on medicinal plant efficacy. It also offers practical guidance for researchers, herbal practitioners, and those involved in pharmacognosy, sustainable agriculture, and environmental health. By bridging traditional knowledge systems and modern scientific methodologies, this work contributes to a growing field concerned with preserving the therapeutic value of plants in the face of environmental change, while promoting informed, sustainable use of botanical resources.

ACKNOWLEDGEMENTS

I would like to express my deepest gratitude to all those who supported me throughout the course of this study. This work, "Nature's Rhythm: The Impact of Seasonal Variations on Herbal Medicine," would not have been possible without the guidance, encouragement, and assistance I received.

First and foremost, I am profoundly thankful to my research guide ***Dr. Naureen Saba Khan****, Assistant Professor, Dept. of Life Science, Dr. C.V. Raman University, Kargi road, Kota, Bilaspur (C.G), India for her counsel and guidance during my Ph.D studies.*

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I do hereby acknowledge my special thanks to ***Mr. Soumyabrata Jana*** *and* ***Mrs. Debjani Khanra*** *Jana for their heartiest encouragement and support.*

I am grateful to my mother ***Gouribala Acharya****, my elder brother* ***Mr. Bishnupada Acharya*** *as well as to my better half* ***Mrs. Tutul Acharya*** *and my beloved Son* ***Mr. Abhinandan Acharya*** *for their heartiest encouragement.*

Special thanks to the practitioners, herbalists, and traditional medicine experts who generously shared their time and knowledge with me. Their practical insights helped bridge the gap between scientific literature and traditional wisdom.

I would like to thank the authors and publishers of different books and reports, which I have consulted for their permission to record various important documents.

Lastly, I acknowledge nature itself—the ultimate teacher. The changing seasons and their subtle influence on the world around us served as both the inspiration and the subject of this research.

Warm Regards to All of You.

EXECUTIVE SUMMARY

Nature's Rhythm: The Impact of Seasonal Variations on Herbal Medicine explores the intricate relationship between environmental cycles and the potency, efficacy, and safety of medicinal plants. Drawing from both traditional systems of medicine (such as Ayurveda, Traditional Chinese Medicine, and Unani) and modern phytochemical research, the book emphasizes that the therapeutic value of herbs is not static but deeply influenced by seasonal rhythms. The core thesis centers on how **seasonal factors such as: temperature, rainfall, photoperiod, and soil moisture affect the biosynthesis and accumulation of secondary metabolites** in plants. These metabolites, including alkaloids, flavonoids, glycosides, and essential oils, are the pharmacologically active constituents responsible for the healing properties of herbs.

This study reveals the following insights:

- **Seasonality in Phytochemistry:** The book documents shifts in chemical composition and concentration of active compounds across seasons in key medicinal plants like *Withania somnifera*, *Ocimum sanctum*, *Azadirachta indica*, and *Curcuma longa*.

- **Optimal Harvesting Time:** It provides evidence-based guidance on the best seasons and phenological stages for harvesting different parts (roots, leaves, flowers, fruits) to maximize medicinal quality and yield.

- **Traditional Knowledge vs. Modern Science:** The book bridges indigenous wisdom such as Ayurvedic rules of *ritucharya* (seasonal regimen) and *dravya guna* (seasonal effect on herb quality) with contemporary analytical techniques like HPLC, GC-MS, and NMR.

- **Climate Change Implications:** It cautions that changing global climate patterns could disrupt these natural rhythms, potentially altering the effectiveness of herbal remedies and requiring adaptive cultivation and conservation strategies.

- **Application in Herbal Industry:** Practical applications are discussed for herbal practitioners, cultivators, pharmacognosists, and the herbal

product industry, including season-based cultivation calendars, storage guidelines, and formulation strategies.

BLURB

This book explores how changes in seasons affect the healing power, safety, and quality of medicinal plants. It explains how weather factors like temperature, rainfall, and sunlight influence the way plants produce important healing compounds (Plant Secondary Metabolites). Using both traditional knowledge from systems like Ayurveda, Unani, and Traditional Chinese Medicine and modern science, the book shows how old practices often match today's research.

With examples from South Asia, it looks at how climate change may impact the future of herbal medicine. The book also gives practical advice on when to grow, harvest, and prepare herbs to get the best results. Real-life examples and easy language help make the science clear.

This book is useful for herbalists, farmers, researchers and students interested in plant medicine. It is also a great resource for librarians and educators looking for trusted, culturally aware information on how nature and medicine work together.

BIOGRAPHY

Dr. Chandan Kumar Acharya is a senior acemadecian and researcher in the Department of Botany, Bajkul M Mahavidyalaya, West Bengal, India with over 18 years of experience in teaching and plant-based research. He holds a Ph.D. in Phytopathology and Biochemistry, alongside advanced degrees in Plant Pathology, Ecology, and Education. His interdisciplinary expertise focuses on phytochemistry, ethnopharmacology, and the seasonal variation of medicinal plants.

Dr. Acharya has conducted significant research on *Phyllanthus emblica* (Amla), exploring its phytochemical changes across seasons using advanced techniques like FTIR, GC-MS. He led a UGC-sponsored project on the seasonal impact on active herbal constituents, integrating traditional knowledge with scientific validation. His work has been widely published in UGC CARE-listed journals and featured in international conferences.

As the author of a monograph on mangrove ecology and contributor to volumes on herbal medicine, Dr. Acharya brings a culturally grounded, science-driven perspective to this book bridging traditional wisdom with modern Botanical research.

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CHAPTER 1

INTRODUCTION

In Ayurveda, it has been quoted that the safety and quality of crude medicinal plants is based upon three major factors viz. *Desha* (habitat), *Kala* (Time), *Guna* (properties), etc. Among them, *Kala* i.e. the time factor (season, lunar period and day) plays a vital role in influencing the pharmaco-therapeutic potentials of plant parts used by the indigenous people throughout the Globe (Ranade and Acharya, 2015). In Charaka samhita, Sushruta samhita, Sharangdhara samhita and Raja nighantu, it was mentioned that crude drug of medicinal plants should be collected in six ritus (season) according to the parts used for the treatment of various disease ailments. Medicinal plants exhibit significant seasonal variation in their active ingredients, a phenomenon largely attributed to changes in environmental factors such as temperature and rainfall (Ahmad *et al.,* 2011).

In general, it is believed that once the secondary metabolite is formed, it is never metabolized again. But in contrast, modern studies related to the dynamics of secondary metabolites established that the factors like seasonal variations, diurnal variations and disappearances of various stages of developments leads to definitive turnover of these valuable metabolites (Daniel, 2006). For example, in certain plants, the bitter tannin content has been lost when the fruits ripen, whereas anthocyanine disappears when the leaves mature.

Phytochemicals are plant secondary metabolites like alkaloids, phenols, flavonoids, tannins, glycosides, steroids, saponins, terpenoids, coumarin etc. produced through metabolic pathways in response to biotic and abiotic stresses acted upon them (Ramakrishna, 2011). Among them, phenols and flavonoids show antioxidant properties and therefore obtain immense attention by food and pharmaceutical industries (Chu *et al.*, 2000).

It is well-established that the level of secondary metabolite production in many medicinal plant species is correlated with the seasons (Mohiuddin,

2019). Hence, the concept of 'Kala' as mentioned in Ayurveda plays a crucial role to avail highly-valued phytoconstituents in good quantities. Highest saponin content was achieved by Watoo Phrompittayarat (2011) in *Bacopa monnieri* shoot cultivated in rainy season. Tambe S. *et al* (2012) also demonstrated variations in alkaloid and lipid content in leaf, bark and wood of *Butia monosperma*, *Madhuca indica*, *Syzygium cumini* and *Mimusops elengi* of Marathwada region between seasons, with highest concentration (in leaves) during summer. On the other hand, the percentage yields of lupeol in roots of *Desmodium gangeticum* (L.) DC attained its maximum value in the month of Octobor and very low in the month of June (Jayanthy A., *et al* 2013).

Recently, Ramírez-Briones *et al.* (2019) revealed the influence of seasonal changes in leaf metabolic profile of *Diospyros rekoi* "Zapote" trees. Therefore, to avoid unnecessary over-exploitation from their wild habitat and to obtain maximum output, selected seasons should be opted for drug formulations and their synthesis (Singh, 2008; Acharya and Ranade, 2015).

Plant derived substances used by different ethnic group for folk remedies have been studied by the branch of science named, Ethnopharmacology. The field is now accompanies with phytochemistry to identify and characterize the chemical constituents present in the plant or plant extract that is responsible for the pharmacological activities inherent to a specific plant (Mulholland *et al.*, 2005). Modern pharmaceutical research has been carried out to assess the role of seasons, diurnal variation, maturing stages on phyto-constituents of different plants parts (Ranade and Acharya, 2015).

Numerous reports indicate that seasonal variations significantly affect the pharmacological properties of medicinal plants, particularly the anti-diabetic activity of Momordica charantia fruits. The highest anti-diabetic activity was observed in the spring season, followed by summer, autumn, and winter (Kolawole, Ayankunle, 2012). In another study, influence of seasonal variation on antioxidant activity of *Ocimum basilicum* extract reveals that sample collected in winter seasons showed the best antioxidant activity. (Hussain, *et al.*, 2008).The seasonal activity in the vasicine content of five parts of *Adhatoda vasica* was assessed with the help of TLC-UV densitometric estimation technique reveals that highest amount of vasicine was found to be present in the inflorescence and in most parts of the plant in the months of July-Sept. (Arambewela, 1987).

Similarly much of the research work were concentrated on variation of phytoconstituents in respect to different seasonal variation in medicinal plants viz. *Andrographis paniculata* (Sharma, *et al* 2012), *Anogeissus latifolia* (Uday *et al*, 2011)*, Bacopa monnierri (*Watoo Phrompittayarat *et al.*, 2011*), Barleria prionitis (*KP Sahoo, 2012*), Boerhaavia diffusa* (Sahoo, 2012)*, Butea monosperma (*Tambe SS, 2012*), Datura metel* (Kale., 2010)*, Desmodium gangeticum (*Jayanthy A, 2013*), Grewia tenax* (Sahoo, *et al*, 2012)*, Sesbania cannabina and Sesbania bispinosa* (Momin *et al* 2011)*, Sesbania grandiflora* (Momin R.K *et al* 2011), *Mimusops elengi* (Tambe SS *et al.*, 2012)*, Mentha longifolia* (Ahmad, *et al.*, 2011)*, Madhuca indica* (Tambe SS, *et al.*, 2012) *Withania somnifera* (Kale, 2010).

Therefore, the influence of environmental conditions not only affect on plant growth and developments but also for the production of secondary metabolites in plants. The varied production of secondary metabolites in plants leads to varied biological activities when people consumed it.

This book aims to focus on how far the phyto-constituents changes in response to seasonal variations acted upon some commonly used valuable medicinal plants and special emphasis has been given to establish ancient belief in the light of modern scientific interpretations.

1.1 What are Plant Metabolites?

The term ‘metabolites’ usually use to refer small molecules although its broader application is often practiced. Metabolites refer to the intermediate products that are being produced during metabolic reactions and are catalyzed by various enzymes that occur naturally within cells.

Plant metabolites are chemical compounds produced by plants through enzyme-mediated reactions known as metabolic pathways. These metabolites support growth and development as primary metabolites, while secondary metabolites play key roles in defense against herbivores and in attracting pollinators.

1.2 Types of Plant Metabolites

Plant metabolites are of two types:

a. Primary metabolites
b. Secondary Metabolites

1.2.1 Primary metabolites

- These are commonly known as 'Central metabolites' as it maintain the physiological functions of plant body.
- These are found universally in the entire plant kingdom.
- These are the chemical compounds viz. carbohydrates, lipids, proteins, and nucleic acids synthesized during the growth and development processes.
- These are the components or products of fundamental metabolic pathways or cycles such as Glycolysis, the Krebs cycle, and the Calvin cycle.

1.2.2 Secondary Metabolites

- These are not directly involved in metabolic process but usually have many important ecological functions like plants defense mechanism, attract pollinators etc.
- These are the chemical compounds largely fall into three categories like alkaloids, terpenoids, and phenolics.
- These are the compounds that have been synthesized by specially designated pathways, the 'secondary metabolic pathway'.
- In earlier days, secondary metabolites were termed as end products or excretory products or waste products by several biochemists and plant physiologists. This is because secondary metabolites do not get involved in physiological functions of the body as well as in primary metabolisms, but now this concept has been discarded. Recently, it has been established that secondary metabolites are involved in various adaptational and survival mechanisms. Scientists confidently proclaimed that due to the presence of secondary metabolites the plants can be survive and evolved (Daniel, 2006).

1.3 Secondary metabolites in Plants

Plants are the sessile organisms, they can not ran away when they have been subjected to any pathogenic attack, stresses instead they can produce some chemical substances of their own to combat with these external

enemies. These chemicals are known as secondary metabolites or active principles. Secondary metabolites are a diverse group of bioactive compounds produced by plants through secondary metabolism.

These compounds are not essential for plant growth and development but play a crucial role in plant defense, adaptation, and interaction with the environment. Their diversity and complexity have made them valuable resources for medicine, agriculture, and industry, while also highlighting the intricate relationships between plants and their ecosystem.

1.4 Types of Secondary Metabolites

1. **Alkaloids** (e.g., Caffeine, Nicotine)
2. **Glycosides** (e.g., Saponins, Anthocyanins)
3. **Terpenes** (e.g., Limonene, Carotenoids)
4. **Phenolics** (e.g., Flavonoids, Lignin)
5. **Sulfur compounds** (e.g., Glucosinolates)

1.5 Functions of Secondary Metabolites in Plants

1. Defense against herbivores, pathogens, and environmental stresses
2. Attraction of pollinators and other beneficial organisms
3. Antimicrobial and antifungal activity
4. UV protection and antioxidant activity
5. Signaling and communication within the plant and with other organisms

1.6 Importance of Secondary Metabolites

1. **Medicinal properties**: Many secondary metabolites have been used in traditional medicine and modern pharmaceuticals.

2. **Agricultural applications**: Secondary metabolites can be used as natural pesticides, fungicides, and growth regulators.

3. **Food and beverage industry**: Secondary metabolites contribute to the flavor, aroma, and color of fruits, vegetables, and beverages.

4. **Ecological significance**: Secondary metabolites play a key role in plant-plant and plant-environment interactions.

Table: 1.1 Secondary metabolites and their action

Secondary metabolites	Acts as
Alkaloids	Defensive against insects due to Bitter taste
Volatile oil	Attracting insects for pollination due to presence of Pheromones.
Diterpenes and Triterpines	Wound healing and antimicrobial function when present in Resin.
Limonoids and Quassinoids	Insect repellent by protecting woody plants from insect attack
Phenolics	Antioxidant by protecting cellular membrane and tissues containing lipids from oxidation.
Anthocyanines	Pollinator guide to 'colour blind' insect'
Flavonoids	Pollinator guide to 'colour blind' insect'

1.7 Plant secondary metabolism vs Human metabolism

Plants use their own metabolites whether it is primary or secondary to perform their own physiological functions and to combat against several insect infections respectively. Interestingly, when we consume the medicinal plants to treat different disease ailments, the same compounds to which the plant uses for them are utilized by human also.

However, Plant secondary metabolism and human metabolism are two distinct processes that serve different purposes. Plant secondary metabolism involves the production of bioactive compounds, such as alkaloids, glycosides, and terpenes, which play a crucial role in plant defense, growth, and development. These compounds are synthesized through complex pathways and are often specific to particular plant species or families. In contrast, human metabolism encompasses the breakdown and synthesis of molecules necessary for energy production, growth, and maintenance of bodily functions. Human metabolism involves the conversion of nutrients from food into energy, hormones, and other essential molecules, whereas plant secondary metabolism produces compounds that are not essential for plant growth but provide adaptive advantages.

While both processes involve enzyme-catalyzed reactions and biochemical pathways, they operate in different contexts and have distinct outcomes, reflecting the unique characteristics and requirements of plants and humans.

Plant secondary metabolism produces specialized compounds for defense and growth, whereas human metabolism focuses on energy production and biomolecule synthesis.

Plant secondary metabolism occurs in specialized cells and tissues, whereas human metabolism occurs in various tissues and organs.

Plant secondary metabolism is influenced by environmental factors, whereas human metabolism is primarily regulated by hormones and neural signals.

Table: 1.2 Role of secondary metabolites in plants and human

Secondary metabolites	Role in plants	Role in Human
Antioxidants	Neutralizing reactive oxygen species (ROS)	Radical scavenging and oxidative damage leading to ageing.
Carotenoids	Protect chlorophyll and other molecules	Antioxidant, vitamin A precursor, eye health, skin protection
Ascorbic acid	Antioxidant activities. Plant growth, development, and stress tolerance	Antioxidant, collagen synthesis, immune function, iron absorption, neurotransmitters
Cardiac glycosidase	To kill herbivores through stopping its heart beat.	Used as cardiotonics.
Volatile oil	Antimicrobial activity	Repeal the attack of microbe in human body system

So, the study aims to explore following objectives:

- **To explore the Ayurvedic concept of 'Kala' (Time/Season) and its role in determining the optimal harvest period for medicinal plants.**

This includes evaluating traditional knowledge from classical texts such as Charaka Samhita, Sushruta Samhita, and Raja Nighantu, which advocate seasonal collection strategies for maximizing therapeutic efficacy.

- **To examine how seasonal and environmental variations (temperature, rainfall, day length, and lunar phases) influence the biosynthesis and accumulation of secondary metabolites in medicinal plants.**

Scientific studies will be assessed to show how environmental stress acts as a trigger for phytochemical changes that affect pharmacological potency.

- **To identify the phytochemical classes most affected by seasonal rhythms, including alkaloids, flavonoids, tannins, terpenoids, and saponins, and their corresponding bioactivities.**

This objective connects the chemical diversity in plants to their changing seasonal profiles, explaining implications for antioxidant, antimicrobial, and therapeutic actions.

- **To correlate specific seasons or periods with peak production of active constituents in important medicinal species.**

Examples include highest saponin content in Bacopa monnieri during the rainy season, or maximal vasicine yield in Adhatoda vasica from July to September.

- **To highlight the scientific basis behind seasonal metabolite turnover, challenging the older belief that secondary metabolites remain constant once synthesized.**

Modern findings reveal dynamic changes due to developmental stages and environmental stimuli, such as anthocyanin loss in maturing leaves or tannin degradation in ripened fruits.

- **To assess the pharmacological implications of harvesting medicinal plants in the wrong season, including potential reductions in efficacy or therapeutic failure.**

This includes case studies like reduced anti-diabetic activity in Momordica charantia fruits harvested in winter compared to spring.