Unraveling the Mysteries of *Cordia dichotoma's* Seasonal Phytochemical Variation.

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Abstract:

Perhaps that was the well-known plant, *Cordia dichotoma*, which had an intricate array of phytochemical compositions, traditionally known for its medicinal value. These phytochemicals are pretty non-static in the medicinal effects they provide. Recent evidence shows the plant- environment dynamic through its phytochemical composition presenting an interesting variation season dependent. It becomes very critical in maximizing the value of the plant in pharmaceutical applications and other uses.

Effects of different seasons on Cordia dichotoma were studied in detail. The study revealed a seasonal effect on the biocompound of various types and different concentrations. The primary factors of temperature, water supply, and sunlight exposure play a significant role in controlling the plant's metabolism, thus affecting the synthesis and accumulation of such precious phytochemicals. Hence, this seasonal ebb and tide of the plant with the environment demands study of environmental parameters at the time of harvesting and also while utilizing Cordia dichotomy.

The knowledge of seasonality of phytochemicals from Cordia dichotoma thus applies more broadly. The identification of the seasons where individual bioactive compounds are in the greatest concentration will allow for improved harvesting strategies for maximum yields and therapeutic activity. Also adds to knowledge on seasonality for the standardization of extract with a fixed potency so that consistent effects of medicine can be achieved from reproducible results. This study also provides insight into the complex relationship between plant

populations and their environment, thus better approaches to sustainable, informed, and value-added utilization of such important natural resources as Cordia dichotoma.

Keywords- Cordia dichotoma, Seasonal variation, Phytochemicals, Traditional medicine, Ethnobotany, Photoperiod, Bioactive compounds

1. Introduction:

1.1 Background and Rationale of the Review

Background

The deciduous tree, Cordia dichotoma, grows up to 20 meters tall and is distributed extensively across tropical as well as the subtropical parts of the world [6]. The tree becomes distinguished by its charming white flowers as well as edible fruit, which is a good source of minerals as well as vitamins [7]. The tree leaves, bark, as well as the roots, have traditionally been used for the treatment of many diseases, such as fever, cough, diarrhoea, and skin disorders [8]. Phytochemicals are bioactive compounds that are synthesized by plants for purposes including defense, attraction of pollinators, as well as control of growth and development [9]. These compounds demonstrate an array of therapeutic activities, including antioxidant, anti-inflammatory, as well as anticancer activities [10]. But their concentration is not constant, as it can change seasonally based on temperature, humidity, as well as sunlight [11].

Rationale

Understanding the seasonal phytochemical variation of Cordia dichotoma is significant for harvest optimization in therapeutic activity maximization: [12]. This is possible by determining the period during which a particular phytochemical is at its peak concentration; farmers and herbalists could time harvests at this period to ensure optimum extraction. Such knowledge would also be useful in resolving the variations in the reported therapeutic efficacy associated with Cordia dichotoma by different authors [13]. While several authors have reported possibilities of strong anti-inflammatory activity in the plant, a few indicate possible weak and transient activity [14]. Such differences could be based on the part of the plant used, age, and seasonal differences in phytochemicals, among other things. Thirdly, understanding seasonal variation would assist in defining the best conditions under which Cordia dichotoma could be cultivated so as to derive the highest therapeutic yield [15].Elucidating the variables, such as temperature, humidity, and sunlight, that influence the concentration of some phytochemicals, scientists could advance towards formulating techniques that would enable these plants to be cultivated under the best possible conditions for maximum therapeutic value.

The following sentences have been paraphrased: Understanding the seasonal changes of phytochemical variations in the species is necessary for several reasons reasons: It's helpful to optimize the harvesting time of the plant to maximize therapeutic activity [12]. Knowing during what season a certain concentration of phytochemicals is maximized can make a farmer or

herbalist able to schedule harvesting to that time. Secondly, the knowledge on seasonal variation in phytochemicals can be used to bridge the gap on some variations between efficacy of Cordia dichotoma in opened by different authors [13]. Some people revealed serious anti-inflammatory activity while others have just shown claims of weak, non-persistent effects [14]. Such differences can be attributed to phytochemicals. Third, one has to know the seasonal variations in phytochemicals to identify the more relevant growing conditions for optimal therapeutic value of Cordia dichotoma during cultivation [15]. By identifying those variables that affect the content of some phytochemicals, such as temperature, humidity, and sunlight, scientists will be able to identify techniques worthy for improving these variables for cultivation of such plants that would receive maximum therapeutic values.

1.2 Objectives and Scope

Objectives:

- To explore the seasonal variations in the phytochemical composition of Cordia dichotoma.
- To examine the factors influencing the phytochemical variations in Cordia dichotoma.
- To discuss the potential implications of these variations for the use of Cordia dichotoma in traditional medicine and other applications.

Scope:

The following will summarize and review the scientific literature on the seasonal phytochemical patterns of Cordia dichotoma, a traditionally used medicinal plant species with a long history. The review will examine the main classes of phytochemicals of Cordia dichotoma, such as flavonoids, tannins, and alkaloids, as well as the factors that could affect their production and accumulation within the plant. The review will examine the possible effects of the variations for the medicinal and other applications of Cordia dichotoma.

2. Morphology to Medicine: A Comprehensive Botanical Overview

Bird plum or laserwort, the common name for Cordia dichotoma, is a tropical tree species that naturally occurs in Central America, South America, Africa, and Asia [16]. The plant has gained considerable attention over the past few years because of its varied phytochemical content and medicinal uses. Seasonal variation of its phytochemical content is of concern, as it drastically affects its pharmacological activity. This paper will examine the morphology, phytochemistry, and medicine of Cordia dichotoma, focusing on the seasonally oriented variation of its phytochemical constituents [17].

2.1 Botanical Description of Cordia dichotoma-

The trees of Cordia dichotoma are medium-sized, reaching up to 15-20 m high. It has a straight trunk, 50-80 cm in diameter, and is greyish-brown in colour. The bark peels off in irregular flakes.[18] They are simple, ovate-oblong, oppositely arranged on the stem. The leaves are 5-15 cm in length and 2.5-6 cm wide, with a smooth margin and an acute or obtuse apex.[19] The leaves are glabrous on both surfaces, with a prominent midrib and lateral veins. Flowers of Cordia dichotoma is bisexual in nature and are white, fragrant, tubular, or campanulatus corolla, inserted on terminal panicles or cymes. The calyx may be hairy or pubescent and with five lobes.[20] Fruits of Cordia dichotoma are drupes, 1.5-2.5 cm in diameter and green when unripe but bright red or purple when ripe.

2.2 Classification of Cordia dichotoma

Cordia dichotoma is classified based on its morphological aspect along with anatomical features. The following are the major features of this species:

1. Cordia dichotoma-an average-sized tree growing as high as 20 meters.
2. Leaves: Leaves are simple, ovate, with a serrated margin, oppositely arranged on the stem, leathery in texture.
3. Flowers: White, small, and tubular; flowers of Cordia dichotoma appear in clusters and are fragrant. One can see flowers throughout the year.
4. Fruits: The fruits are small, rounded, and fleshy. The fruits, when unripe, are green but turn to black when it ripens.
5. Wood: The wood of Cordia dichotoma is hard and heavy, and durable. It is extensively used for furniture, tools, and implements [19].

2.3 Morphological Characteristics:

C. dichotoma is a deciduous tree, which grows to a height of 20 meters, with a straight, cylindrical, and sometimes buttressed bole [22]. The bark is smooth and greyish-brown, exfoliating in thin scales [23]. Leaves are simple, opposite, and elliptic-oblong to ovate-shaped with a shiny, dark green upper surface, and light green underside [24]. The leaves are 5-15 cm long and 3-7 cm wide, respectively, with a short pointed or obtuse apex, and a cuneate or rounded base [25]. Leaves are entire along the margins, having or may be produced with a few teeth towards the apex [26]. Stipules linear, caducous, 1-2 cm long [27].

Flowers are bisexual, white, and fragrant about 2-3 cm in diameter.[28]. Flowers are arranged in a cymose paniculate inflorescence, supported by a peduncle 2-5cm long. [29] The calyx is campanulate with 5 lobes 1-1.5 cm long, pubescent on the outer surface.[30] The corolla is tubular, divided into 5 lobes that are 1-1.5 cm in length, and glabrous on the inner surface. The stamens are 4-5 mm long, inserted at the base of the corolla [31]. The ovary is superior, supported by a slender style [32].

The fruits of C. dichotoma are drupes and are 1.5-2 cm in diameter, unripe green, and turn to red and black upon ripeness [33]. Fruits are ovoid or ellipsoid, borne in clusters of 2-6 [34]. Seeds are ovoid or ellipsoid, 1-1.5 cm long [35].

2.4 Phytochemical Composition of Cordia dichotoma Leaves

The general phytoconstituents reported in different studies concerning the leaves of Cordia dichotoma include flavonoids, tannins, saponins, alkaloids, terpenoids, and steroids.

- **Flavonoids:** Flavonoids are a group of compounds represented in plant life. They are credited with many biological activities, such as antioxidant, anti-inflammatory, and anticancer. Cordia dichotoma leaves have been researched and reported to contain several flavonoids. The principal flavonoids found in Cordia dichotoma leaves are quercetin, kaempferol, and myricetin.
- **Tannins:** Tannins are chemical compounds that can be defined depending on their astringency properties. They possess bioactive properties, having antioxidant, antimicrobial, and anti-inflammatory activities. Some research reports identified the presence of tannins in the Cordia dichotoma leaves. The predominant tannins found in Cordia dichotoma leaves are gallic acid and ellagic acid.
- **Saponins:** Saponins comprise such classes of compounds that are characteristically differentiated by producing soapy lathers. Various biological activities are manifested with these compounds, such as antimicrobial, antioxidant, and anti-inflammatory activities. Different literature have also reported on the prevalence of saponins in the leaves of Cordia dichotoma. Gypsogenin and hederagenin are major saponins found in Cordia dichotoma leaves.
- **Alkaloids**: Alkaloids are the group of nitrogenous compounds. They have shown many types of biological activities such as antimicrobial, antioxidant, and anti-inflammatory activities [42]. Many reports have identified the presence of alkaloids in the leaves of Cordia dichotoma. The two major alkaloids from the leaves are cordiamine and cordianine [43].
- **Terpenoids**: The terpenoids are those substances that are derived from isoprene units. They show diversity in their biological activities which include antimicrobial, antioxidant, anti-inflammatory, and activity against various other disorders. Terpenoids were identified in the leaves of Cordia dichotoma by many reports [44]. Ursolic acid and oleanolic acid have been identified as major terpenoids present in the leaves of Cordia dichotoma [45].
- **Steroids**: Steroids are group-of compounds having steroid nucleus. They observe a wide range of biological activities; antimicrobial, antioxidant, and anti-inflamatory activities [46]. Presence of steroids has been reported through various studies in the leaves of Cordia dichotoma. The major sterols in Cordia dichotoma leaves are sitosterol and stigmasterol [47].

Phytochemical Compound	Description
Flavonoids	**Present in significant amounts, known for their antioxidant and anti-inflammatory properties.**
Phenolic Compounds	**High levels, contributing to the leaves' antioxidant and antimicrobial activities.**
Tannins	**Moderate levels, responsible for astringent properties and potential medicinal uses.**
Saponins	**Present, known for their detergent-like properties and potential health benefits.**
Terpenoids	**Include essential oils and other volatile compounds, contributing to the aromatic properties of the leaves.**

Table No. 1- Phytochemical Composition of Cordia dichotoma Leaves

3. Traditional Wisdom and Therapeutic Relevance

Traditional medicine uses Cordia dichotoma for many purposes, including fever, rheumatism, as well as digestive ailments [48]. In Ayurveda, Cordia dichotoma is another eminent drug for diseases of the respiratory tract, such as bronchitis, and also bronchial asthma [49]. The traditional wisdom regarding this plant with regard to its medicinal use comes from its characteristic phytochemical property wherein alkaloids, glycosides, and phenolic compounds were found to be prescribed [50].

It is widely established that the phytochemistry of this plant varies according to seasons [51]. Several studies reported seasonal variation of bioactive compounds i.e. cordioside, cordiol, and caffeic acid caused by variations in temperature, humidity, and light during that time of time [52]. This variability is expressed in different parts of this plant such as leaves, stems, roots, etc. [53].

Seasonal phytochemical variations of Cordia dichotoma can have significant ramifications in medicinal applications. For instance, the increased levels of cordioside and cordiol in spring could add to the antioxidant and anti-inflammatory action of the plant [54]. Similarly, the higher concentrations of caffeic acid and phenolic compounds in summer might attribute antimicrobial

and antiviral properties to the plant [55]. On the other hand, diminished concentrations of autumnal alkaloids may reduce the analgesic and antipyretic efficacy of the plant [56].

The phytochemical diversity of Cordia has great prospects in the generation of novel therapeutics. The bioactive phytochemistry has been shown to be active in anti-cancer [57], anti-diabetic [58], and antihypertensive [59]. Furthermore, seasonal change in phytochemical composition can provide an inviting premise towards framing specific therapeutic products which are individuated with the health conditions and seasons [60].

3.1 Folk and Regional Usage Patterns

A study appearing in the Journal of Ethnopharmacology determined that the leaves of Cordia dichotoma contained the greatest total content of phenols as well as antioxidant activity over the summer season [61]. In all likelihood, this is the plant's response to the stressor in the environment, namely temperature increase or much higher amounts of sunlight.

Another research was published in The Journal of Medicinal Plants Research, revealing that the monsoon bark of Cordia dichotoma has the highest total flavonoid content [62]. Phytochemicals known as flavonoids possess antioxidant and anti-inflammatory properties.
According to folk and regional usage patterns, Cordia dichotoma is widely used in South Asia for therapeutic purposes. The bark of the plant is used for treating fever, dysentery, and diarrhea [63]. Leaves, however, are used to treat skin ailments such as ringworm and eczema and the fruit for coughs and colds [64].

In Maharashtra state, Cordia dichotoma is referred to as “geega” and the leaves are employed for wound healing as well as for burns (Gaitonde et al., 2011). In the Gujarati state, fever is treated using bark, while diarrhoea is treated using the fruit [65].
Besides its medicinal applications, Cordia dichotoma is used for several cultural as well as religious purposes within South Asia. For instance, its leaves are employed during worship of the Hindu deity Durga [66] in India. Traditional instrumentation is made from its wood in Nepal [67].

4. Chemistry Within: Profiling Bioactive Compounds

In this paper, we will unravel the secrets of seasonal phytochemical variation of Cordia dichotoma, analyzing the bioactive compounds of the plant as well as their medicinal benefits [68]. We will further address the effects of seasonal variation on the application of Cordia dichotoma as a medicine as well as its possible commercialization.

4.1 Bioactive compounds of Cordia dichotoma

The species Cordia dichotoma is reported to contain a vast array of bioactive compounds such as flavonoids, tannins, saponins, alkaloids, and terpenoids. These all have demonstrated a

variety of pharmacological activities such as anti-inflammatory, antioxidant, antimicrobial and anticancer [69].

The flavonoids are the polyphenolic compounds that are widely distributed among many plants, such as Cordia dichotoma. Antioxidant compounds protect cells from oxidative damage caused due to free radicals. Hence, it is reported that Cordia dichotoma contains a variety of flavonoids like quercetin, kaempferol along with myricetin [70]. These compounds are helpful for health purposes such as anti-inflammatory, antiviral, anticancer, etc. Other polyphenolic compounds tannins found in Cordia dichotoma have been shown to produce astringency, which minimizes swelling and inflammation [71]. Also, tannins have antimicrobial activity; therefore, they can cure infections.

Saponins are glycosides of the plant Cordia dichotoma. Saponins, due to their structural chemistry, can produce soap-like froths when shaken with water. Saponins have a variety of pharmacological activities like anti-inflammatory, antimicrobial, and anticancer effects [72].
Alkaloids which are one of the types of nitrogenous compounds found in Cordia dichotoma, show a wide range of medicinal activities such as analgesic, anti-inflammatory, and anticancer activity [73].

Terpenoids are a large class of compounds made up of isoprene units and show a wide variety of structures and activities. They are structurally diverse and exhibit various forms of activity. Evidence points towards a large number of therapeutic activities of terpenoids such as anti-inflammatory, antimicrobial, and anticancer [74].

5. The Rhythm of Nature: Seasonal Dynamics in Phytoconstituents

The natural world is a symphony of cycles and rhythms, with vegetation displaying spectacular variations as seasons change. A typical exemplar of the season dynamism of the natural world is Cordia dichotoma, a plant species of Indian origin as well as tropical and subtropical parts of the world [75]. The phytoconstituents of the plant, the biological compounds of the plant, vary greatly with seasons, providing an insight into the complex interplay between the plant and its environment [76]. The season phytochemical variation of Cordia dichotoma is examined through 20 authentic sources in this paper, detailing the mechanisms involved as well as the possible significance.

5.1 Seasonal Phytochemical Variation: A Natural Phenomenon

Phytoconstituents from plants are affected by several factors, such as intensity of light, temperature, and availability of water [77]. These environmental conditions vary seasonally, resulting in seasonally predictable phytochemical variation. Phenolic compounds, flavonoids, and tannins, for example, have been shown to vary seasonally in Cordia dichotoma [78].

5.2 Influence of Environmental Factors (Light, Temperature, Rainfall)

Understanding the seasonal variation of phytochemicals is of essential significance for a number of reasons**.** The first weights the maximum utilization and harvesting of medicinal plants upon optimal timings of their use so that bioactive compounds are found in maximal amounts [79]. The second weighs the ecological adaptability demonstrated by the influence of season on the plant [80]. Finally, it serves to highlight the seasonally differing health benefits of the consumption of the various types of plants [81].

5.3Comparative Analysis Over Seasons

Studies have proved that the phytochemical content of Cordia dichotoma changes largely from season to season. For example, summer was shown to be the season of highest phenolic content in the plant, most probably as a protection response of the plant to increased sunlight exposure (Singh et al., 2016). Similarly, it has also been shown that the flavonoid content was reported to be highest in the rainy season due perhaps to higher water availability [82].

5.4 Implications on Bioactivity

The phytochemical seasonal variation of Cordia dichotoma can be explained by a combination of mechanisms. One such factor is the metabolic response of the plant to environmental stimuli. For example, enhanced exposure of the plant to sunlight during summer can trigger the production of phenolic compounds, which function as built-in sunscreens for the plant [83]. In the same manner, extra water during the rainy season can enhance the synthesis of flavonoids, being involved in water-stress tolerance [84].

6. Tools of the Trade: Advances in Phytochemical Analysis

The techniques and instrumentation employed for phytochemical analysis have evolved considerably over the past several years, generating new information on the phytochemical content of plant species such as Cordia dichotoma [85]. Knowledge of the seasonal phytochemical pattern of Cordia dichotoma is essential for its maximal utilization for pharmaceutical purposes, and with the techniques and instrumentation described here, unraveling the secrets of the medicinal plant is possible [86].

These techniques and tools have been used for the phytochemical analysis of Cordia dichotoma, with remarkable seasonal fluctuations in its composition. For instance, analysis by [87] indicated that the bark of Cordia dichotoma is richer in phenolic compounds as well as flavonoids during summer, as compared to the winter season. In another study by [88], the leaves of Cordia dichotoma have higher tannin content as well as saponin content during the monsoon season, as compared to the summer season.

6.1 Conventional Methods (TLC, UV-VIS)

Thin Layer Chromatography (TLC) is a standard procedure for the separation, identification, and quantification of phytochemicals of plant origin [89]. In thin-layer chromatography, a small amount of plant extract is placed on a thin layer of adsorbent material (for example, silica gel or alumina), which is developed using a solvent system. The phytochemicals in the extract move up the adsorbent material at different rates depending on their chemical properties, which leads to their separation and identification. TLC has been used in several studies to assess the phytochemical diversity of Cordia dichotoma. In one such study [90], it was established that flavonoids and tannins of Cordia dichotoma leaves were more abundant during the summer as compared to the winter. Similarly, another study [91] found that the bark of Cordia dichotoma had a greater concentration of alkaloids during the rainy season than in summer.

Another method generally used for phytochemical analysis from plants is UV-visible spectroscopy. By measuring the amount of ultraviolet and visible light that these phytochemicals absorb, one can identify and quantify them [92]. The UV-visible spectroscopy is applied for the analysis of the seasonality of flavonoids and tannins in Cordia dichotoma.

Kumar et al. (2016) discovered, through their study, that flavonoids existed in higher concentrations within the leaves of Cordia dichotoma during the summer than during the winter season. The quantification of the flavonoids was based on the use of UV-VIS spectroscopy, a study that discovered the concentration of such compounds differed considerably throughout the year. Another study by [93] discovered that the bark of Cordia dichotoma contained higher concentrations of tannins during the rainy season than during the summer season.

Besides TLC and UV-VIS spectroscopy, other standard techniques have been employed to examine the phytochemical variation of Cordia dichotoma. For instance, High-Performance Liquid Chromatography (HPLC) was employed by [94] to examine seasonal variation of phenolic acids from the leaves of Cordia dichotoma. The research established that the leaves have higher concentrations of phenolic acids during summer compared to winter.

6.2 Modern Techniques (HPLC, GC-MS, FTIR, LC-MS/MS)

HPLC is a versatile tool that is extensively employed for the separation, identification, and quantitation of phytochemicals from plants. In one research study, HPLC was employed for the examination of seasonal variation of the flavonoid content of Cordia dichotoma [95]. The study revealed that flavonoid content of the plant changed considerably with time, as its highest concentration occurred during the summer season. The reason for such variation of flavonoid content is the variation of environmental factors like temperature, humidity, and sunlight.

GC-MS analyzes widely for phytochemicals present in plants. Sharma et al. utilized the GC-MS technique for volatile compound identification of Cordia dichotoma [96]. The analysis indicated the presence of a variety of volatile compounds such as aldehydes, ketones, and terpenes. The study also revealed that the types of volatile compounds underwent significant

variation throughout the year since there were compounds restricted to some particular seasons only. FTIR is a functional group analysis from plants.

FTIR was employed in a study to assess the differences in chemical composition of Cordia dichotoma with the seasons [97]. The analysis showed the plant has diverse functional groups that are hydroxyl, carbonyl, and carboxyl. The study also established that relative proportion of functional groups varies significantly across seasons, with some groups being present only in particular seasons.

LC-MS/MS is a very sensitive analytical method employed for the identification of the phytochemicals of the plant. LC-MS/MS was employed by Kumar et al. for the study of seasonal variation of the content of phenolic acids of Cordia dichotoma [98]. LC-MS/MS analysis revealed the presence of a diverse array of phenolic acids, such as gallic acid, caffeic acid, as well as ferulic acid, within the plant. LC-MS/MS analysis revealed further that the relative level of such phenolic acids differed considerably during the year, with certain acids being present only for specific seasons.

LC-MS/MS study of the variation of Cordia dichotoma alkaloids by season [99]. Chemically, the plant was found to have very diverse types of alkaloids like nicotine, berberine, and salsoline. There is much difference in the relative abundance of this class of compounds, depending on the season, and certain alkaloids were found during specific seasons only.

Similarly to this, some authors have introduced a combination of approaches in the study of seasonally changing phytochemical composition in Cordia dichotoma. In this respect, Gupta et al. applied HPLC, GC-MS, and FTIR to assess seasonal variation in phytochemicals from leaves, bark, and fruits from the plant [100].

7. Season-Driven Shifts in Pharmacological Efficacy

Multiple reports have affirmed seasonal variations in the phytochemical contents of Cordia dichotoma. For instance, the reports state that the content of flavonoids and phenolic compounds were at their maxima during summer season [101]. This might probably be a consequence of an elevated temperature and sunlight. The alkaloids and terpenoids were increased during winter, indicating a metabolic process which happened due to cold stress [102].

These variations can be attributed to several environmental factors, such as:

- Temperature: An increase in summer temperature should increase the activity levels of the enzymes that synthetize phytochemicals [103].
- Light: Greater exposure of plants to sunlight during summer months initiates photosynthesis, where secondary metabolites are produced in greater quantity [104].

- Soil Moisture: Seasonal changes in precipitation and humidity can directly affect nutrient absorption, influencing phytochemical composition [105].

7.1 Pharmacodynamic and Pharmacokinetic Considerations

One of the essential features commonly overlooked is its seasonally fluctuating chemical composition, significantly influencing both the drug action (pharmacodynamic) as well as the body action on the drug (pharmacokinetic) properties of its extracts. An appreciation of its variable patterns is of primary significance for the optimal realization of the therapeutic potentials of Cordia dichotoma as well as its appropriate, safe usage.

Pharmacodynamic Implications: The Altered Therapeutic Profile

Phytochemical concentrations are variable since they are implicated in the pharmacodynamic activity of Cordia dichotoma extracts. A certain extract with a higher phenolic content would have greater antioxidant activity during the current season, hence ensuring a better therapeutic effect on conditions such as oxidative stress [106]. However, when the concentration of a particular bioactive compound is lower, its therapeutic effect on the target site will also be lower. The greater variability in biological activity and therapeutic efficacy would pose a hazard to conventional herbal medicine. An extract from Cordia dichotoma manufactured during a particular season would have different biological activity and therapeutic value as compared to an extract obtained from a different seasonal crop. This variability predicts the need for strong quality control and standardization of herbal products regarding seasonally induced variation in the chemical composition of the plant [107].

Pharmacokinetic Implications: Absorption, Distribution, Metabolism, and Excretion

Beyond pharmacodynamics, seasonal changes in phytochemical composition and the prevailing introduction of implications for bioavailability and pharmacokinetic properties of Cordia dichotoma extracts [108].

Absorption: Some compounds enhance the absorption of other active compounds. For instance, some saponins may enhance flavonoids' absorption and, to some extent, the absorption of phenolics by enhancing their permeability across the cell membrane [109].

Distribution: Their distribution within the body is a function of their ability to bind to proteins, and that, in turn, depends on other phytochemicals available in the extract [110].

Metabolism: Metabolism of the compounds of Cordia dichotoma may be inhibited or induced by other compounds in the extract. Certain flavonoids may inhibit cytochrome P450 enzymes, thereby affecting the metabolism of other drugs or other phytochemicals in the extract [111].

Excretion: Their excretion depends on their physicochemical properties as well as on their interaction with other compounds in the extract [112].

These parameters are of paramount importance in determining the proper dose and interval of administration of Cordia dichotoma preparations. Phytochemical composition fluctuations by season can lead to variations in bioavailability as well as possibly unpredictable therapeutic effects [113].

7.2 Experimental Studies on Seasonal Extracts

There have been several experimental works aimed at evaluating the seasonal variation of phytochemicals in Cordia dichotoma. In one such study that was published in Journal of Medicinal Plants Research, the phytochemical content of Cordia dichotoma extracts derived from different seasons of the year had been examined by the authors [114]. In their study, the authors identified that the rainy season-obtained extracts had higher total phenol and flavonoid compositions than their summer season- and winter season-obtained counterparts. The authors opined that higher rainfall during the rainy season could have led to the higher phytochemical composition of the extracts [115].

In another research study carried out in the Journal of Ethnopharmacology, the authors examined the antioxidant activity of Cordia dichotoma samples harvested during different seasons [116]. They found that the samples harvested during the summer season possessed the greatest antioxidant activity, followed by samples from the rainy season and winter season. The authors assigned the higher antioxidant activity of the summer samples to greater levels of phenolic acids and flavonoids [117].

8. When to Harvest? Timing Nature for Maximum Benefit

Cordia dichotoma is characterized by a diverse complement of phytochemicals such as flavonoids, tannins, glycosides, and essential oils. The substances have antioxidant, anti-inflammatory, antimicrobial, and anticancer activities [118]. Differences in concentration within the seasons of the year pose interesting issues of optimal time of harvest for optimal therapy.

8.1 Post-harvest Handling and Storage

Studies have shown that concentrations of phytochemicals within Cordia dichotoma change considerably with seasons. These variations are caused by climate, the quality of the soil, as well as plant physiology [119]. For example, research indicates flavonoids have optimal levels during certain seasons of the year, indicating that harvest time is essential [120].

Spring: Nutrient Awakening- In the spring, Cordia dichotoma re-emerges from its dormant state, triggering an increase in its metabolic activity. In the spring season, young leaves and flowers contain flavonoids as well as polyphenols, essential for the growth of the plant as well as for its development [121]. Harvesting in the spring can provide for the highest amounts of such healthy compounds, so spring time is the best time for the collection of young shoots as well as flowers [122].

Summer: Peak Production- The summer season is generally regarded as the peak season for Cordia dichotoma, as the plant is at the peak of its maturity. The production of secondary metabolites such as essential oils and other phytochemicals is highest in this season [123]. Studies have revealed that the fruit of Cordia dichotoma is rich in vitamins as well as minerals during the summer season [124]. Hence, summer is a great season for fruit collection for maximal nutritional as well as therapeutic purposes.

Autumn: Transition Phase- With the approach of autumn, Cordia dichotoma follows a transition phase. The concentration of some phytochemicals, including tannins, could rise as preparation for winter, whereas others could decline [125]. Harvesting is still possible during this time, with the variation of concentration making correct timing essential.

Winter: Dormancy and Reserves- Cordia dichotoma undergoes dormancy during winter, where there is low phytochemical production [126]. Although there are some compounds retained within the tissues of the plant as reserves, quantities will be low as compared to other seasons. Winter is not a recommended time for harvest, especially where the intention is to collect the highest content of phytochemicals [127].

8.2 Seasonal Harvesting Strategies

For best harvesting, some best practices have to be followed:

- **Timing**: Aim to harvest in late spring to early summer when phytochemical concentrations are at their peak [128].
- **Selective Harvesting**: Harvesting of young leaves, flowers, and ripe fruit is emphasized so as to retain the highest concentrations of desirable compounds [129].
- **Environmental factors**: Observe the local climatic conditions, as temperature and rainfall fluctuations can affect phytochemical production [130].
- **Sustainable Practices**: Adopt sustainable harvesting techniques to ensure the longevity of Cordia dichotoma populations and preserve their ecological role [130].

9. Bridging Knowledge Gaps: Challenges in Seasonal Phytochemistry

The study of seasonal variations in phytochemistry of the plant Cordia dichotoma has some challenges. It involves, among others, consistent long-term collection of data. The phytochemical analysis is extensive, not only time-consuming but also capital extensive because of the equipment and expertise required. Most of the experiments are, therefore, focusing on one point in time or some seasons to draw any yearly trends.

Another challenge relates to the complexity of interactions that phytochemicals engage into with each other. They are not known to be mere independent entities themselves in the plant, but occur as complex biological compounds within the plant. Besides, these naturally interacting compounds themselves and others within the tissues of a plant. The above-

mentioned processes can influence the production, stability, and bioavailability of individual phytochemicals by isolating and analyzing the seasonally induced variation [131].

A common method, therefore, is required in phytochemical research as well as reporting. Data comparison among studies would also be difficult in the absence of a common method for data collection, analysis, and reporting and so will the generalizations then concerning phytochemical variation by season.

9.1 Inconsistencies in Literature

To meet such challenges, several possible avenues for future research could be pursued. First, long-term, multisite research on Cordia dichotoma and other useful medicinal plants would be needed. Such studies must allow the simultaneous generation of standardized and consistent information with respect to the phytochemical content and concentration and should be done on a yearly basis. Secondly, further research is required on the phytochemical interactions with other chemicals in the plant. Seasonal variations in phytochemical profiles could be investigated through the mechanism of synergistic, antagonistic, additive, or indirect interactions with other vascular plant chemicals to optimize production and extraction of those compounds [132]. Thirdly, it is important to adopt standardized methods and reporting protocols for phytochemical studies. In this way, comparisons can be made across studies that would help discern broader trends towards seasonal phytochemical variation [133].

10. Toward Precision Herbalism: Standardization and Future Prospects

Precision herbalism is any treatment modality whereby the individualized application of herbal medications is based on the unique phytochemical content of the raw plant material. It is further acknowledged by precision herbalism that not just bioactivity, but also safety and efficacy of herbal products depend upon the phytochemical matrix [134]. In other words, when evaluating Cordia dichotoma from a precision herbalism perspective, much attention is directed toward the perfect timings of harvest, choice of parts of the plant with specific phytochemical profiles, and the standardization of extraction methods for guaranteed quality of the product.

10.1 Determinants of Phytochemical Variation

There are many factors accounting for the changes in seasonal variation of phytochemical composition of Cordia dichotoma.

Environmental Influence: Temperature, rainfall, and soil are the main forces behind the variation of phytochemicals. For example, high temperatures could increase the enzymatic activities leading to the degradation of some phytochemicals whereas low temperature would reduce metabolic activity causing accumulation of some compounds [135].

Photoperiod: Duration of exposure to daylight may influence biosynthesis about phytochemicals production. For instance, it is established that the flavonoid production of

Cordia dichotoma is directly correlated with the length of the photoperiod, with greater flavonoid content being produced during the long days of summer [136].

Soil Nutrients: Soil nutrients, including nitrogen, phosphorus, and potassium, can influence the phytochemical status of the plant. For instance, deficiency of nitrogen has been correlated with elevated production of alkaloids by some plant species, though the correlation depends on the plant species as well as the prevailing environmental conditions [137].

Pests and diseases: The pest and disease infestation can further affect the phytochemical content of Cordia dichotoma. For instance, stressed plants due to attack by insects or fungal infestation might have elevated levels of defense compounds like terpenoids, and phenolic acids [138].

10.2 Future Prospects

The prospects of Cordia dichotoma as a herbal product look bright with its complete value being realized by multi-disciplinary research. Its research and development opportunities lie on the following fields:

Advanced Analytical Techniques: Application of advanced analytical techniques, including metabolomics and chemometrics, can be made for the unraveling of phytochemical diversity of Cordia dichotoma as well as its reaction to environmental stimuli. Machine learning can be used for phytochemical variation prediction based on environmental information, allowing identification of the best time for harvest, as well as extraction procedure.

Sustaining practices: Sustaining practices provide for the long-term inventory availability of Cordia dichotoma as a medicinal plant. Sustaining practices involve the implementation of agroforestry practices, the maintenance of wild populations, as well as cultivation regimes that have low impacts on the environment.

Video: There is a need for clinical trials for determining the safety and efficacy of herbal products of Cordia dichotoma. These need to be designed taking into account the phytochemical richness of the plant material as well as the effect of such richness on the bioactivity of the products.

Precision Medicine: Precision medicine provides new possibilities for individualized application of herbal products according to the patient needs. For Cordia dichotoma, precision medicine can include choosing a focused phytochemical pattern for the therapy of targeted diseases, as well as individualized dosing regimen adjustment depending on individual pharmacokinetic and pharmacodynamic characteristics.

Collaboration of different disciplines: Interdisciplinary cooperation is needed for constant refinement of precision herbalism. This includes cooperation between botanists, chemists,

pharmacologists, and clinicians for acquisition of complete appreciation of phytochemical diversity of Cordia dichotoma as well as its medicinal qualities [140].

10.3 Regulatory Implications and Pharmacopoeial Standards

Pharmacopoeias like the Indian Pharmacopoeia (IP), British Pharmacopoeia (BP), and United States Pharmacopeia (USP) established standards for quality, purity, and strength of drugs. The need to include certain criteria regarding Cordia dichotoma among the provisions of the above pharmacopoeias is required to address the problem of seasonality. The most important aspects that must be considered are:

Standardized Extraction Procedures: Standardized extraction procedures should be drawn up, keeping in view seasonal variance of phytochemical levels and maximizing extraction of bioactive compounds letting aside the harvest seasons [141].

Marker Compounds Quantification: Identification and quantification of relevant marker compounds (like specific phytochemicals characterizing Cordia dichotoma) with relatively stable seasonal levels or improvable for seasonal fluctuation will be also critical for quality control [142].

Acceptable Variation Ranges of Phytochemical Content: Acceptable ranges of the marker compounds with regard to their level from season to season will allow for more standardized uniformity in the final product by therapeutic efficacy [143].

Guidelines for Seasonal Harvesting: Finally, setting guidelines for the best time of year under harvest based on the desired composition of the target phytochemicals may help achieve less variation and a better therapeutic value [144].

Geographical parameters: Geographical location has the effect on phytochemistry, so considering geographical as well as seasonal variations is equally essential for the total standardizations [145].

11. Summing Up: Integrating Nature, Science, and Tradition

The Cordia dichotoma, being one of those trees with a broad distribution across diverse habitats, is used traditionally both medicinally as well as for food. Despite its utility, seasonally fluctuating levels of its bioactive compounds are a limiting factor for its constant usage. Finding the reasons behind such fluctuations involves observation of nature, scientific studies followed by exhaustive research, as well as the immense pool of traditionally gained knowledge on the plant.

The multi-faceted season-dependent phytochemical composition of Cordia dichotoma is scrutinized here. It highlights the need for considering environmental cues such as temperature, rainfall, as well as photoperiod as potential regulators of synthesis as well as accumulation of

compounds. It demands the application of advanced analysis techniques for accurate quantification as well as identification of the diverse repertoire of phytochemicals by parts of the plant, by seasons.

The inclusion of native knowledge offers rich insight into the dynamics of the plant as well as its optimal time of collection. Local people have a heightened consciousness of the lifecycle of the plant as well as the time of year the respective parts of the plant enjoy their optimal medicinal or nutritional value. Integrating such information of a traditional nature with scientific information, scientists will be able to formulate new, sustainable, as well as efficient, ways of utilizing Cordia dichotoma for productive purposes.

In the long run, Cordia dichotoma seasonally based phytochemical distribution secrets call for a multileveled approach. It includes ecological studies, phytochemical profiling, pharmacological evaluations, as well as ethnobotanical studies. By bringing all of these varied insights together methodically, it is possible for us to harness the full capabilities of the plant as a resource so that it can be used sustainably for generations.

11.1 Summary of Key Findings

The research, aptly named "Unraveling the Mysteries of Cordia dichotoma's Seasonal Phytochemical Variation," extensively examined the phytochemicals of the plant all year round, where striking fluctuations in its concentrations of essential bioactive compounds have been discovered. Examining seasonal changes is crucial for understanding how such natural substances drive the medicinal efficacy of Cordia dichotoma. This study thus reveals the following important findings:

- **Peak Yield Phytochemical**: The research has further made an attempt to identify the periods within the season where phytochemical contents of some medicinal compounds such as the research study were carried out on the most abundant flavonoids, phenolics, and alkaloids. Such definitions of peak seasons would enable one to time the harvest and thus selective cultivation of the raw materials with the maximum therapeutic activity.
- **Environmental Aspect:** The study revealed an evident relationship between the environment, temperature, rainfall, and exposure to sunlight with respect to the production of their phytochemicals. This shows that such environmental stimuli elicit certain pathways of metabolism in the plant, which in turn regulate the synthesis and accumulation of the particular compounds produced.
- **Specific Use:** By knowing the seasons of optimum amounts of individual phytochemicals, scientists can now find specific applications of the plant. For example, if it is found that a particular flavonoid is predominant during the summer, then a plant may be harvested in summer and best suited for manufacturing flavonoid-based medicines for therapeutic or commercial cosmetics purposes.
- **Sustained Harvest:** Sustained harvesting is designed through research to inform the collectors when it is best in the year to remove the plant materials sustainably so that

there will be a continued supply of Cordia dichotoma and reduce the over-exploitation part.

- **The implications of the study are vast.** By determining how the chemical makeup of Cordia dichotoma is seasonal, we can:
- **Process Improvement**: Design optimal phytochemical extraction processes for individual phytochemical separation based on how long they are available, developing the most cost-effective process.
- **Maximizing therapeutic efficacy**: Harvest plant material where phytochemical yields are maximal for the production of extremely potent, highly effective herbal drugs.
- **Practice sustainability**: Implement sustainable cultivation practices that conserve populations of Cordia dichotoma so that generations can have access to the plant.

12. Conclusion

In summary, demystifying the secrets of season-to-season phytochemical variation of Cordia dichotoma is not merely an intellectual exercise. It is an essential step towards the realization of the therapeutic value of the medicinal plant. In developing optimal harvesting processes, standardization of herbal products, and the manipulation of cultivation methods for maximizing production of desirable active ingredients, we can refine our knowledge of how environmental factors affect the production of bioactive compounds. This study opens the way for a wiser, sustainable, and efficient utilization of Cordia dichotoma by traditional as well as modern medicine, for the benefit of human well-being and health. Further studies aimed at determining how specific genes control the synthesis of the critical phytochemicals as well as their intricate interactions with the surrounding environment will undoubtedly realize even further potential in the years to come.

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