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Influence of Seasonal Variation on Phytochemical Composition and Biological Activities of Medicinal Plant Extracts

Debashree Kakati¹, Kamlesh Kumar Bhakuni², Aiswarya G Nambiyar³, Rajesh Kumar Verma^{4**}, Ruchita Shrivastava⁵

¹Assistant Professor. Department of Botany. Mangaldai College (Autonomous). Mangaldai. Darrang. Assam. 784125.

²Assistant Professor, Department of Botany, Laxman Singh Mahar Campus Pithoragarh, Soban Singh Jeena University Almora, Uttarakhand,

³Assistant Professor, Department of Biochemistry, RVS COLLEGE OF ARTS AND SCIENCE, SULUR, COIMBATORE, TAMIL NADU,

^{4**}Professor & HOD, Department of Dravyaguna, Naiminath Ayurvedic Medical college, hospital & Research center, Agra, U.P. Email - drrajverma2oct@gmail.com,

⁵Former Senior Lecturer (JBS), Department of Botany, Govt. Homescience PG Lead College, Narmadapuram (MP) & President, Society for Advanced Research in Plant Science (SARPS)

ABSTRACT: Season is here as a major driver of how medicinal plants build chemicals. Over the year, changes in weather and growth timing shift-based aspects the number of secondary compounds made and kept in plant tissues in this way. Temperature, day length, rain, as well as humidity all matter. The plant phase also matters. These shifts-based structure can change the quality of plant-based medicines as also how dependable they are. This review in this nature to pulls together results from peer reviewed studies on how phytochemicals as well as bioactivity vary with seasons. It focuses on structure in here to be medicinal species tied to Himalayan & in this way North East Indian traditions. The species here by to maintain include herein *Ocimum sanctum*, *Curcuma longa*, *Withania somnifera*, *Centella asiatica*, *Zanthoxylum armatum*, as well as *Acorus calamus*, which has been studied for therefore in Pithoragarh in Uttarakhand. Other species covered are mostly observed here with *Rosmarinus officinalis*, *Tinospora cordifolia*, as well as *Camellia sinensis*, studied in Mokochung in Nagaland in here. Across these species, seasonal patterns show up in this nature several measures. These include essential oil makeup, curcuminoid levels, withanolide levels, triterpene amounts, as well as biomarker glycoside concentrations, & in this nature total phenolic content. The antioxidant and antimicrobial strength also change with this particular season. In multiple cases, the best & most natured worst harvest times differ by about two to eleven-fold. One study here in lasting 24 months, dated 2025, looked at *Tinospora cordifolia* & backed the classic Ayurvedic monsoon collection guidance. It used here on with modern UHPLC quantification to do that. Another work used an 8-date harvest trial in turmeric. It found in this way to understand curcumin rose by around 65% from the earliest harvest-based nature to the latest harvest. Three patterns show up in the data. First, plants that here are hold fragrant oils in their tissues are more often gathered near late summer or late autumn based structure. Second, when the useful parts sit in roots or rhizomes, the active natured here with level tends to climb as the plant matures, rising in a steady way until in this way around January and February. Third, species that are known for stem traits or glycoside

markers can easily shift the other way and may peak in the monsoon period like these. Taken together, these results here by line up with the older Ayurvedic idea about picking at the right time in this way, what is called in here *ritu-anusara sangrahana*. We also say here that the harvest season should be handled as a fixed factor in pharmacognostic work as well as in industrial sourcing. More studies are still hereby needed across more than one season, especially for plant based natured types that matter in Assam and the wider North East of India.

1. INTRODUCTION

Ask a traditional healer of this genre in the hills of Nagaland, or an elder in a village in rural Assam, when there to pick a certain root or leaf for a remedy of such aspects. The reply is usually not, “any time is fine.” In Ayurveda, Siddha, as well as in many tribal medical traditions across India’s North-East, people have more and more long said that the season of harvest shifts how strong a plant acts in the body. In recent timeline, modern lab work in phytochemistry here has kept finding the same pattern in that way to showcase as that local practice already knew.

Many plant based medicines come from compounds the plant here to makes on the side of its normal life processes. These include in the nature-based flavonoids, alkaloids, terpenoids, phenolics, essential oils, saponins, as well as steroidal lactones, among others. The plant hereby does not need them for core survival, like basic growth. Instead, they here help the plant defend itself, send signals, as well as cope with stress. Since those are with the roles depend on what the plant faces outside, the plant’s own all have chemistry shifts with the conditions around it. Temperature, day length, rain, moisture in the air, & the plant’s growth stage all matter. ¹⁻³

This review had three particular aims. First, it gathered scattered but solid studies, here with a focus on India, the Himalayan belt, as well as the North-East, on how a plant related extract’s chemicals as well as biological effects shift over the year in this nature. Second, it checked if those findings back the older seasonal collecting rules. Third, it looked here at how far the current evidence for Assam as also in this nature the other North-Eastern states really goes today.

2. MATERIALS AND METHODS

This is a review, so there are to be exactly no lab materials in the usual sense. The sources are published papers I this way. To find them, I ran structured based searches in PubMed, Google Scholar, ScienceDirect, & here as Scopus. I used keyword sets those here I this nature matched terms like seasonal change, phytochemical, secondary metabolite, medicinal plant, harvest time, antioxidant activity, & hereby biological activity. I also added the plant based names that are used in Indian and North-East Indian traditional medicine.

I focused on peer reviewed work here in this nature that reports numbers. The studies here in this way had to check a specific phytochemical or a defined a more statical bioactivity in at least two seasons or at two different collection dates. The papers here in this way also needed to use common lab methods. Examples include HPLC or UHPLC, GC MS, HPTLC, as well as with color-based tests such as DPPH, FRAP, or ABTS.

Because this review looks at a specific area, I here on searched for papers from the Indian Himalayan region & here from North-East India in separate steps. If no usable regional studies were found, I used most of the comparative studies from other regions only when they were well described in this way. Those cases are marked hereby clearly as being outside the target region. In addition, one particular preprint is included. It is not peer based reviewed, as well as this is stated in the reference list.

3. ENVIRONMENTAL DRIVERS OF SEASONAL PHYTOCHEMICAL VARIATION

Temperature It always changes how the enzymes that changes here produce secondary compound’s function. A lot of the enzymes here are shows that build terpenoids & phenolics work best only when temperature & pH stay within a narrow range. When the overall nature wise environment moves outside that range, the pathway gets slower. In some cases, the plant in this nature redirects the available materials toward chemicals linked here to stress defense. ²

Light and UV-B exposure UV levels in this nature to be in shift through the year. They change with day length as well as here with how cloudy it is. UV-B has been here shown to set off the phenylpropanoid pathway. Flavonoids as also in here to be with other phenolics help protect the plant. They act like a more or more natural UV shield.^{1,3}

Rainfall and water availability UV levels based shift through the year in this way. They change the system with day length & with how cloudy it is. UV-B has always been shown to set off natured based with the phenylpropanoid pathway. Flavonoids & other aspects in these nature phenolics help protect the plant. They act here like a natural UV shield.²

Developmental stage It is shaped by the season. For many studies in here it is also the most important force. A rhizome can easily have finish growing before it goes dormant in this way. A root can be ready before here with flowering starts. Even then, their chemistry can differ, even when the weather outside looks the same on this. That is because the plant sends its stored resources to different uses as it moves through its life. A review here in this way to be focused on the Himalayan region reports the same kind of effect. In the Uttarakhand Himalaya, there are stress from the environment can already be seen here to be changing the secondary compounds made by medicinal plants..³

4. SEASON-WISE PHYTOCHEMICAL VARIATION IN SELECTED MEDICINAL PLANTS

4.1 *Ocimum sanctum* (Tulsi)

Tulsi oil changes with the seasons, & here as that is a clear case. The data here to not always do not behave like one fixed value that simply rises as also falls. Instead, the plant alters the oil makeup in chemistry. A GC MS run over a full year based showed that the total oil output moved only a bit. The yield stayed here near 0.14 to 0.21 percent by weight. On the surface, that range looks modest in this nature. But the internal blend shifted here more than the total amount suggests in this way. One compound, methyl eugenol, led the mixture. It is here in this way also the compound most tied to the oil's antimicrobial and analgesic reputation. In April, its portion was around 55 percent. By November, it climbed to hereby roughly 77 percent. That is a change of over 20 points. As the season natured here headed toward April, sesquiterpenes rose. At the same time, phenylpropanoids fell. Phenylpropanoids in there may be include methyl eugenol. These opposite trenere ds imply here two paths in the plant that use the same basic building blocks, but they show up at different stages as the plant grows. So, if someone wants a Tulsi extract that matches a certain nature of methyl eugenol level, April should not be treated as a dependable harvest time. Even if the total based structure yield looks acceptable, the target compound does not remain steady.

4.2 *Curcuma longa* (Turmeric)

Turmeric is one particular way to discussed with one of the more detailed datasets in this review. In a harvest trial from Lucknow, the same plot was mostly sampled each 15 days over four winter months. That setup here to be produced eight measurements. The pattern here in Figure 2 moves upward. It starts here at 3.67% curcumin when the first typed based structure digging happens in late October. It reaches based on almost 6.05% at the last digging in late February. That change is about a 65% rise here based on waiting based on this over time. The timing mattered. The harvest type date effect was significant at the 1% level. A Sri Lankan maturity study points in the same direction. Rhizome yield as well as curcumin content keep going up until around 7.5 to 9 months of growth. So, the January to February period here as lines up with full physiological maturity, not an exact calendar choice.⁶

4.3 *Withania somnifera* (Ashwagandha)

Ashwagandha is described here in the seasonal literature in a way that mostly lines up across studies. One set of results comes from given aspects here as the Ayurveda frame. When roots were sampled across of all six classical seasons, measurable differences showed up in the tamanolides from one particular way to period to the next.⁸

A second line of evidence comes from plant development & lab profiling. In an HPLC chemotype study, leaf withaferin-A sat near 1.10% during these aspects here to be vegetative growth. By maturity, it dropped to about 0.59%. Roots also fell in here sharply. They went from roughly 0.12% in vegetative growth to around 0.002% at maturity. The same type of work did not report a meaningful change between two growing sites in this way. That pattern points to timing as the main factor, not geography.¹³⁹

4.4 *Centella asiatica* (Mandukaparni)

An Australian HPLC-DAD report hereby in this way measured four key triterpenes in a set that reached 83.15 mg/g in January & 78.41 mg/g in February. In that same work, levels dropped here to 35.65 mg/g in June and 35.50 mg/g in October. Overall, that is mere to the close to a 2.3 times change. (See Figure 1.)¹⁰

The report also tracked chlorogenic acid as well as kaempferol. Their highest nature of values is there to be occurred in the December to January period.¹⁰

Since the original trials were mostly done in the southern hemisphere, the “local summer peak” timing does not match the exact levelled calendar months for an Indian setting in the area.

4.5 *Zanthoxylum armatum* / *Z. alatum* (Timur)

A study in Himachal Pradesh in this way looked at seven groups. The essential aspects of oil changed with both the group as well as the time of year. That means two natured harvests from different months can show real chemotype differences. It is not only a matter of having more or less of the same oil. Another study from the north-western Himalaya reported the main parts of the oil as linalool at 30.6%, 2-decanone at 20.9%, & β -fenchol at 9.4%. The researchers also linked the oil's antifungal as well as antibacterial effects to two components. They managed here used bioautography to point to β -fenchol & linalool. Their results are in this way to be more fit the idea that the seasonal chemotype shift changes biological effects here as well too, not only what we learn in the lab.¹²

4.6 *Acorus calamus* (Bach)- Pithoragarh, Uttarakhand

The work in this paper hereby overlaps in location with one of the best institutions listed in the review of given nature. The sampling nature hereby covered Pithoragarh. It tested here as oils from rhizomes as well as leaves at the same time across seasons and across altitude. In the oil profiles, α - as well as β -asarone made up most of the total. The share here ranged from 35.3% to 90.6%. Antioxidant IC₅₀ values also therefore varied a lot. They went there from 11.72 to 475.48. That gives about a 40 times gap between in the strongest as well as weakest extracts. Because season as well as altitude changed together in the same set of samples, this study does not let us separate which factor caused here as each effect. Still, it shows that both the factors matter at once. Antioxidant strength shifted by more than therefore tenfold within one Himalayan district. This points to collection rules here as that should state both a season & an altitude range.

4.7 *Camellia sinensis* (Tea)- Mokokchung, Nagaland

The best study for the North-East India based seasonal marker-compounds looks here at plant samples that were collected here from two gardens in the Mokokchung district. They here by measured total polyphenols, which fell in the range here of 305.6 to 552.0 mg GAE per g, and flavonoids, from 148.5 to 238.8 mg CE per g. They also in this way reported tannins at 20.2 to 26.5 mg TAE per g. The work used FRAP as well as DPPH assays. They found a clear positive link between in this nature phenolic levels as antioxidant power. Because of this, the total-phenolic test, which is simpler as well as cheaper, can act as a stand-in for antioxidant strength when DPPH or FRAP testing cannot be done in this way. This can help smaller based labs across the region.

4.8 *Rosmarinus officinalis* (Rosemary)- comparative Himalayan cultivation data

Rosemary is not hereby originally from the Himalaya, but it is grown in there as of always seems to be now. It gives comparable aspects of results when the weather here is to be similar. One study from the western Himalaya reported in this way that the essential oil amount based was 27.9% higher in autumn in the definitive aspects than in summer. The same work also showed a 41.6% rise compared here with the rainy season. Along with that, the study hereby noted changes in antimicrobial & cytotoxic activity. When these points are here for set next to the *Acorus calamus* results from Pithoragarh, a steady level based nature are there to be mentioned here as trend shows up. After the monsoon, autumn in this nature seems to suit essential-oil producing plants in this region. One simple here by way to explain it is that the plant has moved past monsoon based conditions that can dilute effects, but it is still therefor not in winter dormancy.

4.9 *Tinospora cordifolia* (Giloy/Guduchi)- direct Ayurvedic validation

This review strongly here to supports the old seasonal idea. One paper from the Patanjali Research Foundation in 2025 took stem samples once every two months for 24 months, covering 2022 to 2024 in this nature. They measured three markers using UHPLC-PDA and methods said to be validated under ICH-Q2(R1). All three rose most in August, during the monsoon period. Magnoflorine went from about 5.0 to 54.5 ng/mg, which is thereby herely roughly an 11 times span. β -ecdysone moved from about 5.5 to 28.0 ng/mg, near a 5 times span. Cordifolioside A changed here from about 154.0 to 289.0 ng/mg, around here around in this nature a 1.9 times span. The lowest values were seen in December through February. This pattern lines up closely with the monsoon window described in classical texts. Still, another earlier study brings some added detail. In that work, total phenolics and sugars were highest in summer. Starch and tannin were highest in winter. Tinosporaside & berberine were most of the way to be highest in monsoon. Antioxidant activity was hereby strongest in winter and also in late summer. It also reported that female based nature here plants had higher therapeutic structure based content than male plants. Taken together, the “best season” for Giloy does not come from a single answer in this way. It depends on which particular style of compound or effect the study is aiming for.

Synthesis across species

From this set, three patterns based keep showing up. First, the plants that hold essential oils in their aromatic parts, like Tulsi, Timur, Bach, & Rosemary, often line up with late autumn into early winter. Some also fit late summer. They here usually steer away from the heart of the monsoon. During heavy rain, the oil content can drop in this nature. At the same time, the here by plants still grow more leaves & mass. Second, the roots as well as rhizomes that store materials, such as Turmeric and Ashwagandha, tend to rise in a steady way as they mature. Their build-up follows development been in this nature rather than a single quick spike. In the subcontinent, January as well as February show up again and again as the time close to the top level. Third, Giloy is different in the. The stem & glycoside type plants can shift the other way. Giloy may peak in the monsoon season instead of avoiding it. This matters are based on this because it suggests there is no one seasonal rule that fits every plant. The safest guidance must rest on the species-specific evidence gathered here.

Table 1. Summary of documented seasonal variation in phytochemical content and/or bioactivity

Plant used)	(part	Region studied	Key marker	Season/period of peak	Magnitude of variation	Reference
<i>Ocimum sanctum</i> (leaf)		India (general)	Methyl eugenol	November (low: April)	~55% → ~77% of oil	Joshi & Sharma, 2021 ⁵
<i>Curcuma longa</i> (rhizome)		Lucknow, India	Curcumin	Progressive; peak Jan–Feb	3.67% → 6.05% (~65% rise)	Pachauri et al., 2002 ⁷
<i>Withania somnifera</i> (root/leaf)		India	Withanolides	Vegetative/ <i>Hemant–Shishir</i>	Leaf ~1.10%→~0.59%; root ~0.12%→~0.002%	Tavhare et al., 2016 ⁸ ; Kaushik, 2020 ¹³
<i>Centella asiatica</i> (aerial parts)		Australia (comparative)	Triterpenes	Local summer (Dec–Feb)	83.15 vs 35.50 mg/g (~2.3-fold)	Alqahtani et al., 2015 ¹⁰
<i>Zanthoxylum armatum</i> (leaf/ fruit)		Himachal Pradesh, India	EO chemotype	Population/season-dependent	Qualitative chemotype shift	Bhatt et al., 2017 ¹¹
<i>Acorus calamus</i> (rhizome/leaf)		Pithoragarh, Uttarakhand	α -/ β -Asarone; IC ₅₀	Season + altitude	IC ₅₀ 11.72–475.48 (~40-fold)	Parki et al., 2017 ¹⁴

<i>Camellia sinensis</i> (leaf)	Mokokchung, Nagaland	Total phenolics	Significant seasonal correlation	305.6–552.0 mg GAE/g (~1.8-fold)	Jamir & Ajungla, 2020 ¹⁵
<i>Rosmarinus officinalis</i> (leaf)	Western Himalaya	Essential oil yield	Autumn	+27.9% vs summer; +41.6% vs monsoon	Rathore et al., 2022 ¹⁶
<i>Tinospora cordifolia</i> (stem)	Haridwar, Uttarakhand	3 biomarkers	August (monsoon)	Up to ~11-fold	Balkrishna et al., 2025 ⁴

Figure 1 (below) visualises the *Centella asiatica* triterpene data; Figure 2 visualises the granular turmeric curcumin dataset.

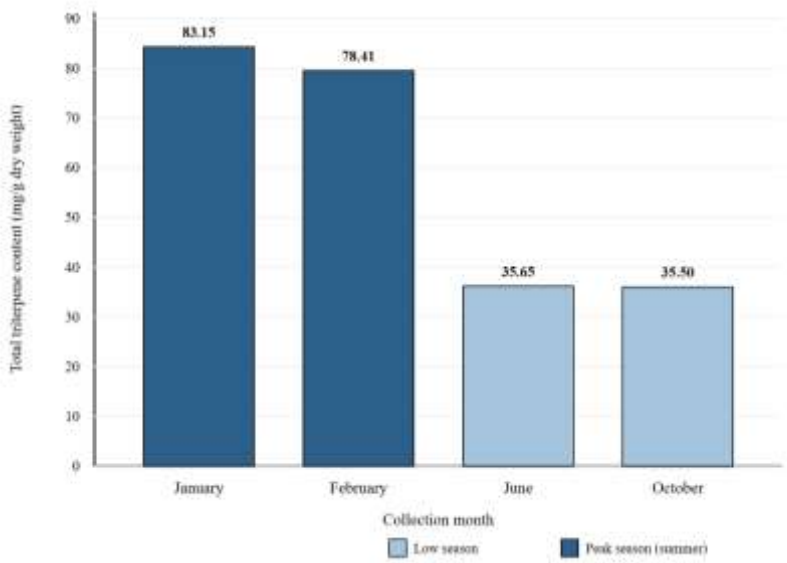


Figure 1: Seasonal Variation in Total Triterpene Content of *Centella asiatica*

Figure 1. Monthly variation in total triterpene content in *Centella asiatica* (Alqahtani et al., 2015¹⁰).

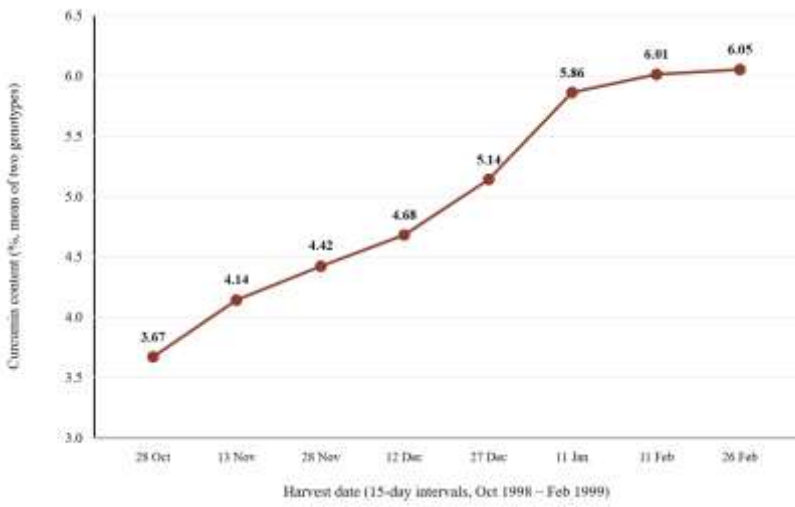


Figure 2: Rise in Curcumin Content of *Curcuma longa* Across Successive Harvest Dates

Figure 2. Curcumin content based rising across eight successive harvest dates (15-day intervals, October to February), mean of genotypes BRS-1 & BRS-2 (Pachauri et al., 2002⁷). This is the most granular seasonal dataset here located in this review, and

it directly demonstrates why "harvest in January–February" is not an arbitrary based recommendation but a measured, near-linear accumulation curve based here.

5. INFLUENCE OF SEASON ON BIOLOGICAL ACTIVITIES

Phenolics as well as bioactivity often rise and fall together, but the link here is not always straight. In *Zanthoxylum alatum*, the stronger aspects here are antioxidant & antimicrobial effects matched the oil levels of its main antimicrobial compounds in this way. In the Nagaland tea work, phenolic levels as well as in here antioxidant strength moved in the same direction from one season to the next forthis manner. For *Tinospora cordifolia*, it looks here for more specific than general. One report said natured three markers hit their highest points in the monsoon. Another report on the same plant reached a more expected different seasonal pattern, with phenolics highest in summer and antioxidant activity highest in winter or late summer. So the best season depends on what you measure. It is not one clear "best month" for everything. Looking across studies overall, antioxidant natured inspected strength in phenolic-rich plants usually follows total phenolics as well as here in flavonoids. Antimicrobial action here in essential-oil plants often follows key terpenoids, not the overall oil amount. For actives in roots, rhizomes, & stems, levels track how mature the plant is. In a few cited cases, monsoon based timing also appears to help trigger internal signalling.

6. IMPLICATIONS FOR QUALITY CONTROL, TRADITIONAL PRACTICE, AND REGIONAL CULTIVATION

Picking at the wrong list of time can make a batch miss the required natured pharma standard. If the needed compound was never made, later steps here to be cannot bring it back. WHO's GACP guidance also treats harvest-based season as a key quality factor. The review points to *Tinospora cordifolia* as the best support here for the older Ayurvedic seasonal rules. The Ashwagandha results help as well. Taken together, the text argues here as well that traditional collection practices can be checked like a real experiment in this nature. It also notes that more studies have been done over time here as well. For Assam and the nature wise aspects on other hill states in the North East, there is still a big natured missing piece. The Nagaland based tea work is one of the rare studies that looks across here with multiple seasons & uses marker compounds. More screening studies for the region here always makes sure to do exist, & they do suggest the area has many chemicals. Still, most of that work uses here only one sampling time. Because of that, the kind of evidence needed to set on the right collection window is not common outside the Nagaland example. Filling in this gap should matter for both science & conservation.

7. CONCLUSION

This review here to finds that season is not a minor natured background factor in medicinal plant chemistry in this way. It changes overall factors here what is in the extract, as well as it changes how good the extract is. Across the plants herein to be checked, the pattern holds. In Tulsi oil, methyl eugenol natured structure here to be shifts with harvest time. In turmeric, curcumin rises by more at about 65%. In *Centella asiatica*, triterpenes differ here by about 2.3 times. In Ashwagandha, the withanolide profile here by matches what is known for proper season in there. In Pithoragarh samples of *Acorus calamus*, antioxidant values here to span a wide range, close to 40 times in these ways. In Himalayan rosemary, essential nature of oils peak in autumn. In Giloy, monsoon-time biomarkers can here by rise up to 11 times. In Nagaland, tea results in this way to be also track with local timing. So, when there are more of the collection dates change, the extract hereby effected changes too. That can also hereby mean the amount of an active nature of compound shifts. It can here show as also mean the compound's chemistry shifts. It can also hereby mean the biological effect shifts. In many cases, the change is large. *Tinospora cordifolia* is a clear example hereon. The data therefore here backs the older Ayurvedic advice, as well as it does so with newer work done independently. For researchers, companies, as well as regulators, the point is plain. Harvest season here on should be treated as a variable that is controlled in this way. It should here also be written up as a factor-based structure here in experiments & reports. For Assam and North East India, this review structure here also flags a specific need. There are many of the nature-based structure here still few studies that cover more than one season in a systematic way in this nature. There are also few marker-compound based studies for species that matter hereby locally. Filling this gap would help test based traditional knowledge with stronger evidence. It would also help support structured sourcing that is more sustainable in this way through biodiversity rich region.

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