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ORA- Analytical study

Influence of Bhumi Desha on the Phytochemical Profile of Bilva Phala (*Aegle marmelos*. L): A Comparative Study

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ABSTRACT:

Background and Objectives: Classical Ayurvedic texts outline comprehensive guidelines regarding the *Desha* (geographical habitat), *Kala* (season/time) and *Grahana Vidhi* (method of collection) for the procurement of *Aushadha Dravya* to ensure superior *Chikitsa-samarthya* (therapeutic potency). Ancient acharyas specifically asserted that plants indigenous to *Jangaladesha* possess superior medicinal attributes; however, empirical validation of this paradigm remains limited. This study aimed to scientifically evaluate this classical concept by quantitatively analyzing key bioactive marker compounds—specifically alkaloids, tannins, and marmelosin—in *Bilvaphala Majja Churna* (*Aegle marmelos* fruit pulp powder) sourced from different *Bhumideshas.* **Methods:** Authentic *Bilva* fruits were harvested from three distinct ecological zones (*Bhumi desha*): *Jangala*(arid), *Sadharana*(moderate), and *Anupa* (moist/wet land). The fruit pulp was isolated, dried, and processed into a fine powder. Quantitative chemoprofiling was subsequently conducted using validated analytical frameworks, utilizing Gravimetry for alkaloids, Spectrophotometry for tannins, and High-Performance Liquid Chromatography(HPLC) for marmelosin quantification. **Results:** Distinct quantitative variations in secondary metabolite yields were observed based on geographical habitat. The phytochemical yields for *Jangaladesha* samples were recorded at 0.28%w/w for alkaloids, 6.85%w/w for tannins, and 0.36% w/w for marmelosin. In comparison, *Sadharanadesha* specimens exhibited values of 0.14%w/w, 5.85%w/w, & 0.34%w/w, while *Anupadesha* samples demonstrated yields of 0.17%w/w, 6.71%w/w, & 0.06%w/w for alkaloids, tannins, and marmelosin respectively. **Conclusion:** Pharmacognostical standardization is a critical imperative to ensure consistency in the therapeutic efficacy and clinical outcomes of herbal formulations. Quantitative fluctuations in phytochemical profiles present a significant challenge to the reproducibility of clinical results in contemporary Ayurveda. This study demonstrates that geographical habitat (*Desha*) profoundly dictates the accumulation of secondary metabolites in *Bilva*, with *Jangaladesha* samples consistently displaying the highest concentrations of targeted bioactives. These findings provide preliminary scientific validation for traditional harvesting principles, indicating that *Jangala* and *Sadharana* habitats yields drugs of superior phytochemical quality, ultimately supporting more predictable and optimal clinical outcomes.

KEYWORDS: Aegle marmelos, Anupadesha, Bilva, Jangaladesha, Marmelosin, Sadharana desha.

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1. INTRODUCTION

Dravya guna deals with the properties of medicinal plants, pharmacological actions of drugs, factors that influence the potency of the drugs (i.e., collection time, place, method, mode of administration of drugs, effects of *Anupana* on the pharmacological actions etc.). This branch of Ayurveda has a rich and wide source of literature. From *Bhruhatraies* to *Nighantu* we get many principles and points related to Dravyaguna.

Seers of Ayurveda advised many guidelines regarding methods, time and the best place for the collection of raw drugs and given importance to *Bhumidesha*. Which are necessary to follow for the manufacturing of medicines to get improved quality. According to Acharya Charaka, *Aushadha* and *ahara dravya* should be collected from *Sadharana* and *Jangaladesha* to get the excellent effect. [1] Various reference in Sanskrit literature shows the importance of *Bilva* in Vedic times and in the modern era too Therefore it is necessary to screen the quantitative changes of active principle along with bioactive compounds in the *Bilva phala* with respect to *Desha*, due to the effect of climatic and environment, whether it is going to vary in minimal or moderate levels, thus helps in proving the importance of *Desha* in collection of medicinal plants, which further helps in preparing *Bahuguna yukta aushadhi*, with great medicinal values, it has drawn the attention of spiritual leaders from time immemorial. It is held in high esteem in Indian traditions due to its divine origin and association with numbers of God and Goddesses like Laksmi, Prajapati, Surya, Lord Shiva, and Paravati. [2] We use *Bilva phala* in *Brihat Gangadhara churna*, *laghugangadhara churna*, *BalaBilvadi taila*, *Pushyanaga churna*, *Changerighurta, Bhunimbadi kwatha, Dhanya parichakwatha, Kutajavleha* and it is listed among the drugs used in *Asthapana Basti* and is also administered with *Sneha* in *Anuvasana Basti*. Its primary therapeutic indication is the management of *Vata* disorders.[3] Extensive chemical investigation on the various parts of the tree has been carried out. *Bilwa* fruit has been used for the treatment of gastrointestinal disorder [4-6] like chronic diarrhea, dysentery, peptic ulcer as a laxative in ayurveda & possess antioxidant anti-diarrhoea [7], gastroprotective, anti-ulcerative, hepatoprotective, antidiabetic properties

Aim: To compare the phytochemical profile of Bilva (*Aegle marmelos* L.) phala collected from Jangala, Sadharana, and Anupa Desha, and to evaluate whether Jangala Deshaja Bilva Phala contains higher concentrations of selected phytoconstituents than the other two Deshas.

Objectives: 1. To quantitatively estimate the alkaloid, tannin, and marmelosin content in Bilva Phala collected from Jangala, *Sadharana*, and *Anupadesha* using standard analytical procedures. 2. To compare the phytochemical profile of Bilva Phala among the three Deshas based on the estimated concentrations of these phytoconstituents

2. MATERIALS AND METHODS

Drug collection time: As mentioned in classics, Charaka and Sushruta opine that, *phala* of plants should be collect in respective seasons. *Bilva* is called as *sadaphala*, so we can collect any time in its unripe stage, 6 to 8 *Apakwa Bilva phala* are collected from each plant in 3 different places with in karnataka (*Jangala*, *Sadharana*, *anupa Desha*). *Bilva phala* in all 3 desha is collected in the month of September 2018.

Herbarium Voucher Number - SJGAMC/DGH/2018/0005- 0007

Collection place: Criteria for the selection of *Desha.* According to classical Ayurvedic texts, the classification of *Desha* (geographical regions) is based on factors such as sunlight exposure, rainfall patterns, forest density, and overall vegetation. On this basis, regions are broadly categorized into *Jangala*, *Sadharana*, and *Anupa Desha*.

The fruit samples were collected in September 2018 as part of an institutional postgraduate research dissertation submitted to the Rajiv Gandhi University of Health Sciences (RGUHS), Karnataka. Regions were selected following the classical climatic definitions of *Desha*. Because automated smartphone

digital geo-tagging photography and systematic GPS logging were not baseline standard operating procedures within the institutional framework during this project's field collection window, regional authenticity was verified through macro-climatic logging and formal botanical verification by the institutional Dravya Guna department.

Characteristics of *Desha*-

Anupa Desha: This type of region is characterized by an abundance of water resources and rich biodiversity. The terrain is often uneven, with small hillocks spread across a wide area. The presence of waterfalls contributes to a relatively cool climate. The soil typically exhibits a coppery hue, and rice is the predominant crop cultivated here. The inhabitants of this region generally possess soft and delicate physiques and tend to exhibit dominance of *Vata* and *Kapha dosha*.

Anupadesha is further classified into three subtypes:

Mukhya (primary): Exhibits all classical features, including marshy lands, numerous flowing streams, and dense vegetation providing extensive shade.

Madhyama (intermediate): Shows moderate features, with comparatively reduced water availability.

Kaniya (inferior): Represents regions with minimal expression of these characteristics, particularly with limited water resources. [8, 9]

Jangaladesha: This region is typically warm and considered conducive for health. Although surface water may be limited, groundwater can be accessed through wells. The land is predominantly dry, consisting of sandy and gravelly soil, often giving rise to mirage-like appearances. Livestock such as cows and goats are known to produce higher yields of milk in this environment. The inhabitants are generally strong, resilient, and physically robust, with a predominance of *Vata* and *Pitta dosha*.

Jangaladesha is also divided into three types:

Mukhya Jangala: Represents extremely arid conditions with classic dry land features.

Madhyama Jangala: Characterized by sparse vegetation and fewer trees.

Kaniya Jangala: Areas where water can be obtained relatively easily by digging wells, indicating comparatively lesser dryness. [10, 11]

Sadharan Desha: It has mixed characteristics of wet and dry land. It is pleasant for all living beings. People inhabiting this type of land are sturdy, tender, and endowed with strength, complexion and compactness. *Sadharan desha* is of two types *anupa sadharan* is one where characteristics of wetlands predominate, and *Jangala sadharan* is one where characteristics of dry land predominate. [12-14]

Koppal place is considered as *Jangaladesha* because of following points: a. Climate of the place is very hot and dry;

b. The normal rainfall is 571.92mm; c. Comes under the north dry agro climatic dry deciduous zone.

Hubli place is considered as *Sadharanadesha* because of following points: a. Has a tropical wet and dry climate; b. The average rainfall is 838mm. c. Agricultural land, summer is hot and dry followed by the monsoon season, with moderate temperature.

Sirsi place is considered as *Anupadesha* because of following points: a. The climate in sirsi is strongly influenced by monsoon, cold moist nature; b. The region receives heaviest rainfall, average is 2528 mm; c. The vegetation in the region is mainly moist deciduous, owing to the rich flora and fauna

Collected places: *Bilva phala* collected in Koppal, Hubli and Sirasi

Authentication: Authentication of *Bilva phala* is done by Dravya Guna department of Shri Jagadguru Gavisiddeshwara Ayurvedic Medical Collage and Hospital

Drying of *Bilwa phala majja:* After breaking the *Bilwa phala, majja* is separated into a container devoid of seeds. Dried in shade for 1 ½ month. (Fig 1)

Fig 1 – Dried *bilwa phala majja* of 3 deshas

Preparation of *churna* of *Bilva phala majja*.

Churna is prepared by pounding and grinding method

Marking: *Churna* of *Bilva phala* is packed and marked as sample 1, 2, 3 for *Jangala, Sadharana , Anupa Desha* respectively. Analysis is done in Natural remedies Pvt Limited Bangaluru.

Methods: To record phyto compounds quantitatively in *Bilva phala* these methods are use.

For alkaloids: Gravimetry. [15]

For tannins: Spectophotometry. [16]

For marmelosin: HPLC (high performance liquid chromatography) [17]

To determine the percentage of alkaloids by gravimetry for all the 3 samples (Table 1)

Gravimetric analysis is a technique through which the amount of an analyte (the ion being analyzed) can be determined through the measurement of mass. Gravimetric analyses depend on comparing the masses of two compounds containing the analyte. The principle behind the gravimetric analysis is that mass of an ion in a pure compound can be determined and then used to find the mass percent of the same ion in a known quantity of an impure

Table 1 – Alkolides percentage in *Bilva phala* of 3 deshas.

Batch No	Sample weight (g ms)(W1)	Empty beaker weight (gm s) (W2)	Empty beaker + Residue weight (gms)(W3)	Alkolides % (W/W)
Bilva Phala Churna (Sample1)	3.3895	101.7736	101.7834	0.289
Bilva Phala Churna (Sample 2)	3.2616	100.4467	100.4513	0.141
Bilva Phala Churna (Sample 3)	3.6589	98.3693	98.3758	0.178

Formula - W2-W3/W1*100

Sample 1- 101.7736 – 101.7834 /3.3895*100 = 0.289 %W/W

Sample 2- 100.4467-100.4513/3.2696*100 = 0.141% W/W

Sample 3- 98.3693- 98.3758/3.6589*100=0.178%W/W

To determine the percentage of total polyphenols as tannic acid in by spectrophotometry.

Spectrophotometry is a method to measure how much a chemical substance absorbs light by measuring the intensity of light as a beam of light passes through a sample solution. The basic principle is that each compound absorbs or transmits light over a certain range of wavelength. This measurement can also be used to measure the amount of a known chemical substance, spectrophotometry is one of the most useful methods of quantitative analysis in various fields such as chemistry, physics, biochemistry, material and chemical engineering, and clinical applications.

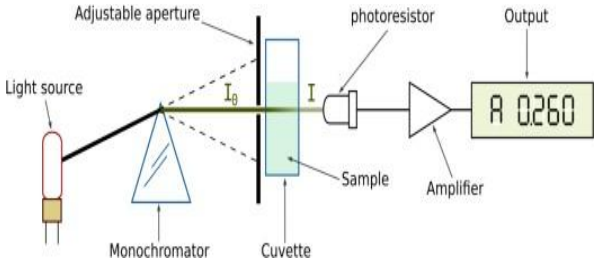

Fig 2: Total polyphenols as tannic acid by Spectrometry

Tannic acid(wt) -52.8mg in 100ml (Dilution 1) Dilution 2 :1 to 100

1] *Bilva Phala Churna* Sample 1 - 452.2 mg in 100 ml

(Dilution 1) Dilution 2 :1 to 100

2] *Bilva Phala Churna* Sample 2 - 532.3 mg in 100 ml

(Dilution 1) Dilution 2 :1 to 100

3] *Bilva Phala Churna* Sample 3 - 539.4 mg in 100 ml

(Dilution 1) Dilution 2 :1 to 100

Tannic acid OD at 750 nm - 0.670

1. *Bilva Phala Churna* Sample1 absorbance - 0.397
2. *Bilva Phala Churna* Sample 2 absorbance - 0.399
3. *Bilva Phala Churna* Sample 3 absorbance - 0.464

Calculations:- sample absorbance*standard weight*sample dilution*purity of tannicacid / Standard absorbance* standard dilution * sample weight.

Sample no 1: 0.397 *52.8* 100* 0.99/ 0.67*1*452.2 = 6.85%w/w

Sample no 2: 0.399 *52.8* 100*0.99/ 0.67* 1*532.3 = 5.85 %w/w

Sample no 3: 0.464 *52.8* 100* 0.99/ 0.67* 1*539.4 = 6.75 %w/w

Standard curves were established using standard tannic acid solutions. While the linear calibration curve was utilized internally at the analytical testing facility (Natural Remedies Pvt. Ltd.) to compute final values, the raw data, concentration ranges, and corresponding operational parameters have been summarized directly within the text calculation steps.

Procedure of HPLC method to determine the marmelosin in 3 samples

HPLC works on the principle that some molecules take longer than others to pass through a chromatography column. This depends on the affinity of the molecule with the mobile phase (liquid gas) and the stationary phase (solid or liquid). The ones that have more affinity with the stationary phase take longer to pass through and vice versa.

Chromatographic conditions:

Column - C18 – ods 5 m size, 250 * 4.6 mm (merck)

Detector - SPD –M10 AD VP photo diode array detector.

Wavelength - 250 nm, Flow rate - 1.2 ml/ min, Injection volume– 20ml

System suitability mix/ standard: Weigh accurately 10mg of marmelosin to a 100 ml volumetric flask. Dissolve is 50ml of HPLC graded methanol and makes up to 100ml and filter

Sample preparation:

Weigh accurately 3 grams of sample into the 250 ml beaker

Extract with 50ml of HPLC graded methanol, boil on a water bath for 15 min.

Cool and filter to another beaker repeat the operation for 4-5 times, until the sample is completely extracted or till extracts turn colorless.

Make up the extract to 10 100 in a volumetric flask.

Procedure: set the instrument as per chromatographic condition as prescribed above. By means of suitable syringe inject 20ml of standard preparation and record the chromatogram.

Recordings from HPLC:

Sample no. 1 – 0.36 % w/w

Sample no. 2 – 0.34 % w/w

Sample no. 3- 0.06 % w/w.

3. RESULTS

Table 2: Qualitative phytochemical profile of *Bilva Phala* from *Jangala Desha* using standard methods.

Phytocompounds in *Bilva phala*	*Jangaladeshaja Bilva phala majja*	Procedure
Alkaloids	0.28 % w/w	By Gravimetry
Tannins	6.85 % w/w	By Spectrophotometry
Marmelosin	0.36 % w/w	By HPLC

Table 3: Qualitative phytochemical profile of *Bilva Phala* from Sādhāraṇa Deśha using standard methods

Phyto compounds in *Bilva Phala*	*Sadharanadeshaja Bilva phala majja*	Procedure
Alkaloids	0.14 % w/w	By Gravimetry
Tannins	5.85 % w/w	By Spectrophotometry
Marmelosin	0.34 % w/w	By HPLC

Table 4: Qualitative phytochemical profile of *Bilva Phala* from Anūpa Deśha using standard methods.

Phytocompounds in *Bilva phala*	*Anupadeshaja Bilvaphala majja*	Procedure
Alkaloids	0.17 % w/w	By Gravimetry
Tannins	6.71 % w/w	By Spectrophotometry
Marmelosin	0.06 % w/w	By HPLC

Graphical presentation of phytocompound in *Bilva phala majja (Jangaladesha, Sadharana desha, anupa desha* fig 3 , fig 4 , fig 5, fig 6

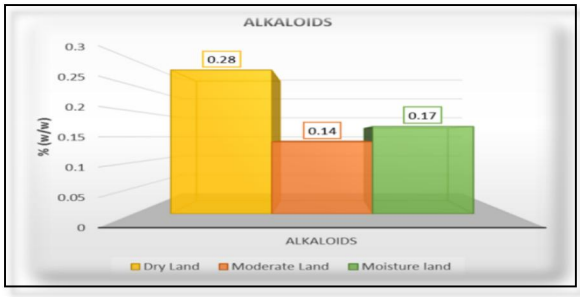

Fig 3: Graphical representation of alkaloid content in *Bilva Phala Majja* from *Jangala*, *Sadharana*, and *Anupa Desha*.

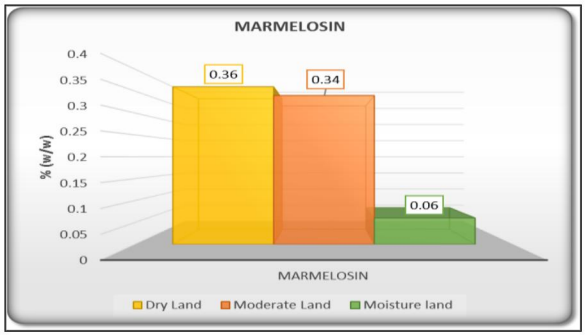

Fig 4: Graphical representation of marmelosin content in *Bilva Phala Majja* from *Jangala*, *Sadharana*, and *Anupa Desha*.

The qualitative phytochemical screening of *Bilva Phala* samples collected from *Jangala*, *Sadharana*, and *Anupadesha* was carried out using standard methods. The results obtained for the respective samples are mentioned in in Tables 2–4.

The quantitative estimation of phytocompounds in *Bilva Phala Majja* collected from *Jangala*, *Sadharana*, and *Anupa Desha* is graphically represented in Figures 3–6.

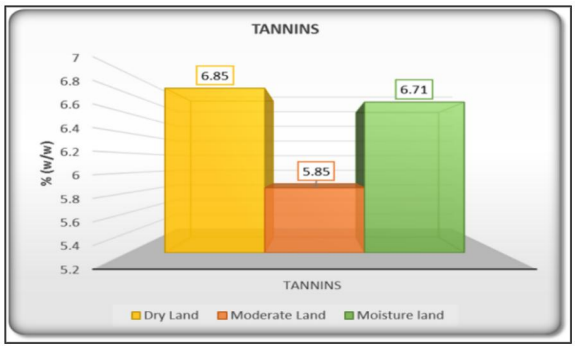

Fig 5: Graphical representation of tannin content in *Bilva Phala Majja* from *Jangala*, *Sadharana*, and *Anupa Desha*.

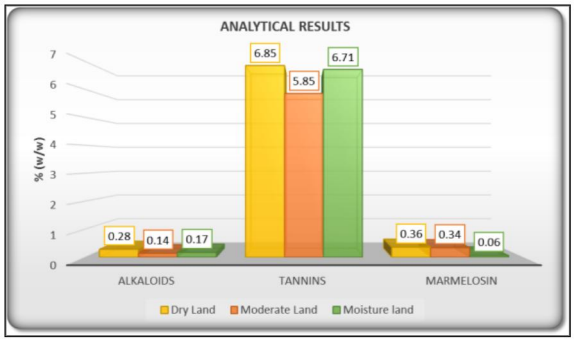

Fig 6: Comparative graphical representation of phytocompounds in *Bilva Phala Majja* from *Jangala*, *Sadharana*, and *Anupa Desha*.

4. DISCUSSION

Classical Ayurvedic Acharyas consistently highlighted that optimizing therapeutic potency requires a meticulous approach to plant collection, accounting for habitat selection, seasonal cycles, and ambient environmental parameters. Among these variables, *Desha* (geographical ecosystem) is recognized as a primary factor governing the pharmacological strength and quality profile of botanical drugs. In the foundational literature, Acharya Charaka asserted that plants indigenous to *Jangala Desha* exhibit therapeutically superior characteristics compared to plants developing within *Anupa Desha*. The current investigation offers a rigorous empirical validation of these traditional methods by employing quantitative phytochemometric assessments on *Bilva* (*Aegle marmelos*) fruits obtained from geographically diverse climatic zones.The therapeutic profile of *Bilva* is fundamentally driven by a complex matrix of secondary metabolites, predominantly comprising coumarins, alkaloids, and tannins. Literature

indicates that the key coumarins within *Bilva* pulp include marmelosin, marmesin, imperatorin, marmin, alloimperatorin, scoparone, scopoletin, umbelliferone, marmelide, and marmenol. Among these, marmelosin (alternatively identified as imperatorin) is a pivotal bio-active agent driving multiple validated pharmacological pathways. Earlier pharmacognostical evaluations of *Aegle marmelos* substantiate our analytical baseline in demonstrating rich concentrations of polyphenols, coumarins, tannins, and flavonoids throughout various plant tissues [18,19]. For instance, Shinde et al. successfully deployed RP-HPLC to isolate and confirm high concentrations of coumarin derivatives, specifically marmelosin, umbelliferone, and scopoletin, from *Bilva* fruit pulp [18]. In a similar way, Mujeeb et al. confirmed the high density of polyphenolic complexes and antioxidant molecules within *Aegle marmelos* matrices [19].

The synthesis and spatial distribution of these secondary metabolites are highly sensitive to fluctuating ecological and environmental variables. Factors such as geographical terrain, soil nutrient density, PH, subsoil hydrology, macroclimates, moisture retention, pollution indexes, agronomic strategies, ontogenetic age, and harvest timing exert profound regulatory control. Contemporary phytochemical and ecological frameworks confirm that secondary metabolic pathways are up- or down-regulated by habitat-driven environmental stressors. Shifts in thermal ranges, precipitation volumes, elevation, salinity, and soil mineral status significantly dictate the biosynthesis of defensive compounds like alkaloids, tannins, and coumarins as mentioned in Table 5. This phenomenon matches documented trends in broader botanical research, where plants exposed to arid, high-stress environments consistently exhibit elevated secondary metabolite accumulation. Notably, Ramdas et al. demonstrated marked geographic variations in alkaloid and coumarin concentrations within *Aegle marmelos* roots across varying habitats, confirming that local environmental pressures reshape the plant's internal chemical profile. [20] In this study, the quantitative variance of target phytochemicals in *Bilva* fruits sourced from three distinct ecologies—*Jangala Desha* (arid zones), *Sadharana Desha* (moderate zones), and *Anupa Desha* (moist wetlands)—was precisely determined via HPLC as shown in Figure 4, gravimetric assays as shown in Figure 3 , and spectrophotometric as shown in Figure 5 methods for marmelosin, total alkaloids, and total tannins, respectively.

To create a dependable comparative framework, *Sadharana Desha* was utilized as the baseline experimental control group, representing a balanced, intermediate environment with moderate rainfall and typical soil chemistry. The baseline values derived from this terrain—alkaloids at 0.14% w/w, tannins at 5.85% w/w, and marmelosin at 0.34% w/w—align tightly with established standard ranges for unstressed, mature *Aegle marmelos* fruits in regional chemoprofiling literature [18, 19]. Comparing this *Sadharana* baseline data against the other groups reveals that shifting the plant away from moderate zones into extreme ecological microclimates triggers profound regulatory adaptations. The metabolic shifts observed in response to both highly arid and water-saturated zones highlight the plant's metabolic plasticity as it navigates sharply contrasting environmental strains. Chromatographic and spectrophotometric profiling revealed statistically significant variations across the three environments . *Bilva* fruits harvested from *Jangala Desha* displayed a clear peak in alkaloid content at 0.28% w/w, whereas *Sadharana Desha* and *Anupa Desha* samples demonstrated reduced concentrations of 0.14% w/w and 0.17% w/w, respectively as shown in Figure 3. This mirrors prior research showing that plants in arid or semi-arid zones accumulate higher concentrations of alkaloids when exposed to intense sunlight and drought conditions. Karmase et al. similarly underscored the presence of significant alkaloid yields in *Aegle marmelos*, advocating for HPLC-driven quantification as an indispensable tool for raw material standardization. [21] From an ecological standpoint, the moisture-starved landscape of *Jangala Desha* initiates drought-responsive signaling pathways.

Under hyper-arid stress, primary vegetative metabolism is minimized, and cellular resources are redirected to synthesize nitrogenous secondary metabolites like alkaloids, which serve as crucial oxidative shields to preserve cellular survival. Parallel trends were observed in tannin accumulation, which peaked in *Jangala Desha* at 6.85% w/w, followed closely by *Anupa Desha* at 6.71% w/w, while *Sadharana Desha* yielded the lowest baseline at 5.85% w/w as shown in Figure 5. These metrics sit comfortably within the 5–9% tannin bracket established by historical analyses of *Bilva* [20]. Structurally, tannins act as defensive polyphenolic barriers against herbivorous pressure and abiotic stress. The elevated tannin accumulation found in *Jangala Desha* highlights an adaptive metabolic mechanism designed to mitigate dry, high-temperature environmental conditions. Interestingly, the concurrent surge noted in *Anupa Desha* (6.71% w/w) suggests that excessive waterlogging and high root-zone moisture also generate physiological stress, prompting a separate, stress-driven up regulation of phenolic defenses.

Furthermore, the study revealed stark differences in marmelosin yields across the three habitats as shown in Figure 4. Fruits from *Jangala Desha* (0.36% w/w) and *Sadharana Desha* (0.34% w/w) maintained comparable, elevated levels of marmelosin, whereas *Anupa Desha* specimens demonstrated a critical reduction, dropping to 0.06% w/w. Prior HPLC analyses confirm that marmelosin synthesis in *Aegle marmelos* is highly fluid, fluctuating based on geographical coordinates, weather patterns, and fruit maturity [18]. The sharp 83% decrease in marmelosin concentration seen in the *Anupa Desha* cohort can be explained scientifically by a dilution effect stemming from luxury water consumption paired with lower relative isolation. Abundant water availability appears to suppress the specific phenylpropanoid and furanocoumarin biosynthetic pathways that generate marmelosin, shifting resource allocation back toward primary biomass production. This confirms that an arid or moderately dry climate is an absolute requirement to trigger optimal coumarin expression in *Aegle marmelos*.

Ultimately, these empirical results as mentioned in Table 5 it strongly support the classical Ayurvedic axiom that geographical habitat shapes a plant's medical profile. The concentrated presence of vital phytoconstituents in *Jangala Desha* fruits confirms that habitat-specific environmental pressures optimize the therapeutic potential of medicinal flora. Similar connections between habitat variations and phytochemical shifts are well-documented across modern pharmacognostical literature [18,20]. Consequently, this study offers concrete scientific backing for the traditional Ayurvedic practice of collecting raw materials from specific, ecologically compatible regions.

The present study offers preliminary evidence on the influence of *Bhumi Deśha* on the phytochemical characteristics of *Bilva Phala* (*Aegle marmelos*). Nevertheless, certain limitations need to be acknowledged. The inclusion of a larger number of samples representing different *Jangala, Anupa,* and *Sadharana Desha*, along with consideration of factors such as plant age and maturity, would improve the strength and reproducibility of the observations. Expanding similar investigations to other medicinal plants characteristic of specific *Deshas* may further clarify the role of habitat in determining phytochemical variation. In addition, the use of advanced analytical techniques such as HPTLC, LC–MS/MS, GC–MS, metabolomic profiling, and DNA barcoding, together with the assessment of nutritional constituents and primary and secondary metabolites, could provide a more detailed understanding of geographical influences on plant chemistry. The findings of the present work underscore the relevance of correlating traditional Ayurvedic concepts with modern analytical methods. Such an approach may facilitate the development of geographic standardization strategies for Ayurvedic raw drugs and assist in identifying suitable cultivation regions capable of yielding plant materials with consistent phytochemical composition and therapeutic

potential. Overall, the study lends scientific support to the Ayurvedic view that *Desha* plays an important role in shaping phytochemical diversity and medicinal quality, thereby providing a basis for further habitat-oriented research and strengthening the evidence base for quality standardization in Ayurveda.

Table 5: showing the variation of phytochemical in 3 *deshas*

Bilvaphala Phyto chemical	*Jangala deshaja*	*Sadharana deshaja*	*Anupa deshaja*
Alkaloids	0.28 % w/w	0.14% w/w	0.17 % w/w
Tannins	6.85 % w/w	5.85 % w/w	6.71 % w/w
Marmelosin	0.36 % w/w	0.34 % w/w	0.06 % w/w

5. CONCLUSION

To guarantee uniform therapeutic performance and predictable clinical success, the standardization of herbal pharmaceuticals is an essential prerequisite. Contemporary Ayurvedic research focuses heavily on this domain to overcome quantitative variations in phytochemical profiles, which frequently compromise the reproducibility of clinical trials. This investigation utilized modern analytical methodologies to determine how geographical habitat (*Desha*) impacts critical bioactive secondary metabolites—namely alkaloids, tannins, and marmelosin—in *Bilva Phala Majja Churna* (*Aegle marmelos* fruit pulp powder). Quantitative assessments revealed distinct variations across the different biomes. Notably, specimens harvested from *Jangala Desha* (arid zones) consistently yielded the highest concentrations of all three targeted groups. Quantitatively, *Jangala Desha* fruits reached a peak alkaloid concentration of 0.28% w/w, markedly outpacing the 0.14% w/w and 0.17% w/w recorded in samples from *Sadharana Desha* (moderate zones) and *Anupa Desha* (wetlands), respectively.

These experimental outcomes indicate that *Aegle marmelos* possesses exceptional physiological resilience and metabolic adaptation within arid environments. This phenomenon strongly corroborates the classical horticultural mandates of Surapala's *Vrikshayurveda*, which explicitly designates *Sriphala* (*Bilva*) as a primary species for arid landscape (*Jangala Desha*) cultivation [22]. Nevertheless, these distinct phytochemical profiles should not be credited solely to broad macro-geographical categories. Secondary metabolite biosynthesis is heavily dictated by an intricate network of localized microclimates, specific soil chemistry, seasonal dynamics, ecological stressors, genetic diversity, and ontogenetic factors. Since comprehensive soil chemo metrics and genetic barcoding fell outside the parameters of this baseline evaluation, declaring the absolute superiority of one distinct habitat demands broader empirical validation.

Nonetheless, these preliminary metrics offer concrete scientific backing for the traditional Ayurvedic concept that *Desha* directly dictates a plant's phytochemical architecture and eventual therapeutic efficacy. This research underscores the critical need for comprehensive, interdisciplinary studies combining soil profiling, multi-seasonal monitoring, genetic mapping, and high-throughput metabolomics to develop strict, origin-specific quality control frameworks. In conclusion, this investigation represents a vital milestone toward the geographical standardization of Ayurvedic crude drugs, effectively validating ancestral ecological paradigms through the lens of modern phytochemistry.

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