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Multifaceted pharmacognostic characterization and quality assurance *of Syzygium laetum, S. occidentale,* and *S. palghatense*

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Abstract
This research provides a detailed pharmacognostic investigation of three *Syzygium* species, *S. laetum*, *S. occidentale*, and *S. palghatense* emphasizing organoleptic characteristics, powder microscopy, and fluorescence analysis. Shade-dried leaf and bark powders were systematically examined to detect distinguishing features useful for species identification and quality assurance. Organoleptic evaluation identified clear differences in texture, colour, odour, taste, and powdering behaviour across the species. Microscopic studies revealed species-specific anatomical attributes, including variations in stomatal types, crystal deposits, stone cells, and sclereids. Fluorescence analysis under visible and ultraviolet light offered additional chemotaxonomic distinctions, reflecting differences in phytochemical composition. Collectively, the findings establish dependable diagnostic parameters for authenticating raw herbal materials, ensuring quality standardization, and facilitating their traditional and pharmaceutical utilization. This study strengthens the pharmacognostic database and highlights the significance of integrating morphological and chemical analyses in herbal drug validation.

Keywords: *Syzygium laetum*, *Syzygium occidentale*, *Syzygium palghatense*, organoleptic, powder microscopy, fluorescence analysis

Introduction
The genus *Syzygium* (family Myrtaceae) comprises over 1,200 species distributed predominantly across tropical and subtropical regions of Asia, Africa, and Oceania, with many species recognized for their ethnomedicinal and pharmacological importance (Elliot & Jones, 2010; Uddin *et al*., 2022) [6, 20]. Several *Syzygium* species, are traditionally used in various cultures for managing ailments such as diabetes, inflammation, and microbial infections due to their rich phytochemical composition (Dogara *et al*., 2024; Kumar *et al*., 2008) [5, 11]. Active compounds such as flavonoids, tannins, glycosides, and phenolic acids extractable from these species have been linked to antioxidant, antimicrobial, and anti-inflammatory effects, supporting their therapeutic relevance (Ochieng *et al*., 2022; Sharma *et al*., 2013) [15, 17].

To ensure safety, efficacy, and reproducibility in herbal medicine, precise botanical identification and quality standardization of raw materials are imperative (Chen *et al*., 2006; Muyumba, 2021) [4, 14]. Pharmacognostic evaluation serves as a vital tool for this purpose, encompassing organoleptic, microscopic, and physicochemical analyses (Mandal *et al*., 2023) [12]. Organoleptic parameters including texture, colour, odour, and taste, offer preliminary yet valuable criteria for authenticating plant materials in raw or powdered forms. Microscopic analysis further aids in detecting distinctive anatomical features such as stomatal types, calcium oxalate crystal forms, stone cells, and sclereids which are conserved across species and critical for diagnostic authentication (Singh *et al*., 2018; Yadav *et al*., 2018) [18, 21]. Such microscopic markers provide an indispensable safeguard against adulteration and substitution in herbal raw materials, an issue increasingly recognized in global herbal markets (Mandal *et al*., 2024) [13].

Fluorescence analysis under UV and visible light has gained prominence as a rapid, non-destructive technique for discerning phytochemical profiles and developing chemotaxonomic fingerprints (Gupta *et al*., 2006; Ramanathan *et al*., 2019) [7, 16]. This technique exploits the differential fluorescence emission of secondary metabolites like flavonoids and phenolics, which vary across species and solvent extractions (Jagtap & Koche, 2023) [8]. The integration of fluorescence analysis with traditional pharmacognostic tools enhances the reliability of species identification and quality control, thereby ensuring the safety and therapeutic integrity of herbal drugs (Tandon & Sharma, 2017) [19].

Despite significant research on *S. cumini* and *S. aromaticum*, pharmacognostic and phytochemical information on *S. laetum*, *S. occidentale*, and *S. palghatense* remains limited. Addressing this gap is critical for expanding the pharmacognostic database, facilitating standardization, and supporting the wider medicinal use of these species. The current study undertakes a comprehensive pharmacognostic evaluation of these three species by combining organoleptic assessment, powder microscopy, and fluorescence spectroscopy to establish definitive diagnostic criteria and reinforce quality assurance measures in herbal medicine practice.

Methods

Organoleptic features

The organoleptic features of *S. laetum*, *S. occidentale*, and *S. palghatense* (*S. laetum*, and *S. palghatense* from Nelliyampathy and *S. occidentale* from Athirapilly-Vazhachal) were (powdering behaviour, particle size, texture, colour, feel, odour, and taste) in fresh and dried forms were systematically observed and documented.

Powder microscopy

Shade-dried leaves and bark of the *S. laetum*, *S. occidentale*, and *S. palghatense* were finely ground using a mortar and pestle, then passed through a 40-mesh sieve to ensure uniform particle size. The powdered samples were soaked overnight in 4% potassium hydroxide (KOH) to soften the tissues for microscopic preparation. After softening, the powders were stained with safranin to differentiate lignified elements. The stained materials were mounted on glass slides with glycerine, which provided optical clarity and prevented drying during observation. Microscopic evaluations were carried out using a Nikon ECLIPSE E200 trinocular microscope fitted with a Zeiss AxioCam ERc 5s camera, capturing distinct anatomical characteristics at multiple magnifications. The experimental procedures were conducted following standard pharmacognostic methodologies recommended for anatomical characterization and species authentication (Anonymous, 2008; Jagtap & Koche, 2023; Khandelwal, 2002; Singh *et al*., 2018; Tandon & Sharma, 2017) [1, 9, 10, 18, 19].

Fluorescence analysis

Pharmacognostic fluorescence analysis was performed on the leaf and bark powders of *S. laetum*, *S. occidentale*, and *S. palghatense* to identify potential bioactive constituents. The powdered samples were individually treated with various solvents such as acetone, acetonitrile, methanol, and distilled water. Each treated sample was examined under visible light (254 nm) and ultraviolet light (366 nm) to observe colour variations and fluorescence patterns. The observed colour and fluorescence responses reflected the presence of phytochemicals and secondary metabolites, providing qualitative indicators for species differentiation and chemical characterization. The fluorescence characteristics under UV illumination proved to be an effective pharmacognostic approach for species authentication and establishing quality control standards (Gupta *et al*., 2006; Jagtap & Koche, 2023; Tandon & Sharma, 2017) [7, 9, 19].

Results

Organoleptic Features

The organoleptic evaluation of the three *Syzygium* species revealed distinctive traits essential for their identification. Leaves of *S. laetum* and *S. palghatense* were easily powdered, whereas *S. occidentale* leaf powdering was moderately easy. Bark grinding was more challenging, with the bark of *S. occidentale* being the most difficult to grind, followed by *S. palghatense* and *S. laetum* exhibiting moderate to difficult powdering behaviour (Table 1). Uniform particle size was seen in leaf powders of all species, but bark powders showed uneven particle distribution with fragments. Texture varied notably: *S. laetum* leaves were moderately coarse; *S. occidentale* leaves were slightly coarse and fibrous; *S. palghatense* leaves were fine and smooth. Bark texture ranged from coarse, fibrous in *S. laetum*, highly fibrous in *S. occidentale*, to granular and fibrous in *S. palghatense*. Colour differences were pronounced with *S. laetum* leaves appearing green to dark green, *S. occidentale* light green, and *S. palghatense* pale green. Bark colours ranged from light to dark brown in *S. laetum* and *S. palghatense*, and light brown in *S. occidentale*. The feel of leaf powders was light and flaky in *S. laetum*, soft and slightly granular in *S. occidentale*, and light, fine, and smooth in *S. palghatense*. All bark powders were rough and gritty, with *S. palghatense* also showing granular texture. No distinctive odour was detected in any species, while the taste of leaves ranged from neutral or mildly bitter (*S. laetum*), no characteristic taste (*S. occidentale*), to slightly bitter (*S. palghatense*). Bark taste was slightly astringent in *S. laetum* and *S. occidentale*, but moderately astringent in *S. palghatense*.

Powder Microscopy

Microscopic examination of *S. laetum*, *S. occidentale*, and *S. palghatense* leaves and bark revealed distinctive anatomical features supporting species differentiation. *S. laetum* leaves showed stomata and crystal deposits along with starch grains, with stone cells present in the petiole and crystal fibers observed in the bark. In *S. occidentale*, stomata were predominantly on the lower leaf epidermis, accompanied by both rosette and prismatic calcium oxalate crystals; its bark contained clusters of stone cells and rosette crystals. *S. palghatense* exhibited stomata with abundant sclereids and crystals on the leaf epidermis, while the bark revealed fibre sclereids and distinct medullary rays containing starch grains. These microanatomical markers provide reliable diagnostic traits crucial for accurate botanical identification and authentication of powdered raw materials among these closely related species (Plate 1).

Fluorescence Analysis

The three *Syzygium* species demonstrate distinct fluorescence signatures across UV and visible light wavelengths, with *S. palghatense* exhibiting the highest total fluorescence intensity (approximately 430 units in methanol extract), substantially exceeding *S. laetum* and *S. occidentale*. Leaf tissues consistently show stronger fluorescence responses than bark across all species, particularly under UV 254 nm (yellow coloration), indicating concentrated phenolic compound accumulation. *S. laetum* displays prominent red fluorescence under UV 366 nm in both tissues, while *S. occidentale* presents a more homogeneous wavelength distribution pattern. Solvent extraction significantly enhances fluorescence detectability compared to powder preparations, with methanol proving most effective. These species-specific fluorescence patterns reflect differential phytochemical composition and represent potential biochemical markers for taxonomic differentiation and quality assessment of *Syzygium* species (Figures 1-3).

Discussions

In the present study, the organoleptic evaluation of *S. laetum*, *S. occidentale*, and *S. palghatense* revealed perceptible differences that have significant diagnostic potential. Jagtap and Koche (2023) [9] emphasized that pharmacognostic parameters such as organoleptic, microscopic, and fluorescence characteristics form the foundation for scientific identification and standardization of herbal materials. The degree of powdering ease, particle uniformity, and textural variations are not only practical indicators of raw material integrity but also reflect underlying anatomical organization and chemical constituents. The variation in colour and tactile response among the species aligns with the findings of Tandon and Sharma (2017) [19], who reported that sensory attributes often correspond with phytochemical content, thus serving as primary quality markers in traditional drug assessment. Bekele and Geleta (2015) [2] further demonstrated that taste parameters, including levels of astringency, are influenced by tannins, alkaloids, and phenolics, which contribute both to medicinal efficacy and consumer acceptability. These correlations reaffirm that organoleptic features remain an essential first-line method for preliminary species differentiation and assessing material quality before advanced analysis.

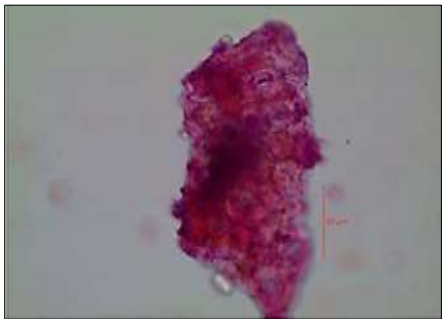
Microscopic observations added a deeper anatomical perspective, supporting accurate species authentication. The presence of rosette and prismatic calcium oxalate crystals, stone cells, and sclereids offers distinct taxonomic characters, consistent with the structural markers documented by Khandelwal (2002) [10]. Singh *et al*. (2018) [18] highlighted that such features serve as stable diagnostic traits unaffected by environmental fluctuations, making them reliable tools for precise identification even in powdered form. In the current study, the detection of starch grains and medullary rays provided additional structural evidence to distinguish between species. These microscopic findings support Jagtap and Koche's (2023) [9] assertion that the combination of cellular details and tissue organization forms a micro-diagnostic framework crucial for preventing adulteration and ensuring authenticity in large-scale herbal trade networks. Such features, when compiled systematically, function as taxonomically stable fingerprints that supplement chemical tests in pharmacognostic practice.

Gupta *et al*. (2006) [7] and Tandon and Sharma (2017) [19] advocated for fluorescence analysis as a sensitive and non-destructive method for assessing phytochemical diversity and identifying plant materials. The present findings concur with their studies, as fluorescence examination under visible and ultraviolet light revealed species-specific emission patterns. These fluorescence responses, driven by interactions between secondary metabolites such as flavonoids, coumarins, and phenolic compounds, provided clear qualitative differentiation among the *Syzygium* species. The solvent-dependent variation in fluorescence intensity further substantiates reports by Jagtap and Koche (2023) [9], indicating that solvent polarity influences the excitation and emission behaviour of phytochemicals. Hence, fluorescence analysis not only confirms morphological and microscopic observations but also introduces a rapid chemotaxonomic dimension to species authentication. Its incorporation into routine quality assessment protocols strengthens the standardization framework by adding a chemical profiling component that is economical and environmentally sustainable.

Collectively, these results reaffirm that a multidimensional pharmacognostic strategy integrating organoleptic, microscopic, and fluorescence analyses provides a scientifically sound and comprehensive approach to herbal drug standardization. As noted by Bhattacharya and Zaman (2009) [3], combining qualitative and structural evaluations establishes a robust foundation for ensuring authenticity, purity, and consistency in herbal formulations. The current study's integrated evaluation supports this paradigm by offering reproducible diagnostic parameters for *S. laetum*, S. *occidentale*, and *S. palghatense*. Such an approach minimizes the risks associated with adulteration, substitution, and quality degradation, issues prevalent in the global herbal raw material trade. Sharma *et al*. (2013) [17] further suggest that future research should extend beyond morphological and fluorescence-based parameters to include physicochemical and chromatographic profiling, thereby achieving a more holistic standardization model. The inclusion of spectroscopic, chromatographic, and molecular analyses in subsequent investigations would enhance the authentication framework developed here, ensuring product safety, therapeutic reliability, and regulatory compliance in both traditional and contemporary phytopharmaceutical systems.

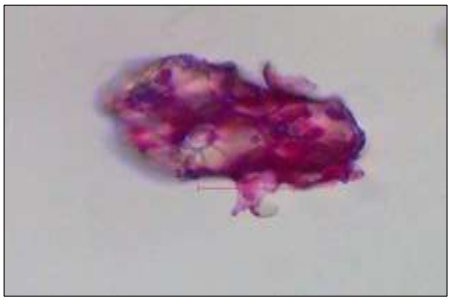
Table 1: Comparative organoleptic features of S. *laetum*, *S. occidentale*, and *S. palghatense*

Feature	*S. laetum*	*S. occidentale*	*S. palghatense*
Powdering Behaviour	Leaf: Easy to grind	Leaf: Moderately easy to grind	Leaf: Easy to grind
	Bark: Moderately difficult	Bark: Difficult to grind	Bark: Moderate to difficult
Particle Size	Leaf: Uniform	Leaf: Uniform	Leaf: Uniform
	Bark: Uneven with fragments	Bark: Uneven with fragments	Bark: Uneven with fragments
Texture	Leaf: Moderately coarse	Leaf: Slightly coarse, fibrous	Leaf: Fine and smooth
	Bark: Coarse, fibrous	Bark: Highly fibrous	Bark: Granular, fibrous
Colour	Leaf: Green to dark green	Leaf: Light green	Leaf: Pale green
	Bark: Light to dark brown	Bark: Light brown	Bark: Light to dark brown
Feel	Leaf: Light, flaky	Leaf: Soft, slightly granular	Leaf: Light, fine, smooth
	Bark: Rough, gritty	Bark: Rough, gritty	Bark: Rough, granular
Odour	No distinctive odour	No noticeable odour	No noticeable odour
Taste	Leaf: Neutral or mildly bitter	Leaf: No characteristic taste	Leaf: Slightly bitter
	Bark: Slightly astringent	Bark: Slightly astringent	Bark: Moderately astringent

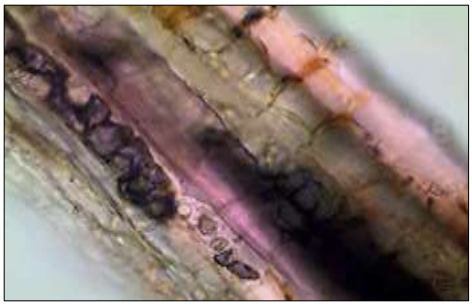


S. laetum leaf epidermis showing stomata and crystals

***S. laetum* leaf with starch grains**



Stone cells from the *S. laetum* petiole

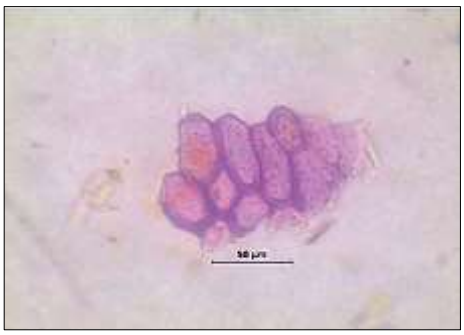


Crystal fibres in *S. laetum* bark

***S. occidentale* leaf lower epidermis with stomata**

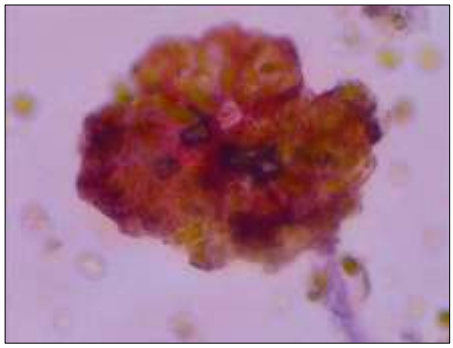
Rosette crystals of calcium oxalate in *S. occidentale* leaves

Prismatic crystals of calcium oxalate in *S. occidentale* leaves

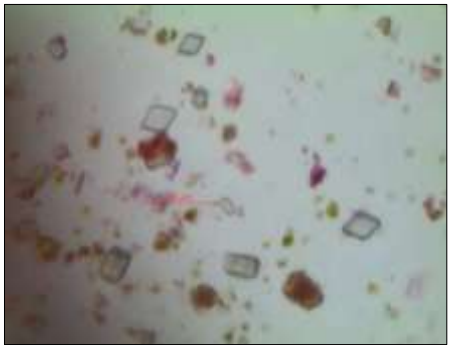


Group of stone cells in *S. occidentale* bark

Rosette crystals of calcium oxalate in *S. occidentale* bark



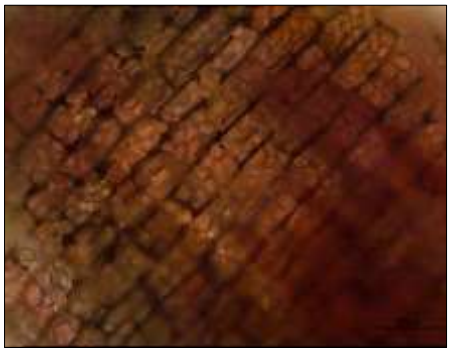
***S. palghatense* leaf epidermis with stomata**



Crystals in *S. palghatense* leaves

Sclereids in *S. palghatense* leaves

Fibre sclereids in *S. palghatense* bark



***S. palghatense* bark medullary rays in sectional view with starch grains**

Plate 1: Comparative powder microscopic evaluation of leaves and bark of *S. laetum*, *S. occidentale*, and *S. palghatense*

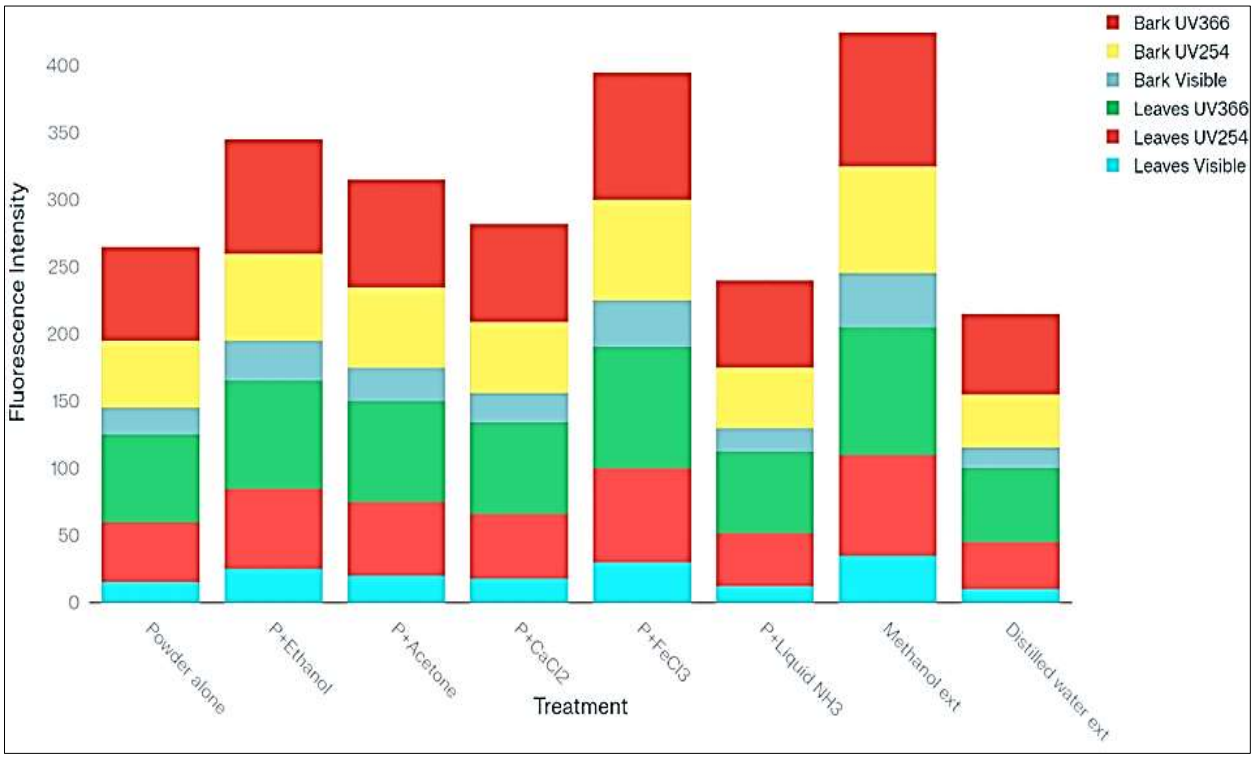


Fig 1: Fluorescence analysis of leaf and bark dry powders of *S. laetum* under visible and UV light

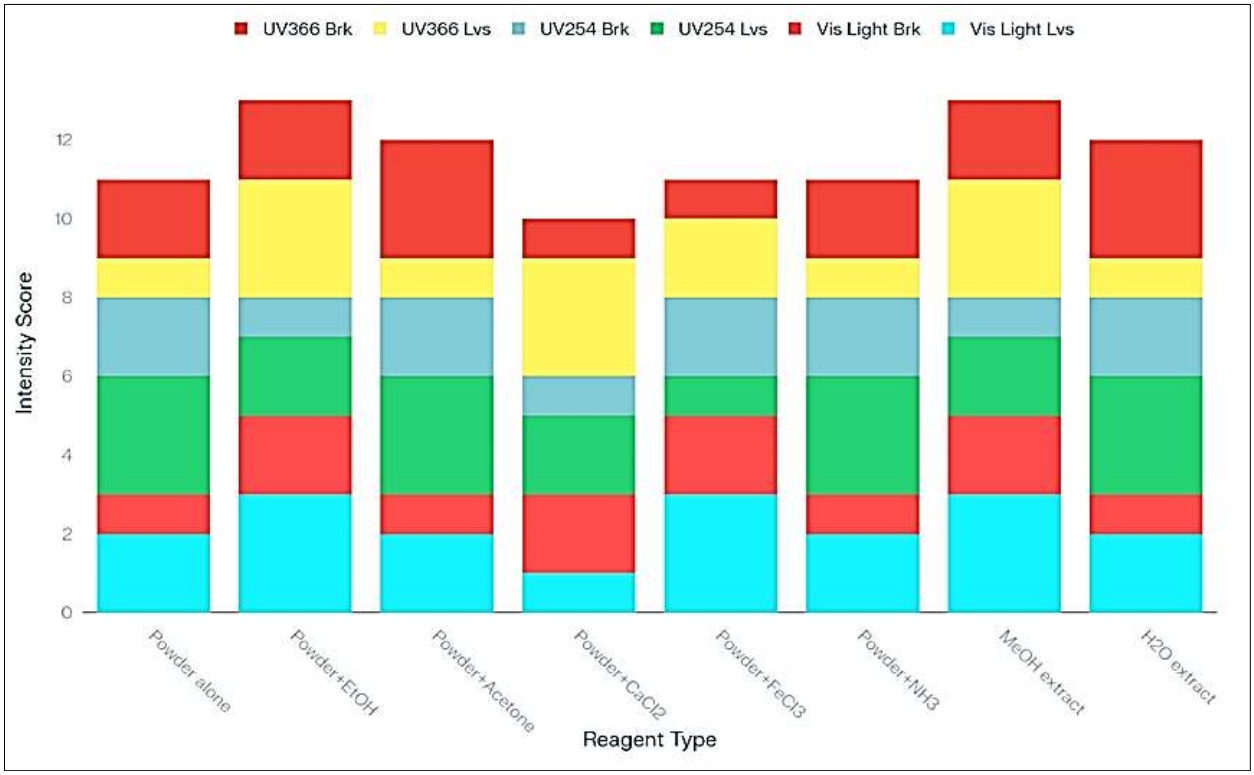


Fig 2: Fluorescence analysis of leaf and bark dry powders of *S. occidentale* under visible and UV light

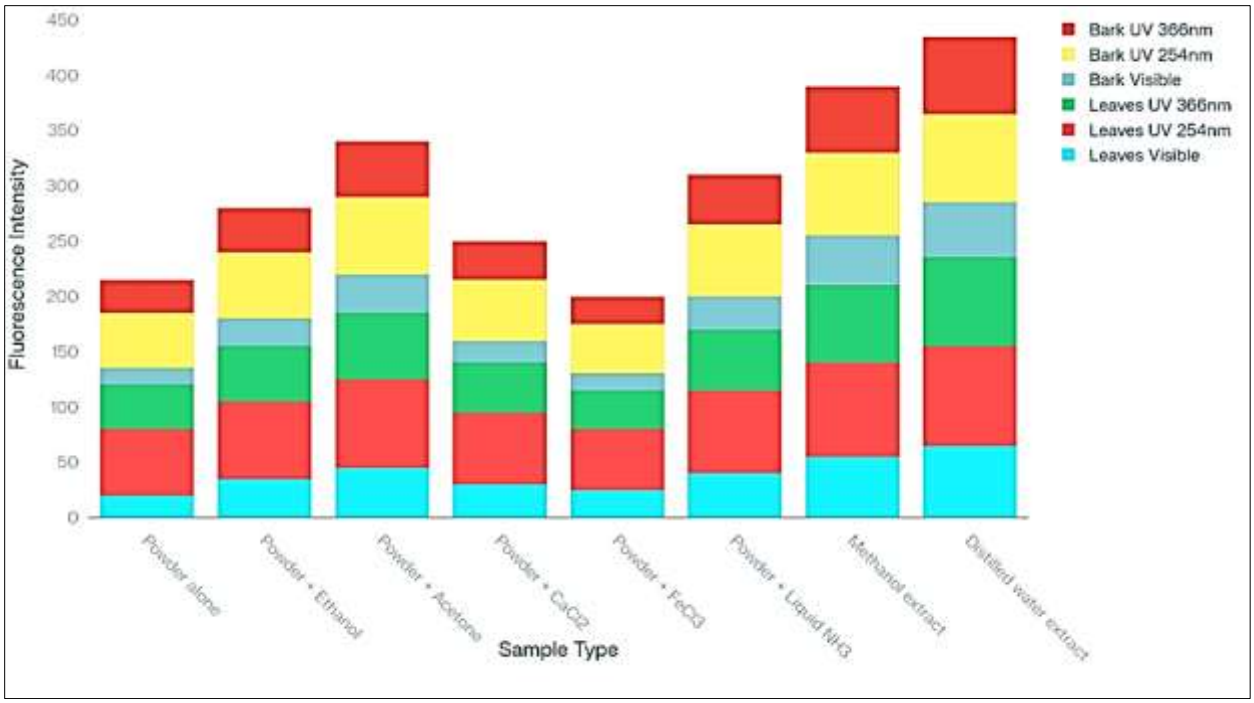


Fig 3: Fluorescence analysis of leaf and bark dry powders of *S. palghatense* under visible and UV light

Conclusion

The present pharmacognostic investigation effectively distinguishes *S. laetum*, *S. occidentale*, and *S. palghatense* through an integrated evaluation of organoleptic, microscopic, and fluorescence characteristics. Variations in powdering behaviour, texture, colour, and taste establish practical benchmarks for preliminary identification of the powdered materials. Microscopic attributes, including differences in stomatal structures, crystal morphology, and sclereid distribution, serve as definitive diagnostic markers confirming species-level distinctions. Fluorescence observations under different solvent treatments revealed unique emission profiles, highlighting this method as a rapid and sensitive qualitative tool for assessing phytochemical diversity. The integration of these complementary techniques provides a comprehensive framework for species authentication and standardization of *Syzygium*-derived herbal materials. These findings reinforce the significance of systematic pharmacognostic evaluation in ensuring the authenticity, purity, and therapeutic reliability of medicinal plants. Future research integrating chromatographic and chemical profiling approaches is recommended to expand the standardization framework and enhance the quality assurance of *Syzygium*-based herbal formulations.

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