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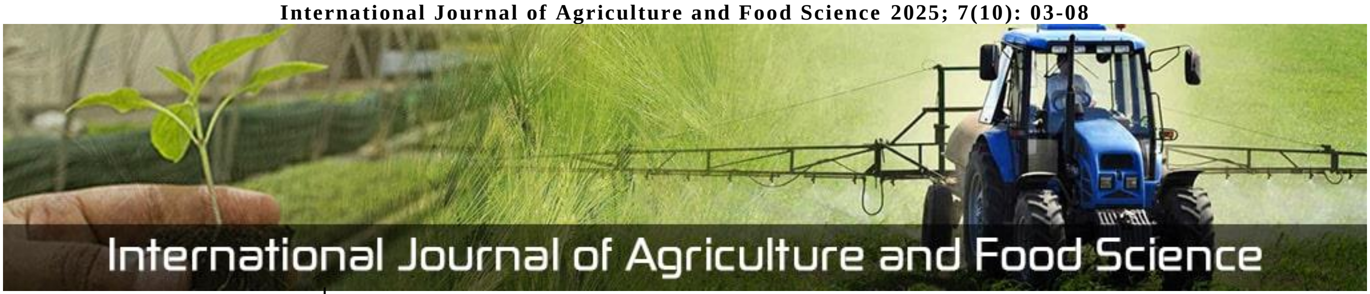


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# Agro-Morphological Variability of Black Pepper (*Piper nigrum* L., Piperaceae) in the Wayand Highlands of Kerala, India

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## Abstract
*Piper nigrum* L., known as the "King of Spices," is a chief cash crop of Kerala, with the Wayanad highlands functioning as one of the principal cultivation zones. This research endeavour is conducted to document the agro-morphological variability of black pepper varieties and note usual cultivation practices in selected locations of Wayanad district, Kerala. Field-based surveys were conducted in five major black pepper-growing regions of Wayanad—Pulpally, Kakkavayal, Kammana, Kalpetta, and Mananthavadi—using a descriptive, cross-sectional design. Data were collected through direct farmer interactions, structured questionnaires, and on-field observations. Data were summarized using descriptive statistics to assess the variability in varietal distribution, support systems, and management practices. A wide diversity of black pepper varieties was documented, including traditional landraces (Karimunda, Valankotta, Neelamundi, Koombukkal) and improved hybrids (Panniyur-1, Panniyur-2, Aswathy, Preethi, Suvarna, Super Gold, Shakthi, Wayanadan-2). Thekkan, Uthirankotta, Shakthi, and Munthirimundi were the most preferred, while Panniyur-1, Panniyur-2, and Bolt were least favoured. Predominant supporting plants included *Areca catechu*, *Cocos nucifera*, and *Gliricidia maculata*, along with *Colubrina* spp., *Erythrina variegata*, and *Swietenia macrophylla*. Major constraints reported were labour scarcity, climate change, flooding, and fluctuating market prices. The most frequently observed diseases were quick wilt, charcoal rot, root rot, stem blight, bacterial wilt, anthracnose, and leaf spot. Common cultivation practices included layering, bush pepper cultivation, the Vietnam model, and multistorey cropping. The study highlights significant agro-morphological variability, varietal preferences, and cultivation strategies in Wayanad's black pepper sector. The findings provide a baseline for future conservation, sustainable production, and farmer-cantered improvements in black pepper cultivation.


**Keywords:** Black pepper, Wayanad, varietal diversity, cultivation practices, diseases, supporting plants

## Introduction
Black pepper (*Piper nigrum* L.), Piperaceae, has persisted as one of the most treasured commodities in transnational trade for centuries [1, 2]. Originating in the tropical forests of the Western Ghats of India, it was among the primitive spices to magnetize Arab, Roman, and later European merchants, persuading the progression of seafaring commerce and colonial expansion [1, 2, 3]. Even today, black pepper endures to be a keystone of the intercontinental spice market, interposing considerably to the global spice wealth. India remains one of the leading producers and exporters, with Kerala much-admired as the time-honored home of pepper agribusiness [2,3]. Within Kerala, the Wayanad district subjugate an undivided rank as a major production epicenter, due to their expedient climate, rich soils, and conventional farming know-how. The spice not only exemplifies an imperative agricultural export but also aids the livelihoods of thousands of smallholder farmers, making it vital to the rural economy of the state [3, 4, 5]. Moreover, pepper cultivation in Kerala has robust socio-cultural and ancient roots, characterizing both agricultural heritage and economic flexibility [5, 6, 7]. Beyond its economic value, black pepper has long been esteemed for its ethnobotanical and restorative properties. In traditional medicine systems such as Ayurveda, Siddha, and Unani, pepper fruits are used as stimulants, carminatives, and cure for respiratory ailments, gastrointestinal disorders, and febrile conditions [8, 9, 10].

Folk practices in Kerala and other parts of South India often incorporate pepper in home remedies for colds, coughs, indigestion, and general weakness, underlining its role as a household therapeutic agent [10, 11, 12, 13]. Contemporary pharmacological conclusions have further endorsed these benefits, signifying that pepper presents antimicrobial, anti-inflammatory, antioxidant, hepatoprotective, and neuroprotective activities [12, 13, 14]. Its major alkaloid, piperine, is particularly well-studied for its bioenhancing property, whereby it surges the bioavailability of several drugs and nutraceuticals, making it an important adjunct in pharmaceutical formulations [14, 15]. Recent research has also reported anticancer, antidiabetic, and immunomodulatory potentials of piperine and other phytoconstituents, underscoring the plant's relevance in contemporary healthcare. In addition, pepper continues to hold cultural and culinary significance; it is a staple spice in Indian cuisine and a symbol of Kerala's spice heritage [16, 17]. Together, these attributes demonstrate that black pepper is not only an agricultural commodity but also a medicinal and cultural resource of enduring global relevance.

The cultivation of black pepper in Wayanad is strongly influenced by diverse agro-climatic conditions and farmer-driven practices that shape both productivity and sustainability [18]. Farmers in the region maintain a wide range of local varieties and landraces, each with distinct agro-morphological traits that contribute to yield potential, stress tolerance, and adaptability [6, 7]. At the same time, cultivation methods such as shade regulation, organic manuring, intercropping, and staking systems vary considerably between farms, reflecting a blend of traditional knowledge and practical innovation [6, 8, 10]. Documenting this variability is essential, as it not only highlights the agro-biodiversity of the crop but also provides insights into the resilience and economic viability of different farming approaches. In this context, the present study was designed to survey the diversity of black pepper varieties cultivated by farmers in the Wayanad, and to record the common cultivation practices adopted in the region. By integrating agro-morphological characterization with farmer-level practices, this work aims to generate baseline information that could support varietal selection, conservation strategies, and sustainable spice production in Kerala.

## Subjects and Methods

**Study area:** The present investigation was conducted in Wayanad district, Kerala, a region renowned for its tropical climate, lush vegetation, and cultural heritage. Wayanad spans an area of 2131 km$^2$, of which approximately 40% is under forest cover and more than 51% is devoted to cultivation. The district is an important center of cash crop production, particularly black pepper, coffee, and other spices, contributing significantly to foreign exchange earnings. The Kabani River, an east-flowing tributary of the Cauvery, serves as a major water resource sustaining the agricultural landscape. For this study, surveys were carried out in five representative locations within the district, namely Pulpally, Kakkavayal, Kammana, Kalpetta, and Mananthavadi, which are known for extensive black pepper cultivation.

**Data collection**

Primary data were collected through direct farmer interactions, field observations, and structured questionnaires administered to six selected farmers representing the study locations. The information gathered included details of black pepper varieties under cultivation, preferred cultivation practices, and farmer perceptions regarding yield and adaptability. Secondary data were obtained through relevant literature, reports, and published sources to supplement field-based findings [19].

## Results

The investigation divulged substantial agro-morphological assortment among black pepper varieties cultivated across the study settings. A wide range of local and better-quality types were authenticated, comprising Karimunda, Balankotta, Agali, Koombukkal, Valankotta, Cheruvalli, Moolanthiri, Upputhiriyan, Neelamundi, Chumalanamban, Cholamundi, Jeeva, Vykha, Muthumani, Vanamundi, Malamundi, Pamban, Paurnami, Palod-2, and Malabar XL. Among the recently improved hybrid categories, Panniyur-2, Aswathy, Preethi, Suvarna, Super Gold, Wayanadan-2, and Shakthi were detailed (Fig. 1). Of these, Thekkan, Uthirankotta, Shakthi, and Munthirimundi transpired as the most favoured varieties due to their malleability and greater recognition among farmers, although Panniyur-1, Panniyur-2, and Bolt were testified as the least preferred varieties owing to moderated performance and susceptibility under local conditions.

The inspection also emphasized the supporting plants (rootstocks) most commonly employed in pepper cultivation. *Areca catechu*, *Cocos nucifera*, and *Gliricidia maculata* were the principal support plants recorded across the study area. Supplementary supportive species included *Colubrina* spp., *Erythrina variegata*, and *Swietenia macrophylla*, expended in particular locations contingent on accessibility and farmer liking. Major encounters consistently reported by farmers included labour shortage, climate change, destabilized market prices, flooding, and landslides, all of which diametrically influence pepper productivity. These constrictions were perceived across different sites, with slight variations in intensity depending on topography and accessibility.

The most common diseases observed in pepper plantations were quick wilt (*Phytophthora* foot rot), charcoal/ root rot, stem blight, spike shedding, bacterial wilt, anthracnose, and leaf spot disease. Among these, quick wilt and charcoal rot were evidenced most recurrently and across multiple sites, specifying their widespread prevalence in Wayanad pepper fields. In addition to varietal and disease observations, several cultivation practices were documented. Farmers employed methods such as layering for propagation, bush pepper cultivation, the Vietnam model, and multistorey cropping systems (Fig. 2, 3). These practices reflect a combination of traditional and adaptive strategies aimed at sustaining pepper productivity under varying agro-climatic conditions.

**Fig 1:** Major pepper varieties opted by the farmers of Wayanad district; **a** Panniyur-1**, b** Karimunda, **c** Wayandan**, d** Jeerakamunda, **e** Chumalanamban**, f** Neelamunda**, g** Cholamundi**, h** Paurnami**, i** Sakthi**, j** Girimunda**, k** Palod-2**, l** Aswathy**, m** Valankotta**, n** Preethi**, o** Suvarna**, p** Karuthavalankotta**, q** Karinkotta**, r** Thekkan**, s** Agali**, t** Uthirankotta

**Fig. 2** Interaction with selected pepper farmers of Wayanad district, Kerala; **a** Mattil Alavi, **b** Balakrishnan, **c** Muhammadali, **d** Jose, e Shaji, **f** Ayoob Thottil


**Fig. 3** Methods of pepper cultivation opted by the farmers; **a, b, e** Bush pepper cultivation, **c** Vietnam model, **d** Layering

## Discussion

The survey clearly demonstrates significant agro-morphological diversity among black pepper varieties cultivated across the locations, backed by both local and improved genotypes that differ in morphology, physiology, and adaptability, with newly bred hybrids further enriching this variation [20, 21, 22]. Extensive research in regional germplasm collections and field surveys shows moderate to high variability in morphological traits such as leaf shape, shoot color, spike length, berry size, and branching among black pepper cultivars. Studies conducted in the Western Ghats grouped varieties into genetically distinct clusters, explaining why local adaptability and farmer preference vary extensively. Morphological differences are underpinned by genetic divergence, highlighting the importance of both indigenous landraces and advanced hybrids in breeding programs [20, 21, 22].

Farmer surveys and performance trials consistently show that Thekkan, Uthirankotta, Shakthi, and Munthirimundi are preferred for their environmental adaptability and stable yields under local conditions; conversely, varieties such as Panniyur-1, Panniyur-2, and Bolt are less popular due to their susceptibility to disease and declining productivity in the target regions. The pattern matches broad empirical observations from genetic evaluations and on-farm trials, where compatibility with agro-ecology and disease resistance drive farmer choices [23, 24]. Research consistently identifies *A. catechu*, *C. nucifera*, and *G. maculata* as dominant support species for pepper due to their structural compatibility, microclimate modification, and accessibility. Studies on rootstock selection emphasize how support plants also impact nutrient uptake, root interaction, and overall pepper performance. Additionally, species like *Colubrina* spp., *E. variegata*, and *S. macrophylla* are chosen in region-specific contexts, reflecting farmer preferences and biodiversity consideration [24, 25, 26].

Recent regional assessments highlight labour scarcity, climate instability, fluctuating market prices, flooding, and landslides as the most pressing challenges impacting pepper productivity. Climate-driven shifts, especially increased frequency of floods and landslides, are consistently cited by farmers and researchers as key constraints in traditional pepper-growing zones. Market instability and poor labour availability further compound vulnerability, making productivity and profitability unpredictable despite genetic improvements [26, 27]. Disease prevalence is a serious constraint, with quick wilt (*Phytophthora* foot rot) and charcoal rot recognized as the most widespread and devastating, alongside anthracnose, leaf spot, stem blight, bacterial wilt, and spike shedding—often exacerbated by changing climate and soil moisture regimes [26, 27].

In response to these challenges, a spectrum of cultivation practices has been documented, including layering for vegetative propagation, bush pepper approaches for space efficiency, the Vietnam model that integrates improved irrigation and mulching, and multistorey cropping systems—all adaptive strategies proven by agronomic research to sustain productivity under changing agro-climatic conditions.[28,29,31] Farmers employ diverse and dynamic methods such as layering propagation, bush pepper cultivation, the Vietnam model, and multistorey cropping, which are validated through agronomic research in Asian contexts. The Vietnam model emphasizes improved irrigation, mulching, and soil treatments to reduce disease and optimize productivity, while bush pepper systems are recognized for their land-use efficiency and adaptability under smallholder conditions. Layering is preferred for vegetative propagation and maintaining genetic fidelity in farmer-led innovation [28, 29, 30, 31]. Together, these adaptive cultivation strategies demonstrate how farmer-led innovations, supported by agronomic research, can buffer pepper production against climatic, biological, and economic uncertainties while sustaining long-term productivity and resilience.

## Conclusion

The study underscores the considerable varietal diversity, disease prevalence, and adaptive cultivation practices shaping black pepper cultivation in Wayanad. Collectively, these findings highlight the critical need for integrated disease management, climate-resilient agronomic innovations, and farmer-centered varietal improvement to ensure sustainable productivity in traditional pepper-growing systems.

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