TAXONOMIC AND GENETIC CHARACTERIZATION OF BLACK PEPPER AND RELATED SPECIES

Thesis submitted to

University of Calicut

for the award of the degree of **Doctor of Philosophy** in Botany

BY

SAJI. K. V

UNIVERSITY OF CALICUT

Calicut, Kerala, India

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CERTIFICATE

I hereby certify that the thesis entitled **"Taxonomic and genetic characterization of black pepper and related species"**, submitted by Saji, K.V. for the award of the degree of Doctor of Philosophy in Botany of the University of Calicut, contains the results of bonafide research work carried out by him during 2001-2005 at Indian Institute of Spices Research, Calicut, under the guidance of Dr. K.S. Manilal, (Former Head, Department of Botany, University of Calicut), D-37, Jawahar Nagar, Kozhikode and the Co-guidance of Dr. K Nirmal Babu, Senior Scientist, Indian Institute of Spices Research, Calicut. This thesis or part of it has not been submitted to any other University for the award of any other degree or diploma. Certified that he has also passed the required qualifying examination.

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This is to certify that the thesis entitled "**Taxonomic and genetic characterization of black pepper and related species**" submitted to the University of Calicut by Mr. Saji K. V. at the Indian Institute of Spices Research, Calicut for the award of the degree of Doctor of Philosophy in Botany is a bonafide record of research work carried out by him under my co-guidance. No part of the work has formed the basis for the award of any other degree or diploma previously.

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Introduction

Black pepper (*Piper nigrum* L.) is one of the oldest spices known to the world. The black pepper of commerce comprises the dried fruits of this perennial climbing vine, which is indigenous to the forests of Western Ghats region of South India. Wild forms of pepper are still found growing in the rich, moist and humus soils of the sub-mountainous tracts of this region. In ancient days, it was collected as a forest produce and it was highly valued as mentioned in the old Sanskrit literature "Kashyapiyakrishisukti" (Ayachit, 2002). The wild forms of black pepper are unisexual while the cultivated forms are bisexual in nature. Probably the bisexual types might have originated from the wild unisexual ones as a result of domestication and conscious and continuous selection for high yielding types and their maintenance by vegetative propagation by people through the ages (Barber, 1906; Zeven, 1976; Ravindran and Nirmal Babu, 1994a).

Black pepper is the most widely used spice and occupies a proud place in both vegetarian and non-vegetarian cuisines of the West and the East. Black pepper contributes towards flavour, taste, anti-fungal, anti-bacterial and antioxidant properties. It is also used in indigenous medicine systems of India, China, Indonesia and Japan for making many medicinal preparations. Several black pepper and green pepper based value added products are available in the market nowadays.

Malabar black pepper has been the main item of trade between India and Europe for centuries more than 3,500 years back (Parry, 1969a). A Greek monk Cosmos Indicopleustes, in 548 AD recorded the cultivation of pepper in India for the first time. From time immemorial, trade in spices of Malabar was the monopoly of the Arabs. They were collecting this valuable spice and selling them in the Mediterranean ports from where they were distributed all over European markets. Arabs were keeping the source of these precious commodities as a trade secret. In olden days spices were considered as valuable as gold and precious stones. In England, throughout the medieval period, 'pepper rent' was exceedingly common and the tenant was obliged to supply his landlord with a fixed quantity of pepper as rent. Often the ransom demanded included pepper besides gold and silver (Gundert, 1868; Clain, 1961; De Waard and Zeven, 1969). The consumption of black pepper grew astonishingly in the days of Roman Empire and pepper became the most typical spice in medieval Europe. It was a status symbol of fine cookery and a description of a lavish feast invariably mentioned pepper, if not other spices. Pepper reigned as a paramount spice for several centuries. Though the trade between India and Rome was established as early as 40 AD after the discovery of monsoons by Hippalus, the discovery of America by Columbus was attributed to the demand for pepper in European countries. It is in search of spices the Portuguese captain Vasco da Gama discovered a direct sea route to India, landed in Calicut on 17 May 1498 (Gundert, 1868) and this in turn lead to a series of events of voyages by the Portuguese and Dutch, and finally resulting in colonization of India by the British. Since then pepper trade had become the monopoly of the Portuguese and other European maritime nations until the seventeenth century.

It was thought that the Indian emigrants to Java introduced it sometimes between 100 B.C. and A.D. 600 to Java. Japanese introduced the crop to Brazil after Second World War. Pepper trading between Java and China was recorded in A.D. 1200 and Marco Polo in A.D. 1280 recorded having seen pepper in Malaysia (Parry, 1969b). However, it was the Dutch in the seventeenth and eighteenth centuries that brought pepper cultivation on to Java, Sumatra, Borneo, Sarawak, the Malay Peninsula, Siam, Philippines and later into the West Indies on a plantation scale. Black pepper is believed to be introduced to America during the middle of 18th century (Gentry, 1955a)

India is producing about 64,000 t black pepper from an area of 216,000 ha (Agri. Data Book, ICAR 2005). India accounts for about 26 percent of the world production and about 18 percent of export (Sarma and Kalloo, 2004). In India, black pepper is cultivated mainly in Kerala, Karnataka and Tamil Nadu. Kerala accounts for nearly 90% of our country's area and production. It is generally grown as an intercrop trailed on various trees in the homesteads of the coastal zones, as a pure crop or mixed crop in the midlands, or slopes and valleys of small hills, whereas in highlands pepper is cultivated as a mixed crop on the shade trees in cardamom, coffee and tea plantations.

Piper nigrum L. belongs to the pepper family Piperaceae of the Series Microembryeae of Monochlamydeae (Bentham and Hooker, 1880). The genus *Piper* is generally distributed in the tropical and sub tropical regions of the world. The main centers of distribution are Central and South America and South Asia (Trelease and Yuncker, 1950).

The other economically important species of *Piper* are Indian long pepper (*Piper longum* L), betel vine (*P. betle* L.), Java long pepper (*P. chaba* Hunter), tailed pepper (*P. cubeba* L.), Kawa pepper (*P. methysticum* Forster), West African pepper (*P. clusi* C.DC.), Benin pepper (*P. guineense* Schum. & Thonn.) and Japanese pepper (*P. kadzura* (Choisy) Ohwi.). In India, black pepper, long pepper and betel vine are the three economically important *Piper* species grown.

The genus *Piper* was established by Linnaeus (1753) in his *Species Plantarum*, where he recognized seventeen species of *Piper*. This genus in general is characterized by very small, highly reduced flowers closely packed to form spikes. The female flower is represented by the naked ovary and the male flower is represented by 2-3 anthers subtended by a bract. The International Plant Name Index (IPNI, 2006) records more than 6000 *Piper* binomials of which 115 are from the Indian subcontinent. About 18 species are found in sub mountainous tracts of Western Ghats and adjacent peninsular and coastal region (Hooker, 1886; de Candolle, 1912; Rama Rao, 1914; Gamble 1925; Ravindran *et al.,* 1987; Velayudhan and Amalraj, 1992, Nirmal Babu *et al.,* 1993 and Tyagi *et al.*, 2004).

Piper species occurring in India are unisexual, but the Central and South American species are generally bisexual types. However, the cultivated black pepper is bisexual. It seems more than 100 cultivars of black pepper are known to India. Of these about 20 of them are widely cultivated in the major pepper growing tracts.

Though black pepper is a much sought after and economically important crop, little is known about its exact distribution pattern, botany, taxonomy and evolution. The important earlier works in this regard are those of Rheede (1688), Miquel (1843), de Candolle (1869), Hooker (1886), Rama Rao (1914), Gamble (1925), Fyson (1932), and Kanjilal *et al.* (1940). Some of the recent taxonomic studies of South Indian *Piper* are those of Manilal (1988), Rahiman (1981) Ravindran (1991) and Mathew (1998). No reports are available on the diversity and variability existing in the wild species and local cultivated types except in the case of Karimunda. The major bottleneck is the unavailability of the live specimens for the study. Hooker (1886) wrote about the genus *Piper* – Thus: -

A most difficult genus, herbarium materials for the analysis of which have never been intelligently collected, whilst the descriptions of the published species are quite inadequate for their accurate determination. ......

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Rahiman (1981) recently carried out studies on the biosystematics of *Piper* species occurring in Karnataka State based on morphological, biometrical, palynological, cytological and biochemical aspects to fix norms for classification of the genus. His studies provided the supporting evidence for the conclusions arrived at by classical taxonomists based on morphological classification. Ravindran (1991) studied the inter specific relationship of *Piper* species using taxonomic, morphologic, numeric and chemotaxonomic characterization and concluded that *P. nigrum* would have originated as a natural hybrid between *P. wightii* and *P. galeatum.* Mathew (1998) conducted morphological, cytological and palynological studies of *Piper* species.

The present study is aimed at characterizing the South Indian *Piper* spp. and 33 most important cultivars representing the diversity in cultivated black pepper (*P. nigrum)* with more detailed taxonomic and morphological characterization and distribution patterns based on Geographic Information System. This is supplemented with more recent molecular taxonomy data for a clear understanding of the species inter relationships of *Piper* including the co-existence of *P. nigrum* and the other species of this family.

Black pepper is one of the oldest spices known to the world. Black pepper of commerce comes from the dried fruits of the perennial climbing vine *Piper nigrum* L. (which is native to the forests of Western Ghats regions of Southern India (Gentry, 1955b). Black pepper, considered as the 'King of Spices' or ' Black Gold', is the most widely used spice of the world, and occupies a proud place in the cuisines of both the west and the east. It contributes towards flavour, taste, anti microbial and antioxidant properties. It is used in many forms of traditional medicine and is an ingredient in many medicinal preparations. Our ancient Sanskrit literature shows that the spice was known and highly valued since Vedic times. It was originally collected as a forest produce and was later domesticated.

The genus *Piper* is considered to be one of the largest genera of angiosperms (Kubitzki *et al.*, 1993; Soltis *et al.*, 1999) comprises of about 6700 names, most of them are certainly duplicates (IPNI, 2006). They are widely distributed in the tropical and semi tropical regions of the world particularly in Asia and Central America.

The phylogenetic position of the Piperaceae is very much confused and one view is that it is a diverse assemblage of dicots termed "paleoherbs" (Donoghue and Doyle, 1989; Loconte and Stevenson, 1991), plants that resemble monocots in certain vegetative characters (adaxial prophyll and scattered vascular bundles).

The species of *Piper* are herbs, shrubs, climbers, creepers or lianas and even trees distributed pantropically in the wet forests. The greatest diversity of *Piper* species occurs in Tropical America with over 700 species followed by Southern Asia with over 400 species. Diversity of *Piper* is also occurring in South Pacific (40 spp.) and in the African tropics (15 spp.) (Jaramillo and Manos, 2001).

Taxonomy and phylogeny

Bentham and Hooker (1880) classified the family *Piperaceae* under the sub class Monochlamydeae in the series Microembryeae. The other families coming under the same series are Chloranthaceae, Myristicaceae and Monimiaceae. Engler (1893) considered Piperales as one of the most primitive groups and placed them at the beginning of the Series. Rendle (1925) believed that Piperaceae is related to Polygoniales (segregated from the Caryophyllales) since he assumed that the flowers

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For the rest I must have the further study of the Order to local botanist in the four great centers of its Indian distribution, namely its transgangetic provinces, the South Deccan, the Malayan Peninsula and Ceylon: in each of which the species should be examined ***on the spot,*** *with a view to matching the sexes, and flowering with fruiting specimens, and to observing the* ***transition from young to old foliage,*** *and the effects* ***of locality and climate on the characters of each species.*** (Hooker 1886, *The Flora of British India.* Vol. V. p-79)

Rahiman (1981) recently carried out studies on the biosystematics of *Piper* species occurring in Karnataka State based on morphological, biometrical, palynological, cytological and biochemical aspects to fix norms for classification of the genus. His studies provided the supporting evidence for the conclusions arrived at by classical taxonomists based on morphological classification. Ravindran (1991) studied the inter specific relationship of *Piper* species using taxonomic, morphologic, numeric and chemotaxonomic characterization and concluded that *P. nigrum* would have originated as a natural hybrid between *P. wightii* and *P. galeatum.* Mathew (1998) conducted morphological, cytological and palynological studies of *Piper* species.

The present study is aimed at characterizing the South Indian *Piper* spp. and 33 most important cultivars representing the diversity in cultivated black pepper (*P. nigrum)* with more detailed taxonomic and morphological characterization and distribution patterns based on Geographic Information System. This is supplemented with more recent molecular taxonomy data for a clear understanding of the species inter relationships of *Piper* including the co-existence of *P. nigrum* and the other species of this family.

7A

Review of Literature

Black pepper is one of the oldest spices known to the world. Black pepper of commerce comes from the dried fruits of the perennial climbing vine *Piper nigrum* L. (which is native to the forests of Western Ghats regions of Southern India (Gentry, 1955b). Black pepper, considered as the 'King of Spices' or ' Black Gold', is the most widely used spice of the world, and occupies a proud place in the cuisines of both the west and the east. It contributes towards flavour, taste, anti microbial and antioxidant properties. It is used in many forms of traditional medicine and is an ingredient in many medicinal preparations. Our ancient Sanskrit literature shows that the spice was known and highly valued since Vedic times. It was originally collected as a forest produce and was later domesticated.

The genus *Piper* is considered to be one of the largest genera of angiosperms (Kubitzki *et al.*, 1993; Soltis *et al.*, 1999) comprises of about 6700 names, most of them are certainly duplicates (IPNI, 2006). They are widely distributed in the tropical and semi tropical regions of the world particularly in Asia and Central America.

The phylogenetic position of the Piperaceae is very much confused and one view is that it is a diverse assemblage of dicots termed "paleoherbs" (Donoghue and Doyle, 1989; Loconte and Stevenson, 1991), plants that resemble monocots in certain vegetative characters (adaxial prophyll and scattered vascular bundles).

The species of *Piper* are herbs, shrubs, climbers, creepers or lianas and even trees distributed pantropically in the wet forests. The greatest diversity of *Piper* species occurs in Tropical America with over 700 species followed by Southern Asia with over 400 species. Diversity of *Piper* is also occurring in South Pacific (40 spp.) and in the African tropics (15 spp.) (Jaramillo and Manos, 2001).

Taxonomy and phylogeny

Bentham and Hooker (1880) classified the family *Piperaceae* under the sub class Monochlamydeae in the series Microembryeae. The other families coming under the same series are Chloranthaceae, Myristicaceae and Monimiaceae. Engler (1893) considered Piperales as one of the most primitive groups and placed them at the beginning of the Series. Rendle (1925) believed that Piperaceae is related to Polygoniales (segregated from the Caryophyllales) since he assumed that the flowers are trimerous. But it is to be noted that in both Polygonaceae and Piperales, the ovule is solitary and orthotropous (Lyman Benson, 1970). Baillon (1872) combined both the families Piperaceae and Saruraceae due to the close relationship of these families; however, many authors separate the two families (Engler, 1893; Eichler, 1878).

According to Takhtajan (1980), Piperales stands nearer to Laurales. Rendle (1925) considered *Piper* as one of the most primitive dicots. But Bessey (1915) and Hutchinson (1926) considered Piperaceae as an independent and terminal offshoot of direct Ranalian ancestry (Lawrence, 1951). Takhtajan (1980) believed that Piperaceae had a common origin with Chloranthaceae. Rousseau (1927), Dasgupta and Datta (1976) assumed that the genus is the basic group from which other genera like *Chloranthus*, *Saururus* and *Peperomia* were derived by minor modification. Corner (1976) believed that Piperales became another phyletic line, the origin of which is lost, but which seems to have led primitively to the parasitism of Rafflesiaceae and Santalacae.

The genus name *Piper* was derived probably from the Greek name for black pepper, *Peperi* (Ravindran, 2000). The family name Piperaceae was first used by L.C. Rich in Hamboldt, Bonpland and Kunth's *Nova Genera et Species Plantarum* in 1815 (Yuncker, 1958). Linnaeus (1753) established the genus *Piper* in his *Species Plantarum*, where he described 17 species of *Piper*. Roxburgh (1832) described 18 species of which seven were from Indian Peninsula. Ruiz and Pavon (1794) introduced the second genus in the family, *Peperomia.* Later many workers described a number of additional genera. The important ones were those of Ruiz and Pavon (1798) of flora of Peru and Chile, Kunth (1822) about the *Piper* from South America and Blume (1826) on East Indian species. Among the major authorities in the Piperaceae, F.A.W. Miquel was the first monographer of Piperaceae. Miquel (1843) in his *Systema Piepracearum* subdivided the family into two tribes *viz.* Piperaceae and Peperomeae with 15 genera and 304 species in the tribe Piperaceae and 5 genera and 209 species in Peperomeae, respectively. De Candolle (1869) monographed the family Piperaceae. His work embraced about 1000 species distributed almost equally between *Piper* and Peperomia in the *Prodromous*. De Candolle's 50 years work was published posthumously in 1923 under the name "*Piperacearum Clavis Analytica*", where he considered only three genera viz. *Piper*, *Peperomia* and *Verhuellia.* A taxonomic key for identifying each species was also provided. After the death of de

Candolle, the American botanist Trelease continued the work extensively for over a period of 30 years along with his colleague Yuncker and eventually published a two-volume work on Piperaceae of northern South America (Trelease and Yuncker, 1950).

Piperaceae is one of the largest families and *Piper* and *Peperomia* are the two major genera. Other genera include *Chavica, Macropiper, Nematanthera, Pothomorphe, Sarcorhachis, Symbryon, Verhuellia* and *Zippelia.* The members are mainly distributed in tropical America and South East Asia (Tucker, 1982b). Some of these members are not consistently maintained at generic level, where as some lines are grouped under subgenera or sections, depending upon the author.

The huge size of the genus *Piper* (more than 1500 spp.) has tempted many botanists to attempt its division for easier management. De Candolle (1869) retained *Piper* as a single genus but established many sub genera. One of his criteria was stamen number, which varies from 2-10. Stamen numbers for sub generic taxa of *Piper* are: three (rarely two) in *Eupiper*, three or four in *Artanthe*, four in *Ottonia*, six (rarely five) in *Enekea*; 3-5 in *Peitobryon.* Practically, stamen number has proved difficult to determine on dried plants at the magnification available. Trelease and Yuncker (1950) did not consider stamen number in their descriptions. Eichler (1878) considered trimery and radial symmetry to typify flowers of Piperaceae. The symmetry of stamen arrangement in both Piperaceae and Saururaceae is basically bilateral for those that have been investigated. The flowers of *Pothomorphe* and *Peperomia* are usually considered the culmination of reduction of Series from types with more numerous floral appendages. This bilateral symmetry and sequence of initiation are vastly different from radial symmetry, previously assumed the basic type for the Piperales. The pairing of stamens in *Piper* and other Piperals investigated so far differs sharply from the radial helical arrangement of stamens of Magnolialian flowers. Bilateral symmetry and paired initiation of floral organs are rare in the Ranales, whereas they appear to be the rule in the Piperaceae and Saruraceae (Tucker, 1982b).

The genus *Piper* shows extreme reduction of floral characters. Heywood and Flemming (1986) and Taylor and Hickery (1990, 1992) considered Piperaceae as one of the most primitive families of Angiosperms, derived from the herbaceous protangiosperm with simple, minute flowers. *Piper* shares characteristic with two other primitive families, Chloranthaceae and Winteraceae, as there are some similarities in morphological characters and pollination mechanisms (De Figueiredo and Sazima, 2004). *Piper* is closely related to *Saurarus* and also to *Chloranthus* and all these three genera show common characters such as naked flowers, one celled ovary, sessile stigma, orthotropous ovule and albuminous seed (Le Mount and Decarenes, 1876; Heywood, 1978). All are regarded as simplification of Magnoliales, Laurales or Ranales. But none of these Orders display the primitive vascular system found in *Piper* (Corner, 1976). Piperales emerge as an order distinguished by the retention of the perisperm and the loss of the testa (Corner, 1976).

Recent studies suggest that the taxa representing major geographic areas could potentially form three monophyletic groups, Asia, the South Pacific and the Neotropics (Jaramillo and Manos, 2001). *Piper* is considered to be more primitive than *Peperomia* (Bentham and Hooker, 1880; Hutchinson 1969). According to Datta and Dasgupta (1977a) the evolution of *Piper* and *Peperomia* were related to adaptation with two different conditions. *Piper* adapted gradually with damper and lower lands with elaboration of the vascular arrangements; *Peperomia* evolved in drier and higher lands, which required reduction of bundle surface volume ratio, a xerophytic adaptation.

Habitat and distribution

Phytogeographical distribution shows that *Piper* and *Peperomia* have probably originated in tropical America at a comparatively high altitude and dry condition (Ravindran *et al*, 2000). The genus *Piper* is one of the major components of the tropical forest ecosystem (Hartemink, 2001). The distribution of *Piper* ranges from sea level to Andes and the sub- Himalayas (Royle, 1839) and are grouped into two major groups- the neotropical species which are mostly shrubs and rarely climbers and the paleotropic species which are climbers, creepers or bushy forms.

The main centre of distribution for neotropical species is Central America. In the Central American forests, the genera is distributed in four different habitats *viz.* edge of the semi deciduous forests, inside the semi deciduous forest, edge of the swampy forest and inside the swampy forests (De Figueiredo and Sazima, 2004). The paleotropic species were mainly distributed in the moist evergreen forests and to a lesser extent in the semi-evergreen forests mainly in Malaysia (about 400 species), Indian sub continent (about 115 species), Philippines (about 133 species) and to a certain extent in China (69 species). Diversity of *Piper* also occur in South Pacific (40 spp.) and in the African tropics (15 spp.) (Jaramillo and Manos, 2001).

Hooker (1886) identified two independent centers viz. the North Eastern region and the Western Ghats in India as two centers of diversity for *Piper*. However, the studies conducted by Rahiman (1987) states that there are three major centers. The sub- Himalayan and north eastern Indian centre is the first one extending from Siwalik range near Pakistan to Mismi hills in the Arunachal Pradesh, through Kumaun, Nepal, Sikkim and Bhutan. The western half of the centre is a narrow strip comprising of the foot hills of the Himalayan ranges and the eastern half is a broader region covering West Bengal, Assam, Arunachal Pradesh, Nagaland, Manipur, Tripura, Mizoram, Meghalaya, Sikkim, eastern part of Bihar and Bangladesh. The second one *viz*. Western Ghat centre extends from Vada near Bombay to Mahendragiri through Khandala Ghats, Mahabaleswar, Goa, Khanapur, Bababudan hills, Anamalai hills and Cardamom hills. The third center is the Eastern Ghats extending from the Chittoor area in Andhra Pradesh to the Puri area of Orissa. While the distribution in the first two centres is fairly dense and continuous, the distribution is sparse and discontinuous in the Eastern Ghats. The South Indian species occur in the Western Ghats from almost sea level to an elevation of 2000m. A damp location with rich organic matter content in the soil and large trees, which provide shade and support for the climbing vines are congenial for *Piper* (Rahiman *et al.*, 1979). The distribution of *Piper* is denser along footpaths, animal tracts, riversides and towards the periphery of the forests, wherever there is a good penetration of light. However, in disturbed forests they occur in good number even in the interior due to the increased light availability (Ravindran *et al.*, 2000).

New technologies such as global positioning systems (GPS) and geographic information systems (GIS) are making it possible to manage genetic variability. Geo-referencing and mapping the distribution patterns of species enables important ecological sights to be identified. Application of GIS to explore the biodiversity of crop species have successfully been implemented, indicating areas of favorable climates for their growth (Menon and Bawa, 1997; Parthasarathy *et al.*, 2003; Roy and Behera, 2005, Parthasarathy *et al.*, 2005).

Whittaker (1972) described three terms for measuring biodiversity over spatial scales: alpha, beta, and gamma diversity. Alpha diversity refers to the diversity within a particular area or ecosystem, and is usually expressed by the number of species (i.e., species richness) in that ecosystem. Beta diversity refers to a comparison of diversity between ecosystems, usually measured as the amount of species change between the ecosystems by counting the total number of species that are unique to each of the ecosystems being compared. Thus, beta diversity allows us to compare diversity between ecosystems (Meffe *et al.*, 2002). Gamma diversity is a measure of the overall diversity for the different ecosystems within a region i.e., "geographic-scale species diversity" or regional diversity.

***Piper* in other countries**

Yongqain *et al.* (1999) prepared the flora of China and reported three genera: *Zippelia, Piper* and *Peperomia* from China. They have reported one species of *Zippelia*, 7 species of *Peperomia* and 60 species of *Piper*. Gilbert and Nain-he (1999) described four new species from China. The new species described by them are *Piper dolichostachyum, P. tsengianum, P. wangii* and *P. yui*. Revision of family Piperaceae was done by Ridley (1924) in which he documented 75 species in Peninsular Malaya. But De Waard and Anunciado (1969) recorded over 400 species of *Piper* from the Malaysian region. Extensive studies on the revision of wild Piperaceae of Philippines have been conducted by many workers. These included studies done by de Candolle (1910) where he recognized a total of 133 species of *Piper* and 26 species of *Peperomia* occurring in the Philippines. The systematic study of the Philippine Piperaceae was later done by Quisumbing (1930) in his extensive studies of the family; he documented 87 species of *Piper* and 21 species of *Peperomia*. He also recognized the classification of the genus *Piper* into six sections namely *Heckaria*, *Eupiper*, *Sarcostemon* and *Muldera*, following the classification by C. de Candolle (1923) while sections *Penninervia* and *Zippelia* were newly proposed. In Thailand, the diversity of *Piper* is restricted to about 30 species (Chaveerach *et al.*, 2002). *Piper, Peperomia and Lepianthes* are the three common genera recorded from Seychelles (Robertson, 1987). Gerlach (2002) reported the presence of *P. nigrum, P. betle* and a new species *P. silhouettanum* J. Gerlach from Seychelles. Gardner (2003) reported six species from New Guinea.

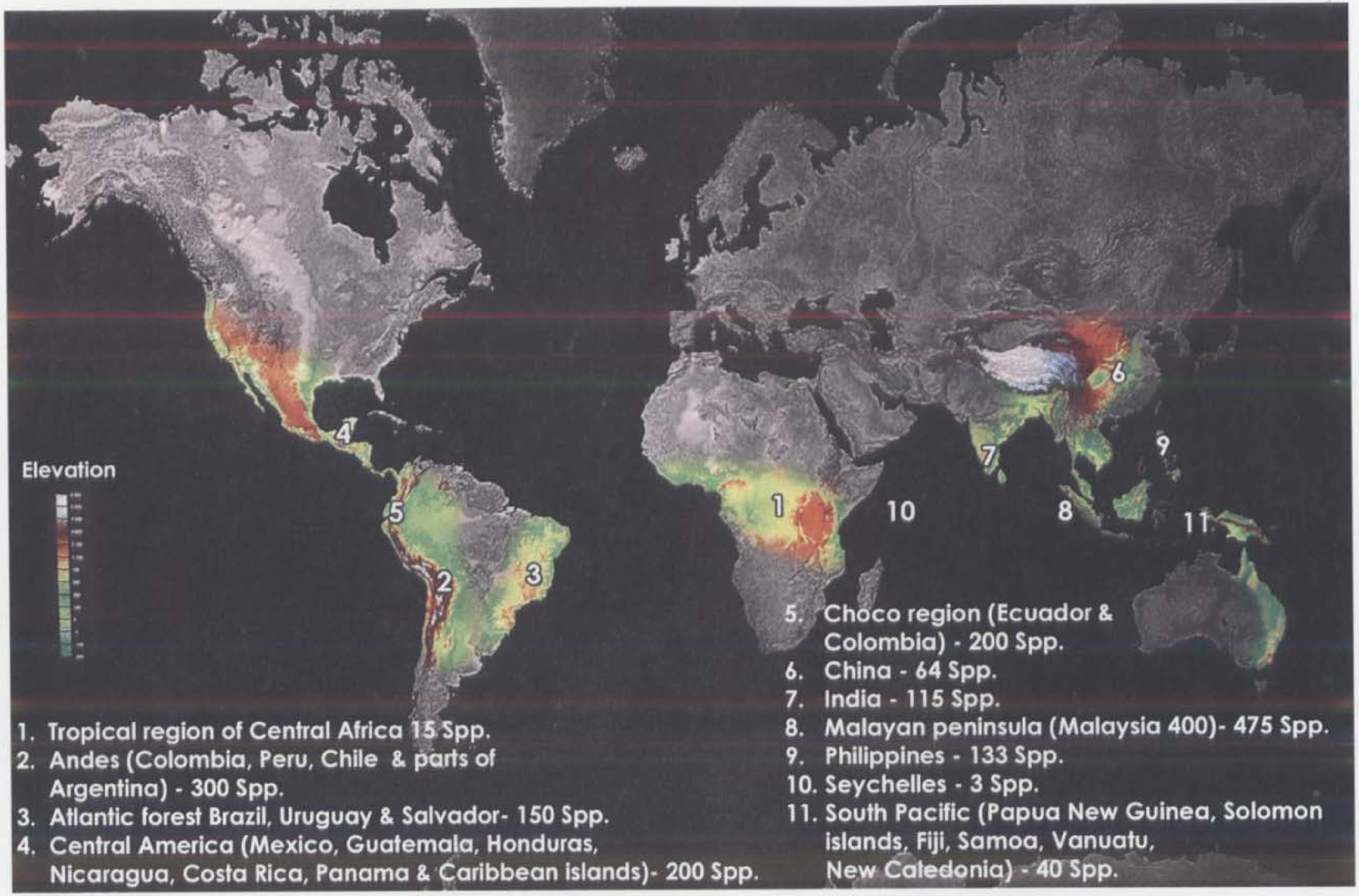


Fig. 1. Geographical distribution of *Piper* species in the world

The Indian scenario

The '*Hortus Indicus Malabaricus*' published by Rheede (1688) is considered to be the earliest record of description about the *Piper* species of Indian region. Five species of *Piper* were described and four were illustrated. Linnaeus (1753) in his *Species Plantarum* included 17 species of *Piper* of which 5 were from India. Later, Casparus (1796) published his *"Flora Malabarica Sive Horti Malarici Catalogue*' where he also described five species. Roxburgh (1832) reported seven species of *Piper* from Indian Peninsula. Miquel (1843) included seven wild species of *Piper* from India in his monograph *Systema Piperacearum.* Out of the 16 species illustrated by Wight (1853) in his *"Icones Plantarum Indiae Orientalis"* 15 were from Indian Penisula. Of the 640 species described by de Candolle (1869) in '*Prodromous*' 82 were from Indian Peninsula.

Flora of British India, published by Hooker (1886) with phytogeographical information is the first major study of *Piper* species from Indian sub continent. He reported 45 species of *Piper* from British India. Hooker divided the genus into six sections, viz. Muldera, Cubeba, Chavica, Pseudo chavica, Eupiper and Heckeria. He has also mentioned a long list of doubtful species. Subsequently, many regional floras came out during the 20th century. The important ones are listed in Table 1.

Floristic study of Western Ghats carried out by Gamble (1925) is adjudged as the best among the regional floras. He has described the species with key for identification of each species. Subsequently the floristic studies were undertaken with a view to preparing a complete and comprehensive flora of India and reported the availability of Piperaceae members. Rahiman and Nair (1987) described eight species viz. *P. attenuatum, P. hookeri, P. argyrophyllum, P. nigrum, P. trichostachyon, P. mullesua* and *P. longum* from Karnataka with key for identification of each species. Ravindran (1991) proposed a key for *Piper* species based on his survey to the southern parts of Western Ghats. He has divided the genus into two groups viz. Pippali and Maricha based on the position of the spikes. Species with erect spikes were grouped in Pippali (*P. longum, P. mullesua* and *P. silentvalleyensis*) and with pendant spikes under the section 'Maricha'.

Fig. 2. Centre of distribution of *Piper* in India

Table 1. Regional and local floristic studies on genus *Piper*

Region/State	Author and Year	No. of species included
Maharashtra		
Flora of Presidency of Bombay	Cooke (1906)	5
Khandala	Santapau (1967)	3
Sawantwadi	Almeida (1990)	4
Karnataka		
Hassan district	Saldanha and Nicolson (1976)	5
Mysore district	Rao and Razi (1974)	3
Karnataka	Sharma *et al.* (1984)	13
Tamil Nadu		
Anamalai Hills	Fischer (1921)	6
Tamil Nadu carnatic	Mathew (1983)	3
Central Tamil Nadu	Mathew (1991)	3
Flora of Courtallum	Nair and Nayar (1986)	2
Kerala		
Flowering Plants of Travancore	Rama Rao (1914)	11
Flora of the Presidency of Madras	Gamble (1925)	13
Flora of Nilgiris and Pulney hills tops	Fyson (1932)	4
Flora of Calicut	Manilal and Sivarajan (1982)	2
Flora of Canannore	Ramachandran and Nair (1988)	6
Flora of Silent Valley	Manilal (1988)	5
Flora of Palaghat	Vajravelu (1990)	6
Flora of Pathanamthitta	Anilkumar *et al.* (2005)	7
Flowering plants of Thrissur forests	Sasidharan and Sivarajan (1996)	5
Flora of Nilambur	Sivarajan and Philip (1997)	5
Flora of Malapruam district excluding Nilambur forest	Babu (1990)	2
Biodiversity documentation for Kerala	Sasidharan (2004)	16
North Eastern Region		
Bengal Plants	Prain (1903)	8
Siwalik and Sub Himalayan tracts	Duthie (1903)	5
Flora of Abhor hills	Burkill (1923, 1925)	13
Flora of Assam	Kanjilal *et al.* (1940)	13
Floristic diversity of Assam	Bora and Yogendrakumar (2002)	3
Forest flora of Meghalaya	Haridasan and Rao (1987)	3
Botany of Bihar and Orissa	Haines (1924)	5

After Gamble's (1925) extensive work, a few more new species were reported and added to the genus *Piper* (Manilal and Ravindrakumar, 1998). Rahiman (1981) described a new species, *P. bababudani,* from the Bababudan hills of Karnataka. Ravindran *et al.* (1987) reported a bisexual species, *P. silentvalleyensis* and another variety of *P. nigrum* L. var. *hirtellosum* from the Silent Valley wild life sanctuary of Kerala. Velayudhan and Amalraj (1992) found a new species *P. pseudonigrum* and Nirmal Babu *et al.* (1993) reported *P. sugandhi* and a sub species *P. sugandhi*. var. *brevipilis* from the forests of Sugandhagiri Hills, Wayanad. Gajurel *et al.* (2000) recorded the occurrence of *P. acutistigmum,* a native of Myanmar, in India. They also reported two new morphologically distinct species viz. *P. haridasanii,* a rare species and *P. arunachalensis* – a new species endemic to Arunachal Pradesh (Gajurel *et al.,* 2001a & 2001b). Sam *et al.* (2004) reported *P. sarmentosum* from the Andaman Islands.

So far about 115 species are reported from India. The *Piper* species reported from the Indian subcontinent are listed in Table 2.

Cultivated black pepper

Black pepper is one of the earliest perennial spices under cultivation in the humid tropics (Mary and Mercy, 1978). It is probable that the cultivated forms in different regions have originated from wild peppers of the same region. Under domestication many changes have been taken place in their characters like leaf length, leaf shape, breadth, spike length, berry size, shape, quality characters like oleoresin content, volatile oil and piperine content etc in addition to unisexual to bisexual nature which contribute to the existing variability in black pepper. About 70 to 100 biotypes are under cultivation (Mathai *et al.*, 1981; Ravindran *et al.*, 2000). They are arbitrarily named after the locality of cultivation, appearance of the vine, leaf shape, spike features etc. No systematic and detailed studies have been made to differentiate the varieties.

Table 2. *Piper* species reported from India

Sl. No	Species	First reported from	Index kewensis reference
1.	*P. accrescens* Van Heurck & Müll.Arg.	India	In *Heurck, Obs. Bot.* 118. (IK)
2.	*P. acutistigmum* C.DC.	Myanmar/ India	*Candollea* i. 188 (1923), in clavi; et in *Candollea*, ii. 196 (1925), descr.ampl. (IK)
3.	*P. anisotis* Hook.f.	Himalaya	*Fl. Brit. Ind.* v. (1886) 86. (IK)
4.	*P. arborescens* Roxb.	Bengal	*Hort. Bengal.* 80 (1814), nomen; Fl. Ind., ed. Carey & Wall., i. 161 (1820); Fl.Ind., ed. Carey, i. 159 (1832). (IK)
5.	*P. arborigaudens* C.DC.	India/Khasi hills	*Candollea* i. 192 (1923), in clavi; et in *Candollea*, ii. 198 (1925), descr.ampl. (IK)
6.	*P. argyrophyllum* Miq.	Western Ghats	*Syst. Pip.* 330. (IK)
7.	*P. arunachalensis* Gajurel, Rethy & Y.Kumar	Arunachal Pradesh	*Bot. J. Linn. Soc.* 137(4): 418 (2001). (IK)
8.	*P. attenuatum* Buch.Ham. ex Wall.	India/Malaya	*Cat. n.* 6642 B. (IK)
9.	*P. aurantiacum* Wall.	Himalaya	*Cat. n.* 6658 A. (IK)
10.	*P. aurorubrum* C.DC	Manipur	In *Fedde, Repert.* x. 519 (1912). (IK)
11.	*P. bababudani* Rahiman.	Karnataka	PhD Thesis, 1991
12.	*P. barberi* Gamble	Tamil Nadu	in *Kew Bull.* 1924, 387. (IK)
13.	*P. bengalense* C.DC.	Khasi hills	*Candollea* i. 189 (1923), in clavi; et in *Candollea*, ii. 197 (1925), descr.ampl. (IK)
14.	*P. betle* L.	India	*Sp. Pl.* 28. (IK)
15.	*P. betleoides* C.DC.	Sikkim; Bengal	*Candollea* i. 186 (1923), in clavi; et in *Candollea*, ii. 207 (1925), descr.ampl. (IK)
16.	*P. boehmeriaefolium* Wall.	Himalaya	Cat. n. 6654 A. (IK)
17.	*P. brachystachyum* Wall.	Himalaya	Cat. n. 6656, partim. (IK)
18.	*P. calvilimbum* C.DC.	Sikkim	*Candollea* i. 213 (1923), in clavi; et in *Candollea*, ii. 210 (1925), descr.ampl. (IK)
19.	*P. caninum* Blume	India	In *Verh. Batav. Gen.* xi. (1826) 214. f. 26. (IK)
20.	*P. carnistigmum* C.DC.	Bengal	*Candollea* i. 186 (1923), in clavi; et in *Candollea*, ii. 193 (1925), descr.ampl. (IK)
21.	*P. caudilimbum* C.DC.	Assam, Bengal	*Candollea* i. 198 (1923), in clavi; et in *Candollea*, ii. 206 (1925), descr.ampl. (IK)
22.	*P. chaba* Hunter	India	in *As. Res.* ix. (1809) 391. (IK)
23.	*P. clarkei* C.DC.	Bengal	*Candollea* i. 186 (1923), in clavi; et in *Candollea*, ii. 192 (1925), descr.ampl. (IK)
24.	*P. clypeatum* Wall.	India	*Cat. n.* 6665 A et B (Fici sp.). (IK)
25.	*P. cornilimbum* C.DC.	Khasi hills	*Candollea* i. 191 (1923), in clavi; et in *Candollea*, ii. 197 (1925), descr.ampl. (IK)
26.	*P. crassistipes* C.DC.	Assam	*Candollea* i. 229 (1923), in clavi; et in Candollea, ii. 214 (1925), descr.ampl. (IK)
27.	*P. crenulatibracteum* C.DC.	Karnataka	in *Fedde, Repert.* x. 521 (1912). (IK)
28.	*P. cubeba* L. f.	India	*Suppl.* 90. (IK)
29.	*P. curtistipes* C.DC.	Sikkim, Khasi hills	*Candollea* i. 225 (1923), in clavi; et in *Candollea*, ii. 213 (1925), descr.ampl. (IK)
30.	*P. dekkoanum* C.DC.	Assam	*Candollea* i. 199 (1923), in clavi; et in *Candollea*, ii. 206 (1925), descr.ampl. (IK)
31.	*P. diffusum* Blume ex Miq.	Bhutan	in *Linnaea*, xx. (1847) 130. (IK)
32.	*P. exasperatum* Vahl	India	*Enum.* i. 332. (IK)

33.	*P. falconeri* C.DC.	India	*Candollea* i. 187 (1923), in clavi; et in *Candollea*, ii. 195 (1925), descr.ampl. (IK)
34.	*P. filipedunculum* C.DC.	Sikkim	*Candollea* i. 186 (1923), in clavi; et in *Candollea*, ii. 193 (1925), descr.ampl. (IK)
35.	*P. galeatum* C.DC.	India	In *DC. Prod.* xvi. I. 242. (IK)
36.	*P. gallatlyi* C.DC.	Assam	*Candollea* i. 229 (1923), in clavi; et in *Candollea*, ii. 214 (1925), descr.ampl. (IK)
37.	*P. gamblei* C.DC.	Sikkim, Bengal	*Candollea* i. 204 (1923), in clavi; et in *Candollea*, ii. 208 (1925), descr.ampl. (IK)
38.	*P. gammiei* C.DC.	Assam	*Candollea* i. 194 (1923), in clavi; et in *Candollea*, ii. 202 (1925), descr.ampl. (IK)
39.	*P. gibsonii* C.DC.	Bombay	*Candollea* i. 184 (1923), in clavi; et in *Candollea*, ii. 190 (1925), descr.ampl. (IK)
40.	*P. glabramentum* C.DC.	Assam	*Candollea* i. 219 (1923), in clavi; et in *Candollea*, ii. 211 (1925), descr.ampl. (IK)
41.	*P. glabrirhache* C.DC.	Nilgiri	*Candollea* i. 193 (1923), in clavi; et in *Candollea*, ii. 200 (1925), descr.ampl. (IK)
42.	*P. grandipedunculum* C.DC.	Khasia India	*Candollea* i. 209 (1923), in clavi; et in *Candollea*, ii. 209 (1925), descr.ampl. (IK)
43.	*P. griffithii* C.DC.	Himalaya	*in Journ. Bot.* iv. (1866) 163. (IK)
44.	*P. guigual* Buch.-Ham. ex D.Don	India	*Prod. Fl. Nep.* 20. (IK)
45.	*P. hamiltonii* C.DC.	Himalaya	in *DC. Prod.* xvi. I. 360. (IK)
46.	*P. hapnium* Buch.-Ham.	India	in *Wall. Cat.* n. 6650 D. (IK)
47.	*P. haridasanii* Gajurel, Rethy & Y.Kumar	Arunachal Pradesh	*J. Econ. Taxon. Bot.* 25(2): 293 (2001). (IK)
48.	*P. hookeri* Miq.	India	*London J. Bot.* iv. (1845) 437. (IK)
49.	*P. hymenophyllum* (Miq.) Wight	Western Ghat	*Icon. Pl. Ind. Orient.* (Wight) 4 (t. 1942). 1853 (IK)
50.	*P. isopleurum* C.DC.	Sikkim	*Candollea* i. 193 (1923), in clavi; et in *Candollea*, ii. 201 (1925), descr.ampl. (IK)
51.	*P. japvonum* C.DC.	Manipur	*Candollea* i. 193 (1923), in clavi; et in *Candollea*, ii. 200 (1925), descr.ampl. (IK)
52.	*P. jenkinsii* C.DC.	Assam	*Candollea* i. 220 (1923), in clavi; et in *Candollea*, ii. 212 (1925), descr.ampl. (IK)
53.	*P. kapruanum* C.DC.	Manipur	-- in *Fedde, Repert.* x. 519 (1912). (IK)
54.	*P. khasianum* C.DC.	Himalaya	in *DC. Prod.* xvi. I. 349. (IK)
55.	*P. laeve* Vahl	India	*Enum.* i. 332. (IK)
56.	*P. lainatakanum* C.DC.	Manipur	in *Fedde, Repert.* x. 519 (1912). (IK)
57.	*P. lanatum* Roxb.	Arunachal Pradesh	*Hort. Bengal.* 80 (1814), nomen; Fl. Ind., ed. Carey & Wall., i. 161 (1820); Fl.Ind., ed. Carey, i. 159 (1832). (IK)
58.	*P. laxivenum* C.DC.	Sikkim	*Candollea* i. 213 (1923), in clavi; et in *Candollea*, ii. 210 (1925), descr.ampl. (IK)
59.	*P. longum* L.	India, Tropical Asia	*Sp. Pl.* 29. (IK)
60.	*P. maingayi* Hook.f.	India	*Fl. Brit. Ind.* v. (1886) 80. (IK)
61.	*P. makruense* C.DC.	Manipur	*in Fedde, Repert.* x. 521 (1912). (IK)
62.	*P. malamiris* L.	India	*Sp. Pl.* 29. (IK)
63.	*P. mannii* C.DC.		*Candollea* i. 196 (1923), in clavi; et in *Candollea*, ii. 204 (1925), descr.ampl. (IK
64.	*P. meeboldii* C.DC.	Manipur	*in Fedde, Repert.* x. 521 (1912). (IK)
65.	*P. mullesua* Buch.-Ham.	India	*Prodr.* Fl. Nepal. 20. 1825 (IK)
66.	P. *muneyporense* C.DC.	Manipur	*Candollea* i. 222 (1923), in clavi; et in *Candollea*, ii. 213 (1925), descr.ampl. (IK)
67.	*P. mungpooanum* C.DC.	Sikkim	*Candollea* i. 185 (1923), in clavi; et in *Candollea*, ii. 192 (1925), descr.ampl. (IK)

68.	*P. nagaense* C.DC.	Manipur	in *Fedde, Repert.* x. 520 (1912). (IK)
69.	*P. nepalense* Miq.	Himalaya	*Syst. Pip.* 318. (IK)
70.	*P. nigramentum* C.DC.	Sikkim	*in Fedde, Repert.* xiii. 299 (1914). (IK)
71.	*P. nigrum* L.	India Malaya	*Sp. Pl.* 28. (IK)
72.	*P. obtusistigmum* C.DC.	Nilgiri	*Candollea* i. 217 (1923), in clavi; et in *Candollea*, ii. 211 (1925), descr.ampl. (IK)
73.	*P. oldhamii* C.DC.	Khasia India	*Candollea* i. 195 (1923), in clavi; et in *Candollea*, ii. 203 (1925), descr.ampl. (IK)
74.	*P. ootacamundense* C.DC.	Madras India	*Candollea* i. 184 (1923), in clavi; et in *Candollea*, ii. 191 (1925), descr.ampl. (IK)
75.	*P. opacilimbum* C.DC.	Nilgiri	*Candollea* i. 184 (1923), in clavi; et in *Candollea*, ii. 191 (1925), descr.ampl. (IK)
76.	*P. ovatistigmum* C.DC.	Sikkim	*Candollea* i. 188 (1923), in clavi; et in *Candollea*, ii. 196 (1925), descr.ampl. (IK)
77.	*P. ovato-acuminatum* C.DC.	Sikkim	*Candollea* i. 187 (1923), in clavi; et in *Candollea*, ii. 195 (1925), descr.ampl. (IK)
78.	*P. ovatostemon* C.DC.	Nilgiri	*Candollea* i. 196 (1923), in clavi; et in *Candollea*, ii. 204 (1925), descr.ampl. (IK)
79.	*P. pallidum* Van Heurck & Müll.Arg.	India	in *Heurck, Obs. Bot.* 120. (IK)
80.	*P. parvilimbum* C.DC.	Khasi hills	*Candollea* i. 197 (1923), in clavi; et in *Candollea*, ii. 205 (1925), descr.ampl. (IK)
81.	*P. pedicellatum* C.DC.	Sikkim, Bengal	in *Journ. Bot.* iv. (1866) 164. (IK)
82.	*P. peepuloides* Roxb.	Himalaya	*Hort. Bengal.* 4; Fl. Ind. i. 157. (IK)
83.	*P petiolatum* C.DC.	Himalaya	in *Journ. Bot.* iv. (1866) 161. (IK)
84.	*P. phalangense* C.DC.	Manipur	*in Fedde, Repert.* x. 518 (1912). (IK)
85.	*P. pseudonigrum* K.C.Velayudhan & V.A.Amalraj	Western Ghats	*in J. Econ. Taxon. Bot.*, 16(1): 247 (1992). (IK)
86.	*P. puberulirameum* C.DC.	India	in *Rec. Bot. Surv. India*, vi. 7 (1912). (IK)
87.	*P. pykarahense* C.DC.	Tamil Nadu	*in Fedde, Repert.* xiii. 300 (1914). (IK)
88.	*P. retrofractum* Vahl.	India	*Enum.* i. 314. (IK)
89.	*P. rhytidocarpum* Hook.f.	Himalaya	*Fl. Brit. Ind.* v. (1886) 92. (IK)
90.	*P. ribesioides* Wall.	Andaman Islands	*Cat.* n, 6637. (IK)
91.	*P. sarmentosum* Roxb.	India	in *Asiat. Res.* xi. 565 (1810). (IK)
92.	*P. schmidtii* Hook.f.	Himalaya, Nilgiris	*Fl. Brit. Ind.* v. (1886) 89. (IK)
93.	*P. saxatile* Wall.	Nepal	in Roxb. *Fl. Ind.*, ed. Carey & Wall., i. 163 (1820); *Fl. Ind.*, ed. Carey, i. 161(1832). (IK)
94.	*P. sikkimense* C.DC.	Sikkim	*Candollea* i. 192 (1923), in clavi; et in *Candollea*, ii. 199 (1925), descr.ampl. (IK)
95.	*P. silentvalleyensis* Ravindran, M.K.Nair & Asokan Nair	Western Ghats	*J. Econ. Taxon. Bot.* 10(1): 167. 1988 [1987 publ. 1988] (IK)
96.	*P. siriboa* L.	India	*Sp. Pl.* 29. (IK)
97.	*P. subpeltatum* Willd. --	India	*Sp. Pl.* i. 166. (IK)
98.	*P. sugandhi* Babu et Naik	Western Ghats	*J. Spices and Aromatic Crops*, 2, 26-33. (1993)
99.	*P. suipigua* Buch.-Ham. ex D.Don	Nepal	*Prod. Fl. Nep.* 20. (IK)
100.	*P. subrigidilimbum* C.DC.	Bengal	*Candollea i.* 193 (1923), in clavi; et in *Candollea*, ii. 201 (1925), descr.ampl. (IK)
101.	*P. sylvaticum* Roxb.	Bengal, Himalaya	*Hort. Bengal.* 4; Fl. Ind. i. 156. (IK)

102.	*P. sylvestre* Lam.	India	*Illustr.* i. 79. (IK)
103.	*P. syringifolium* Vahl	India	*Enum.* i. 328. (IK)
104.	*P. talbotii* C.DC.	Bombay	*in Fedde, Repert.* x. 523 (1912), nomen. (IK)
105.	*P. tenuibracteum* C.DC.	Sikkim	*Candollea* i. 187 (1923), in clavi; et in *Candollea,* ii. 195 (1925), descr.ampl. (IK)
106.	*p. tenuiflorum* Vahl	India	in *West, Bidr. Ste -Croix*, 268. (IK)
107.	*P. thermale* Vahl	India	*Enum.* i. 329. (IK)
108.	*P. thomsoni* Hook.f.	Himalaya	*Fl. Brit. Ind.* v. (1886) 87. (IK)
109.	*P. trichostachyon* C.DC.	Western Ghats	in *DC. Prod.* xvi. I. 242. (IK)
110.	*P. trioicum* Roxb.	India	*Hort. Bengal.* 4 (1814), nomen; Fl. Ind., ed. Carey & Wall., i. 153 (1820); Fl.Ind., ed. Carey, i. 151 (1832). (IK)
111.	*P. tristachyon* C.DC.	Tamil Nadu	in *DC. Prod.* xvi. I. 335. (IK)
112.	*P. voigtii* C.DC.	India	in *Linnaea*, xxxvii. (1871-72) 365. (IK)
113.	*P. wightii* Miq.	India	*London J. Bot.* v. (1846) 552. (IK)
114.	*P. zuccarinii* C.DC.	India	in *DC. Prod.* xvi. I. 365 (Pothos sp. ?). (IK)

Source: Rahiman (1981), Rahiman and Nair (1983), IPNI (www.ipni.org) and Nirmal Babu *et al.* (1993), Velayudhan and Amalraj (1992), Gajurel *et al.* (2000, 2001a & 2001b)

Botany

The *Piper* species occurring in India are generally perennial, scandent or woody climbers or creepers or bushes. The pepper vine has two types of branches, the orthotropic branches and the plagiotropic fruiting branches. The orthotropic branches are vegetative and have monopodial growth habit. After climbing over the support they become woody with thick bark, which form the central axis of the column. The nodes are swollen and each node has a leaf. Leaves are ribbed (veins originating from the base or near the base and ascending to the tip) petiolate, alternate, simple, entire, often unequal sided; petiole grooved and range from very thin and membranous as in *P. argyrophyllum* to thick and coriaceous in texture as in *P. schmidtii*; some are glabrous and others having a few surface scales. Most of the species have small but conspicuous glandular dots, frequently on leaves but sometimes on their tender and fleshy parts as well. Stipules number zero to two, connate to adnate to the petiole (Hooker, 1886; Haines, 1924; Gamble, 1925; Saldanha and Nicolson, 1976).

Inflorescence is a catkin generally called spike, which is either pendant or erect and opposite to the leaves. They are predominantly filiform, sometimes cylindrical as in *P. longum* and *P. hapnium* or rarely sub globose like *P. mullesua.* Peduncle may be glabrous, hirtelleous or puberculous and varies in length and shape. Stamens are generally two in number and in some species it ranges from three to four. Filaments are short, anther lobes two, rarely one, each lob with two pollen sacs which after dehiscence, become one due to confluence. Ovary is single, sessile, sub globose or flask shaped, 1- ovuled; stigma is usually sessile, orthotropous. Fruit is a small indehiscent berry, testa thin, ovule anatropous. Cotyledons are minute with a thick radicle (Le Mount and Decarenes, 1876; Gamble, 1925).

The anatomy of *Piper* stem is unique and varies from that of other dicots in having medullary bundles (pith bundles) in addition to the normal cortical bundles and a sclerenchymatous sheath that supports the cortical bundles internally. Because of the anomalous primary structure, their secondary thickening also becomes abnormal and greatly differs from those of other dicot stems. The anatomy of *Piper* stem was studied by Debray (1886), Ironside (1911), Chibber (1913), Johnson (1914), Hoffstadt (1916), Rousseau (1927), Bond (1931), Kaplan (1936), Metcalfe and Chalk (1950), Burger (1972) and Judd *et al.*, (1999).

Datta and Dasgupta (1977 a, b, 1979) carried out the leaf anatomy of *Piper* spp. and *Peperomia* and came to the conclusion that *P. cubeba* is more primitive than other species studied by them. Santagio *et al.* (2001) studied the leaf anatomy of *P. hispidinervium* under different light conditions. Anatomical studies of leaf of *Piper nigrum* reveal that the epidermis is made up of small rectangular cells and the hypodermis beneath it is of 2-3 layers of large rectangular cells. The hypodermis on the abaxial side is usually of two layers, while on the adaxial side it is three layers. The palisade is relatively narrow composed of one row of cells. The spongy tissue is composed of 3-4 rows of round to irregularly shaped cells. Wax glands or pearl glands are present on the upper and lower surface of the plant (Ravindran *et al.*, 2000). Souza *et al.* (2004) made a comparative morphological and anatomical study of the stem and leaves of three common Brazilian species of Piperaceae and interpreted that the three species show some structural likeness.

The shoot anatomy of *Macropiper excelsum* was studied by Balfour (1957, 1958) as well as Rajni and Anne (1980). The authors state that the phylogenetic position of Piperaceae is much advanced due to its specialized nature of vascular anatomy when compared with the other families like Chloranthaceae and Saururaceae.

Chibber (1913), Datta and Dasgupta (1977 a, b) and Mohandas and Shah, (1980) studied the anatomy of *P. betle*.

Murthy (1959) studied the vegetative anatomy of *P. betle, P. longum and P. subrubrispicum* and noticed similar anatomical features for all the three species, supporting to the earlier findings of Solereder (1908) and Metcalfe and Chalk (1950). Bond (1931) studied the stem endodermis in eight species. Pal (1961) studied the origin and development of the vascular system in the shoot apices of six species of *Piper*. Hoffstadt (1916) studied the histology of *P. methystichum* and *P. umbellatum* and found that both the species are almost identical in structure. Datta and Dasgupta (1977 c) also studied the root anatomy of *P. betle, P. cubeba, P. longum, P. magnificum* and *P. nigrum.* The arrangement of vascular bundles in the roots of *Piper* evolved from a central core of tracheary elements to a continuous ring of radiating tracheary plates. The number of tracheary plates gradually increased in *Piper*, probably with the irrigation from hills to moist low lands. Tucker (1982a) studied the development of inflorescence and flowers in three *Piper* species viz. *P. aduncum, P. amalago* and *P. marginatum.*

Garner and Beakbane (1968) conducted studies on the anatomy of *P. nigrum* (clone Kutching of Sarawak and cultivar Uthirankotta of India). Ravindran and Ramashree (1998) studied the anatomy of the dimorphic branches and the aerial roots of *P. colubrinum.* They noticed that the number and size of peripheral and medullary bundles show variations in the two types of shoots and secondary growth occurs only in the peripheral bundles. They also noticed that the aerial roots of *P. colubrinum* undergone transformation in internal structure when they enter in soil and grow as underground roots. Sasikumar *et al.* (1999a) have characterized two interspeicifc hybrids resistant to 'pollu' beetle based on anatomical and other characters. These hybrids exhibited distinctiveness in morphological and anatomical features from their parents.

Degade (2004) has conducted a study on the anatomical basis of resistance to foot rot disease using a susceptible variety (Panniyur-1), a tolerant one (Kalluvally) and another immune species *P. colubrinum* and revealed that anatomical features such as thicker epidermis, lower number of epidermal appendages, smaller cortical cells, smaller stele, thicker pericycle, larger pericycle cells, smaller vascular bundles and compact arrangement of cells can contribute to immunity against foot rot disease.

Most of the *Piper* species occurring in the paleotropics are dioecious while the neotropical species are monoecious. Barber (1906) and Anandan (1924) recorded abiotic modes of pollen transmission as the most important pollination mechanism in *P. nigrum.* It was widely assumed that *Piper* species were pollinated by wind and or water. Gentry (1985) opined that because of its small dimensions the pollen could be vectored by wind. Menon (1981) studied some aspects of reproductive biology of black pepper. It takes about 11-37 days for the complete emergence of the spike depending upon the variety. First flower appears on the top of the spike 10-15 days after the emergence of spike and the flowering in a spike will be completed within 6-10 days. Protogynous condition of bisexual flowers is a common feature in most of the cultivars but less pronounced in the cultivar Karimunda. The male and female phase of maturity in the protogynous cultivar is spaced by 1-14 day's difference. It is reported that under Malaysian (Sarawak) conditions it takes 16 days for stigma emergence from spike. Anther dehiscence takes place during 12-14 days under Sarawak condition (De Waard and Zeven, 1969). Pollen grains are small, light brown spherical structures with well demarcated exine, having 10 μm diameter and appear in glutinous mass (Menon, 1981; Martin and Gregory, 1962). De Waard and Zeven (1969) stated that positive geotropism, spatial arrangement of flowers, sequential ripening of the stigma and non-chronological dehiscence of anthers stimulate geiotonogamic fertilization. Menon (1949) carried out the pollination studies of *P. nigrum* and concluded that only rain water is responsible for pollen flow. Sreekumari Amma and Vijayagopal (1977) are of the view that rain has no effect on promotion and rainfall appears to be having impact on flower initiation. Sasikumar *et al.* (1992) reported that selfing (geiotonogamy) with occasional out-crossing is the predominant mode of pollination in cultivated bisexual black pepper varieties.

Martin and Gregory (1962) studied the pollination of four neotropical species. *P. amalago, P. scabrum, P. citririfolium* and *P. blattarum*. They suggested that the pollination of the first three species took place by wind action, but in the case of *P. blattarum*, which bears glutinous pollen similar to that of *P. nigrum*, pollination occurs due to the gravitational force, wind and rain water. Semple (1974) studied the pollination studies in five *Piper* species in Costa Rica and reported that small neotropical bees are the major pollinators of these species. Studies by Fleming (1985) with some Costa Rican species also supported this.

De Figueiredo and Sazima (2000, 2004) carried out studies on the distribution, breeding and pollination mechanism of 11 Brazilian *Piper* species. They have reported anemophily in seven species and entomophily in three species viz. *P. amalago, P. crassinervium* and *P. glaberatum.*

Bio systematics

The earliest attempts to apply numerical methods to taxonomy date back from the rise of biometrics in the last century. It was realized early that biometrics could be applied to systematics, but the only eventual development was that of discriminant functions which are useful in one specialized problem of taxonomy (Fisher, 1936). Numerical taxonomy is referred to the numerical evaluation of the affinity or similarity between taxonomic units and the ordering of unit into taxa on the basis of their affinities. This is achieved by the conversion of information on taxonomic entities into numerical quantities. Numerical taxonomy is depending on the following hypothesis (Sokal and Sneath, 1963).

(i) Nexus hypothesis: Every taxonomic character is likely to be affected by more than one genetic factor and conversely most genes affect more than one character.

(ii) Hypothesis of non-specificity: There are no large classes of genes affecting exclusively one class of characters such as morphological, physiological or ecological. This will encourage the use of large number of characters for numerical analyses.

Some earlier studies similar to numerical taxonomy was those of Sokal (1962); Cain and Harrison (1958). Biometrical techniques have been widely used in several cultivated crops like Tobacco, Cotton (Murthy and Pavatte, 1962; Narasimhayya and Rao, 1974; Singh and Bains, 1968; Singh *et al.*, 1971) etc.

Biosystematic studies in *Piper* spp. was carried out by Rahiman and Subbaiah (1984), who made a preliminary comparative flavonoid analysis of eight species of *Piper*. Rahiman and Bhagavan (1985) reported biometrical study using D^2 statistics. They have again studied male and female plants of *P. argyrophyllum*, *P. attenuatum*, *and P. galeatum*, *P. hookeri*, *P. longum* and *P. mullesua* occurring in the Western Ghats region of Karnataka. The female plants were separated into five clusters based on five characters and male plants into four clusters.

Ravindran *et al.* (1992a) studied numerical taxonomy of South Indian *Piper* using 10 species namely *P. attenuatum*, *P. argyrophyllum*, *P. galeatum*, *P. hymenophyllum*, *P. longum*, *P. mullesua*, *P. schmidtii*, *P. silentvalleyensis*, *P. trichostachyon*, *P. wightii* and seven accessions of *P. nigrum*. Thirty different characters were used in this study. Significant correlations were observed between characters like leaf breadth, leaf size index and petiole length. Clustering of characters led to the recognition of six character groups. Although their study supported the existing classification of South Indian taxa of *Piper,* it clearly indicated the distinctiveness of *P. mullesua*, *P. silentvalleyensis* and *P. longum* from the rest of the species and they felt this calls for a revised classification of the South Indian taxa of *Piper.*

Ravindran and Nirmal Babu (1996) carried out the principal component analysis of South Indian *Piper* species, using 17 OTU's and 30 characters. The PC's formed are:

I PC - leaf length, leaf breadth, leaf size index, petiole length, distance from the base to the second pair of ribs, plant type, fruit colour, fruit taste and thrips infestation.

II PC- spike length, peduncle length, spike orientation, and fruit shape.

III PC- leaf length/leaf breadth index, rib number, growth habit and distribution.

IV PC- bract type.

V PC- leaf length/spike length index and spike shape

VI PC- guard cell length, guard cell breadth and leaf texture

VII PC- spike texture

Construction of the dispersion maps showed that with regard to the first three PCs, taking two at a time, cluster 1 - *P. wightii*, *P. nigrum* and *P. nigrum.* var. *hirtellosum*. *P. mullesua* and *P. silentvalleyensis* are having large differences representing PC-2 (spike length, peduncle length, spike orientation and fruit shape) indicating that these characters are important in differentiating the species from others. *P. attenuatum* and *P. argyrophyllum* showed close association indicating there closeness with regard to the PCs. *P. longum* showed very distinctive grouping. This in fact is a unique species in having creeping habit; erect cylindrical spike, laterally fused flowers and fruits. In this study *P. nigrum* showed closest affinity with *P. wightii.*

Ravindran *et al.* (1997a) studied 44 cultivars and 7 wild collections of black pepper (*P. nigrum*) and were subjected to cluster analysis. The 22 characters employed in the study resolved into two distinct sets. Based on character correlations, six clusters were recognized while certain characters did not show correlation with others. Centroid clustering led to the grouping of the OTUs into 11 clusters. Among these, four groups had one cultivar, four had two cultivars, one had four cultivars, another one had seven cultivars while the remaining cluster had 28 cultivars. The cultivars that were unique and did not cluster with any other are Karimunda, Panniyur-1, Vadakkan and Kuthiravaly. The inclusion of 28 cultivars in one group also shows that a majority of common cultivars resemble one another closely and probably had a common origin. This study also indicates the probable origin of black pepper.

Mathew *et al.* (2001) used 51 cultivars of black pepper from Kerala for graph clustering by "Graph Theory" model, based on 27 morphological characters (qualitative and quantitative) aimed at clustering them into groups with an appreciable degree of intra-cluster discreteness and inter-cluster distances. The results were presented in 'Skyline Plot'. Ten C-clusters were formed at the c- value of 0.46 corresponding to a fairly high moat value.

The number of members in different clusters ranged from 3-8. Distribution of various characters among the clusters formed, showed a considerable degree of intra-cluster similarity (connectedness) and inter-cluster distance (*isolation*). Among the 10 C-clusters formed at the c-value of 0.46, three are fairly large ones holding 7-8 members, six are medium sized ones with 4-5 members and one very small with three members. Distribution of various characters among the cultivars shows that considerable degree of solidarity exists in each of the clusters. The highly productive cultivar is clustered with seven fairly high yielding cultivars such as 'Kuthiravaly', 'Kottanadan', 'Thevanmundi', 'Poonjaranmunda', 'Kaniyakadan' and 'Neelamundi', with the cv. 'Areepadappan' as the outlier in the cluster.

Mathew and Mathew (2002) have subjected 13 indigenous species of *Piper* to cluster analysis by metric method. They are grouped into five objectively delimited clusters based on phonetic resemblances determined in terms of values of similarity coefficients (S) using 50 characters from three disciplines (morphology, cytology and palynology). The grouping based on phonetic resemblances showed some agreement with the morphological grouping proposed by Hooker (1886) and Gamble (1925), but certain other disagreements between the two do exist. The notable disagreement is concerning the placement of *P. nigrum*.

Gajurel *et al.* (2002) studied the inter-specific variability of *Piper* species occurring in Arunachal Pradesh in North East India. Thirty-two characters were considered, of which 22 are qualitative and 10 are quantitative. The characters include 26 morphological and 6 anatomical ones. Cluster analysis was carried out using weighted pair group percent disagreement, and dendrogram was constructed. The dendrogram obtained through the analysis revealed that the 18 taxa used in the numerical analysis fall under 6 distinct clusters in two broad sections each with 9 taxa. Their study has helped in establishing the relative affinity among the *Piper* species occurring in the region

Molecular characterization

Genetic variability has been the main driving force to produce improved genotypes. Scientists were primarily using morphological data to characterize and estimate genetic variability in the populations. Although such data has its own merits there are severe constraints that limit their utility in unambiguous differentiation of genotypes and assessment of genetic diversity. Classical phenotypic markers were plentiful in only a few well characterized species such as maize and their utility was restricted by the difficulties involved in constructing multiple marked lines, by the low resolutions of maps produced and by the large amount of labour required to generate and use these markers.

Although isozyme markers, which allow identification of allelic differences, were well established as a potentially useful class of genetic marker, they were limited.

With the advent of DNA markers in the 1980's it has become possible to generate reliable molecular profiles of the genetic resources and utilize this information for gaining a better understanding of the genetic variation in many gene pools. DNA markers have been demonstrated to be powerful tools for differentiation of genotypes at various levels (i) individual differentiation; (ii) differentiation of populations; (iii) discrimination among species belonging to the same genus; and (iv) differentiation among families or genera (Paterson *et al.*, 1991). A number of molecular markers or DNA based marker systems are now available. DNA markers like Restriction Fragment Length Polymorphism (RFLP), Random Amplified Polymorphic DNA (RAPD), DNA Amplification Finger Printing (DAF), Single Nucleotide Polymorphism (SNP), Cleaved Amplified Polymorphic Sequences (CAPS), Simple Sequence Repeat Polymorphism (SSR / Micro satellites), ISSR (Inter Simple Sequence Repeats) have very efficiently supplemented phenotypic markers in characterizing the germplasm and later in preparation of genetic maps (Paterson, 1996; Rafalski *et al.,* 1996). Among them RAPD (Williams *et al.,* 1990) micro satellites (Tautz, 1989) and AFLP (Vos *et al*., 1995) are the important ones as they are quick, efficient, easy and cost effective (Karp *et al.* 1997; Hansen *et al.* 1999; Virk *et al.,* 2000; Jones *et al.* 1997; Zietkiewicz *et al.* 1994).

Despite questions about the reproducibility, random amplified polymorphic DNA (RAPD) marker was the first to become available and is most commonly and frequently used. Williams *et al.* (1990) showed that the differences as polymorphisms in the pattern of bands amplified from genetically distinct individuals behaved as Mendalian genetic markers. Welsh and McClelland (1990) showed that the pattern of amplified bands so obtained could be used for genetic finger printing.

RAPD markers were widely used for understanding the phylogenic and genetic relationship in both intra and inter generic level as well as between families in many crop species viz. sweet potato (Jarret and Austin, 1994; Dhillon and Ishiki 1999), rice (Virk *et al*., 1994; Barooah and Sarma, 2004), common bean (Briand *et al.,* 1998), plum (Bianchi *et al*., 2003), coffee (Sera *et al.,* 2003), sugarcane (Nair *et al.,* 1999), citrus (Coletta-Filho, 1998), apple (Dunemann *et al.,* 1994; Zhou and Li, 2000), *Dalbergia* (Hiremath and Nagasampige,2004) and coconut (Upadhyay *et al*., 2004)

Microsatellites or simple sequence repeats (SSR) are short DNA stretches consisting of motifs of one to six bases that are tandemly repeated. Owing to their ubiquity, hypervariability, abundance and genomic wide distribution, SSR loci represent a new generation of powerful genetic markers for eukaryotes (Staub *et al*., 1996). Use of this marker system, however, is hampered by the requirement for sequence information from flanking regions, from which primers are designed for polymerase chain reaction (PCR) amplification.

ISSR (Inter Simple Sequence Repeats) is a modification of SSR based markers systems. Popularized largely by Wolfe and Colleagues (Wolfe *et al.* 1998), ISSR analysis involved PCR amplification of genomic DNA using a single primer that target the repeat *per se*, with 1-3 bases that anchor the primer at the other 5'end The method provides highly reproducible results which generate abundant polymorphism in many systems (Nagaoka and Ogihara, 1997; Joshi *et al.,* 2000; Blair *et al.* , 1999).

ISSR have been used to study the inter and intra specific variations in cotton (Liu and Wendel, 2001), Korean *Allium* (Hao *et al.*, 2002), cashew (Archak *et al.*, 2003)

Both RAPD and ISSR remain attractive methods despite the availability of sophisticated techniques, because they are easy, quick simple and economical. ISSR markers have been used to characterize genebank accessions as well as to identify closely related cultivars of chest nut (Goulao *et al.,* 2001), fenugreek (Dangi *et al.*, 2004)

Biochemical and molecular markers in diversity analysis of genus Piper

Reports on the use of biochemical and molecular and characterization of *Piper* species and black pepper cultivars are available.

Sebastian *et al.,* (1996) studied isoenzyme (peroxidase, esterase and glutamate oxaloacetate transaminase (aspartate aminotransferase) variation in 11 *Piper* species. Isoenzyme patterns allowed the species to be grouped according to similarity indices species like *P. nigrum*, *P. pseudonigrum*, *P. bababudani* and P. *galeatum* formed the first group while *P. argyrophyllum* and *P. attenuatum* clustered in the second group and the third group comprised *P. chaba*, *P. hapnium* and *P. colubrinum.*

Isoenzymes were utilized to examine the hybrid nature of plants derived form inter specific crosses (Sasikumar *et al.*, 1999a). Hybrid specific bands as well as male parent specific bands were observed in the zymograms of three of the four isozymes, proxidase, esterase and polyphenol oxidase. Paired affinity index of these four enzyme profiles revealed more similarity between the female parents and hybrids than between the male parents and the hybrids.

Lebot *et al.,* (1991) studied 300 accessions of *P. methysticum* (domesticated but reproductively sterile form) and *P. wichmannii* (seed producing wild progenitor) collected from 35 islands of Polynesia, Micronesia and Melanesia for isoenzyme variation in eight enzyme systems. Isoenzymes in *P. methysticum* cultivars from Polynesia and Micronesia were monomorphic for all enzyme systems examined. However, cultivars from Melanesia were polymorphic for aconitase, diaphorase, malate dehydrogenase and phosphoglucomutase. Isoenzymes of *P. wichmannii* confirmed its status as the wild progenitor of *P. methysticum* (kava.) cultivars. Gaia *et al.,* 2003 studied the genetic diversity in 78 clones of black pepper (*Piper nigrum*), including some *Piper* spp, using 8 isoenzyme systems. The phenogram showed that most of the clones of *P. nigrum* L. were quite similar, which could be attributed to the reduced genetic base of the species and homogeneity of the cultivated clones.

Lebot *et al.* (1999) used morphological, phytochemical characters and AFLP profiling of various morpho and chemotypes (in major kavalactones) to define the extent of variation existing between Hawaiian cultivars of *Piper methysticum.* He concluded that Kava in Hawaii has extremely narrow genetic base and morphological and phytochemical variation is controlled by very few genes as AFLP profiles did not show any polymorphism.

Ajith (1997) compared RAPD profiles of 20 micropropagated plants of long pepper and reported high amount of somaclonal variation. Parani *et al.* (1997) used RAPD profiling to study the genetic fidelity of micropropagated plants of *P. longum* L and inferred 90% are similar to the mother plants and 10% were molecular off-types (putative somaclonal variants). Banerjee *et al.* (1999) studied molecular basis of genotypic differentiation between the 6 male and 25 female plants and reported two RAPD markers associated with male plants in dioecious *P. longum.* Philip *et al.* (2000) used RAPD profiles to differentiate three female varieties of *P. longum.* Manoj *et al.* (2004) studied the molecular basis differentiation between male and female plants of *Piper longum* using RAPD.

Jaramillo and Manos, (2001) used phylogenetic analysis of sequences of the Internal Transcribed Spacers (ITS) of nuclear ribosomal DNA based on a worldwide sample of the genus *Piper.* Sequences from a 51 species of *Piper* were aligned to yield 257 phylogenetically informative sites and suggested that taxa representing major geographic areas could potentially form three monophyletic groups: Asia, the South Pacific, and the Neotropics.

Pradeepkumar *et al.* (2001) studied 24 black pepper (*P. nigrum*) accessions, including 9 advanced cultivars and 13 landraces using RAPD markers. Cultivar-specific bands were obtained for all cultivars tested except for Panniyur-3. Among the landraces, cultivar-specific bands were observed for Cheriakaniakadan, Malligesara and Karimunda.

Chaveerach *et al.* (2002) studied inter relation ships between two species of Japanese *Piper*, namely *P. kadsura* (Choisy) Ohwi, *Piper retrofractum* Vahl. and a Thailand species namely *P. chaba* Hunt, using morphological and molecular (RAPD profiles) characters. The results demonstrate a closer relation between *P. retrofractum* Vahl and *P. kudsura* (Choisy) Ohwi than between *P. chaba* Hunt and *P. retrofractum.*

Ranade *et al.* (2002) used RAPD analysis in selected cultivars of Kapoori and Bangla betel vines (*Piper betle* L.) to ascertain their relatedness. They found that groups Kapoori and Bangla type cultivars are separate from each other. The Kapoori cultivars were more heterogeneous while the Bangla cultivars were more homogeneous. The two were clearly separated from each other. Anjali *et al.* (2004) studied genetic diversity amongst landraces of a dioecious and vegetatively propagated *Piper betle* - betelvine using molecular markers. Landraces belonging to four groups, namely, 'Kapoori', 'Bangla', 'Sanchi' and 'Others' formed four well separated groups in the neighbour joining (NJ) tree. All known male or female betelvine landraces have separated in the NJ tree indicating an apparent gender-based distinction among the betelvines

Pradeepkumar *et al.* (2003) conducted RAPD analysis in 22 cultivars of *P. nigrum* (black pepper) from South India and one accession each of *P. longum* L. and *P. colubrinum* Link. Good variability was observed among *P. nigrum* cultivars. *P. colubrinum* to be most distant of the three species. Genetic proximity among *P. nigrum* cultivars could be related to their phenotypic similarities or geographical distribution. Greater divergence was observed among landraces than among advanced cultivars. Landraces grown in southern parts of coastal India and those grown in more northern parts were grouped in separate clusters.

Babu *et al.*, (2003) studied RAPD and AFLP polymorphism among nine species of *Piper.* The exotic species *P. colubrinum* and *P. arboreum* were found to be highly distinct. *P. argyrophyllum, P. attenuatum, P. bababudani* and *P. nigrum* were found to be closely related. *P. betle, P. chaba,* and *P. longum* stood independently. Specific marker probes for each species were developed and were and successfully hybridized with corresponding genomic DNA. The results obtained agreed with the conventional taxonomic interrelationships of these species.

Shahanas *et al.* (2003) reported intra clonal fidelity of rooted cuttings derived from bamboo nursery using RAPD except a single band produced by two primers in the bottom nodal explants of Sreekara.

Johnson George *et al.* (2003) used Inter Simple Sequence Repeat (ISSR) polymorphism to characterize small cardamom, large cardamom, different species of *Vanilla* and *Piper*. The ISSR markers were also used in identifying selected cultivars and hybrids of black pepper.

Wadt *et al.* (2004) studied 49 genotypes belonging to three species of Piper *viz: Piper hispidinervum, Piper aduncum*, and *Piper hispidum*, to assesses the inter- and intra-specific relationships using RAPD markers. The cluster analysis indicated three distinct groupings of the genotypes corresponding to *P. hispidinervum, P. aduncum*, and *P. hispidum*. Their study supported the existence of *P. hispidinervum* and *P. aduncum* as two separate species.

Gaia *et al.* (2004) used RAPD to study the genetic diversity in 18 accessions from 4 natural populations of pimenta de macao (*P. aduncum*) from Brazil.

Johnson George and his co workers (Johnson George *et al.*, 2003; Ganga *et al.* 2004) reported ISSR-PCR along with RAPD are valuable tools for genetic diversity analysis in spices. They (Johnson George *et al.* 2005) also reported usefulness of male parent-specific RAPD markers to identify true hybrids among progenies of inter cultivar crosses.

Nazeem *et al.* (2005) used both RAPD and AFLP analysis to assess the variability and inter-relationships among 49 cultivars of black pepper. Two selections from the variety Karimunda, namely Sreekara and Subhakara, together formed a single cluster with almost 92 percent similarity. But Panniyur 1 and Panniyur 3 which are the progenies of the same parentage were distinctly dissimilar. Keshavachandran *et al.,* (2005) also carried out similar kind of analysis in *Piper* species.

Sreedevi *et al.* (2005) used RAPD to characterize 7 new high yielding lines of black pepper and developed a bar code to identify the varieties. Among the lines studied OPKm, HP-1411 and HP-105 were found to be distinct.

31.A 20

Materials and Methods

Test Plants

The present study was conducted at the Indian Institute of Spices Research (IISR), Kozhikode and its experimental farm at Peruvannamuzhi. Fifteen related *Piper* species (Table 3) and 33 black pepper (Table 4) cultivars collected from various parts of Western Ghats and conserved in black pepper germplasm conservatory are used for the study. Fifteen collections of wild forms of *Piper nigrum* (Table 5) and eight collections of *P. longum* (Table 6) collected from different locations are also used to study intra species variability within these two economically important species. Herbarium specimens of all collections used are maintained at IISR herbarium. Only observations recorded from female plants are used for the study. Similarly, six collections of the most popular variety cv. Karimunda and seven collections of cv. Kottanadan known for high quality are also used to study intra cultivar variability (Table 7).

Table 3. *Piper* species used in the study and their discriminatory characters

Species code	Species studied	Discriminating character
1	*P. longum* Linn.	Indian long pepper, creeping habit, erect spike
2	*P. hapnium* Ham.	Morphologically similar to *P. longum*, bold spike, climbing nature, endangered species
3	*P. mullesua* Ham.	Distributed in high elevation areas, female spikes globular and male spikes cylindrical
4	*P. silentvalleyensis* Ravindran & Asokan	Bisexual species, cylindrical to globular spikes, resembles *P. mullesua* morphologically
5	*P. attenuatum* Buch-Ham.	Common wild species occurring in low elevation, very long spikes, leaves seven nerved, glabrous
6	*P. argyrophyllum* Miq.	Resembles *P. attenuatum* but leaves are five nerved and slightly hairy
7	*P. hymenophyllum* Miq.	Occurring on medium to high elevation, leaves and tender stems are pubescent.
8.	*P. bababudani* Rahiman	A hardy vine with fleshy spike and bold berries
9.	*P. wightii* Miq.	Occurs only at high elevations, shoot tip colour is greenish white
10	*P. schmidtii* Hook f.	Hardy vine occurs only at high elevations, thick leaves, purple shoot tip
11	*P. galeatum* (Miq) CDC	Occurs in medium to high elevation, bold berries, bracts large and boat shaped
12	*P. trichostachyon* CDC	Resembles *P. galeatum,* but spikes are slightly hairy
13	*P. sugandhi* Ravindran, Babu et Naik	Resembles *P. nigrum* but berries are bold and shortly stipitate
14	*P. nigrum* Linn.	Occurs at low to high elevations, dioecious, while cultivated forms are monoecious
15	*P. barberi* Gamble	Endangered species, reticulate venation, peduncle very long

Table 4. Important black pepper cultivars and their distinguishing features

Code no.	Cultivar name	Distinguishing feature
Cultivars of major importance		
1	Karimunda	Very popular cultivar, small leaves, small spikes, high yielder and medium in quality, shade tolerant
2	Kottanadan	High yielding variety of Southern Kerala, leaves broad and ovate
3	Balankotta	Cultivar with large droopy leaves and irregular bearing
4	Neelanmundi	A good yielder from central Travancore, medium in quality
5	Kuthiravally	High yielder and good in quality, long spikes
6	Kalluvally	A drought tolerant variety with good yield, medium in quality
7	Arakulam munda	Well adapted variety with medium quality and regular yielder, early bearing type
8	Narayakodi	Popular south Kerala variety, moderate yielder, medium in quality, stigma lobes persistent
9	Thommankodi	A cultivar from Central Travancore, moderately good in yield, good in quality
10	Perambramunda	A cultivar from North Kerala, good yielder and medium in quality
11	Poonjaranmunda	Cultivar from Central Kerala, good yielder and medium in quality
12	Valiyakaniyakadan	Cultivar with lager leaves, medium in yield and quality
13	Cheiyakaniyakadan	Moderate yielder and early bearing cultivar
14	Uthirankotta	Poor yielder but long spikes
15	Panniyur-1	First improved hybrid in black pepper, high yielding and very popular, medium in quality with bold berries
16	Panniyur-2	Selection of open pollinated progenies of 'Balankotta', high yielder and good in quality
17	Panniyur-3	An improved hybrid with long spikes, high yield and medium in quality
18	Panniyur-4	An improved variety developed from the open pollinated progenies of' Kuthiravally', late maturing type, medium in quality
19	Panniyur-5	An improved selection from 'Perumkodi', good yielder withy medium quality
20	Sreekara	Improved clonal selection from 'Karimunda', high yielding with medium quality
21	Subhakara	Improved clonal selection from 'Karimunda', high yielding with medium quality
22	Panchami	Improved clonal selection from 'Aimpirian', high yielder
23	Pournami	Improved variety tolerant to root knot nematode, good in yield and quality
24	PLD-2	Clonal selection from 'Kottanadan', good in yield and quality
Cultivars of minor importance		
1	Doddagai	Cultivated in some pockets of Chickmagalur district of Karnataka, bold berries but poor setting
2	Kaniyakadan	Moderate yielder and early bearing type
3	Chumalakodi	Good yielding vine, with deep purple shoot tip
4	Nedumchola	A cultivar with small leaves and short spikes, moderate yielder
5	Malamundi	A moderate yielder, medium in quality
6	Karuthapirimunda	Dark green vine spikes slightly twisted.
7	TMB. IV	A collection from Thaliparamba
8	Valiyakarimunda	Like Karimunda but leaves are larger
9	Karimkotta	Healthy vine with dark green colour

Table 5. Wild forms of *Piper nigrum* and their place of collection

Sl. No.	Acc. No.	District	State
1.	5220	N. Canara	Karnataka
2.	5569	Kannur	Kerala
3.	5889	Waynad	Kerala
4.	5899	Waynad	Kerala
5.	5896	Waynad	Kerala
6.	5847	Calicut	Kerala
7.	5422	Palghat	Kerala
8.	370	Palghat	Kerala
9.	4536	Idukki	Kerala
10.	4520	Idukki	Kerala
11.	4635	Idukki	Kerala
12.	5494	Pathanamthitta	Kerala
13.	5480	Pathanamthitta	Kerala
14.	5492	Pathanamthitta	Kerala
15.	5311	Courtallum	Tamil Nadu

Table 6. *Piper longum* accessions and their place of collection

Sl. No.	Acc. No.	Place	State
1	3184	Sirsi	Karnataka
2	4515	Nadukani	Kerala
3	5383	Mukkali	Kerala
4	3270	Karapara (TCR)	Kerala
5	139	Idukki	Kerala
6	3219	Pathanamthitta	Kerala
7	621	Kollam	Kerala
8	5476	Trivandrum	Kerala

Table 7. Karimunda and Kottanadan accessions used in the study

Sl. No	Acc. No.	Remark
1	KS-2	Karimunda collection from Calicut
2	K-50	Karimunda collection from Idukki
3	KS-113	Karimunda collection from Waynad
4	KS-120	Karimunda collection from Waynad
5	KS-161	Karimunda collection from Idukki
6	KS-185	Karimunda collection from Idukki
7	Subhakara (KS-27)	Improved variety of Karimunda, collected from Palghat
8	893	Collection from Wayanad
9	1484	Kottanadan collection from Palode, Trivadrum
10	1485	Kottanadan collection from Palode, Trivadrum
11	1488	Kottanadan collection from Palode, Trivandrum
12	1489	Kottanadan collection from Palode, Trivandrum
13	1494	Kottanadan collection from Palode, Trivandrum
14	5055	PLD-2, improved variety of Kottanadan

Survey and collection

Piper species and cultivars belonging to the geographical area confined to the Western Ghats region in South India and three states viz. Kerala, Karnataka and Tamil Nadu are used in the study.

Wild forms of *Piper nigrum* and the related species are collected from the Western Ghats region comprising all the districts in Kerala, parts of Karnataka and Tamil Nadu. The different regions from where collections are made and their geographical attributes are given in Table 15. Passport information and characterization details are recorded *in-situ* at the time of survey and *ex-situ* from the conservatory at IISR. The National herbarium at Calcutta, Regional herbarium at Coimbatore and the local herbarium at IISR are consulted to confirm the identity of the specimens collected.

The cultivated forms of black pepper are collected from the farmer's fields representing the available genetic diversity in black pepper cultivars. These collections are maintained in the germplasm conservatory at IISR.

Morphological and molecular characterization

All species mentioned in the Table 3 - 7 are characterized morphologically and by means of DNA fingerprinting.

Morphological characterization is done using IPGRI descriptors (IPGRI, 1995). Data are collected either from the plants established in the conservatory or from the original place of collection. Data on morphological characters are recorded from the established vines in the black pepper repository.

Molecular characterization is also carried out to understand the molecular diversity at both inter and intra specific levels and within the species as well as local cultivars and hybrids.

Study on distribution pattern

For understanding the distribution pattern of *Piper* species Geographical Information System (GIS) is utilized. The latitude and longitude of the collection sites are recorded using a Geographical Positioning System (GPS, Etrex, Germany). Wherever it was possible, the exact location is recorded. However, in some cases the latitude and longitude of nearest place had to be recorded subject to the satellite link. The places and the species collected along with latitude and longitude of the places are tabulated in MS EXCEL. These have been plotted in the digitized India Administrative Map with the help of DIVA GIS, 4.0 software of IPGRI.

The Shannon diversity index (Beals *et al.*, 1998) was calculated using the equation

$$H = -\Sigma\, pi \ \mathrm{In}\, pi$$

H= Shannon diversity

pi = Proportional abundance of the i^{th} class = ni/ N

ni = number of Individuals in the i^{th} class

N = Number of observations per cell

Morphology and taxonomy

Most of the illustrations and description given in the earlier flora was based on very old herbarium specimens. In the present study all the description was based on live specimens.

The specimens collected are compared with various herbaria, flora and monographs before final description was made.

High quality photographs of the live specimens are taken using a digital camera (Kodak). Digital images of these live materials are also acquired by scanning using an Hp Scan jet 3970. The important distinguishing features of floral characters like inflorescence, flowers, enlarged bracts, stamens etc. are depicted in a magnified form by using a binocular microscope (Leica) and the images are taken by using the computer software *Leica Qwin.* These pictures are used in the illustrations.

While describing the species, the original citations as indexed in *Index Kewensis* (IPNI, 2006) are given except for two species, *P. sugandhi* (authors name and published journal are given) and *P. bababudani* (reported in a Ph.D thesis; Rahiman, 1981).

The plant species and collections are characterized for 25 qualitative and 8 quantitative characters. Details of the qualitative and quantitative characters observed for wild accessions and local cultivars are given in Tables 8 and 9 respectively. The description of scientific terminology used for morphologic characterization of black pepper is given in Annexure-1.

Table 8. Descriptor states used for characterization of wild species

Sl. No.	Descriptor	Code	Descriptor state
2.1	Plant growth habit	1	Climbing (on support)
		2	Trailing (on ground)
2.2	Branching type	1	Dimorphic
		2	Polymorphic
2.3	Orthotropic shoot tip colour	1	Greenish yellow
		2	Light purple
		3	Dark purple
2.4	Runner shoot production	0	Absent
		1	Few
		2	Many
2.5	Holding capacity	1	Weak
		2	Strong
2.6	Adventitious root production	1	Few
		2	Many
2.7	Lateral branch habit	1	Erect
		2	Horizontal
		3	Hanging
2.8	Lateral branch length	cm	Average length of 25 randomly selected lateral branches.
2.9	Number of nodes	No.	Average number of nodes from 25 randomly selected lateral branches
2.10	Leaf petiole length	cm	Petiole length of 25 randomly selected leaves
2.11	Leaf length	cm	25 randomly selected leaves from the lateral branches (Measured from the base of the mid rib to the leaf tip)
2.12	Leaf width	cm	25 randomly selected leaves from the lateral branches (Measured at the maximum width)
2.13	Leaf lamina shape	1	Ovate
		2	Ovate-elliptic
		3	Ovate-lanceolate
		4	Elliptic lanceolate
		5	Cordate
2.14	Leaf base shape	1	Round
		2	Cordate
		3	Acute
		4	Oblique
2.15	Leaf margin	1	Even
		2	Wavy
2.16	Type of veining	1	Acrodromous
		2	Campylodromous
		3	Eucamptodromous
2.17	Leaf texture	1	Glabrous coriaceous
		2	Glabrous membranous

		3	Glabrous sarcous
		4	Downy membranous
		5	Downy along the veins
2.18	Leaf hairiness	0	Absent
		1	Mainly along the veins
		2	All over the leaf
3.1	Spike orientation	1	Erect
		2	Pendant
3.2	Spike shape	1	Filiform
		2	Cylindrical
		3	Globular
3.3	Spike colour	1	Green
		2	Greenish yellow
		3	Light yellow
		4	Light purple
		5	Dark purple
3.4	Spike length	cm	Average length of 25 randomly selected spikes
3.5	Type of hermaphroditism	1	Staminate flowers only
		2	Pistillate flowers only
		3	Bisexual flowers only
		4	Predominantly male
		5	Predominantly female
		6	Predominantly bisexual
3.6	Peduncle length	cm	From randomly selected 25 spikes
3.7	Number of spikes/lateral branches	No.	Average spike numbers from 25 lateral branches.
3.8	Flower arrangement	1	Free
		2	Fused laterally
3.9	Spike texture	1	Glabrous
		2	Hirtellous
3.10	Bract type	1	Sessile oblong and adnate to the rachis
		2	Peltate orbicular
		3	Cupular with decurrent base
		4	Fleshy, connate, transformed in to a cup.
		5	Deeply copular with decurrent base
3.11	Flower nature (insertion)	1	Sessile
		2	Shortly stipitate
3.12	Fruit shape	1	Ovate
		2	Round
		3	Oblong
3.13	Fruit taste	1	Bitter
		2	Pungent
		3	Spicy
		4	Initially bitter then pungent
3.14	Fruit size	1	Very small ($\leq$ 2 mm diameter)
		2	Small (2.1-4.0 mm diameter)=
		3	Bold (4.1 -6.5mm diameter)
		4	Extrabold ($\geq$6.6 mm diameter)
3.15	Fruit colour change while ripening	1	Green to black
		2	Green to yellow and red
		3	Green to yellow and orange red

Table 9. Descriptor states used for characterization of cultivated pepper

Sl. No.	Descriptor	Code	Descriptor state
2.1	Vine height	cm	Height of the vine from ground level to the top most portion
2.2	Branching type	1	Dimorphic
		2	Polymorphic
2.3	Orthotropic Shoot tip colour	1	Greenish yellow
		2	Light purple
		3	Dark purple
2.4	Runner shoot production	0	Absent
		1	Few
		2	Many
2.5	Holding capacity	1	Weak
		2	Strong
2.6	Adventitious root production	1	Few
		2	Many
2.7	Lateral branch habit	1	Erect
		2	Horizontal
		3	Hanging
2.8	Lateral branch length	cm	Average length of 25 randomly selected lateral branches
2.9	Number of nodes	No.	Average number of nodes from 25 randomly selected lateral branches
2.10	Leaf petiole length	cm	Petiole length of 25 randomly selected leaves
2.11	Leaf length	cm	25 randomly selected leaves from the lateral branches (Measured from the base of the mid rib to the leaf tip)
2.12	Leaf width	cm	25 randomly selected leaves from the lateral branches (Measured at the maximum width)
2.13	Leaf lamina shape	1	Ovate
		2	Ovate-elliptic
		3	Ovate-lanceolate
		4	Elliptic lanceolate
		5	Cordate
2.14	Leaf base shape	1	Round
		2	Cordate
		3	Acute
		4	Oblique
2.15	Leaf margin	1	Even
		2	Wavy
2.16	Type of veining	1	Acrodromous
		2	Campylodromous
		3	Eucamptodromous
2.17	Leaf texture	1	Glabrous coriaceous
		2	Glabrous membranous
		3	Glabrous sarcous
		4	Downy membranous
3.1	Spike orientation	1	Erect
		2	Pendant
3.2	Spike shape	1	Filiform
		2	Cylindrical
		3	Globular

3.3	Spike colour	1	Green
		2	Greenish yellow
		3	Light yellow
		4	Light purple
3.4	Spike length	cm	Average length of 25 randomly selected spikes
3.5	Type of hermaphroditism	1	Staminate flowers only
		2	Pistillate flowers only
		3	Bisexual flowers only
		4	Predominantly male
		5	Predominantly female
		6	Predominantly bisexual
3.6	Peduncle length	cm	From randomly selected 25 spikes
3.7	Number of spikes/lateral branches	No.	Average spike numbers from 25 lateral branches
3.8	Flower arrangement	1	Free
		2	Fused laterally
3.9	Number of stamen	1	One
		2	Two
		3	Four
3.10	Spike texture	1	Glabrous
		2	Hirtellous
3.11	Bract type	1	Sessile oblong and adnate to the rachis
		2	Peltate orbicular
		3	Cupular with decurrent base
		4	Fleshy, connate, transformed in to a cup
		5	Deeply copular with decurrent base
3.12	Flower nature (insertion)	1	Sessile
		2	Shortly stipitate
3.13	Fruit setting	%	Average of 50 spikes
3.14	Number of developed fruit /spike	No.	Average of 50 spikes
3.15	Number of berries/10 spike	No	Average of five sets
3.16	Fruit shape	1	Round
		2	Ovate
		3	Oblong
4.1	100 fruit weight	g	Average from 10 sets
4.2	100 fruit volume	ml	Average from 10 sets
4.3	Yield	kg	Green yield of the vine
4.4	Dry weight of 100 fruits	g	Weight of 100 fully matured berries after drying
5.1	Essential oil	%	Percentage of oil content in fruits
5.2	Oleoresin	%	Percentage of oleoresin content in fruits
5.3	Piperine	%	Percentage of piperine content in fruits

Annexure I. Description of botanical terms used for characterization

Descriptor	Descriptor state	Description
Leaf lamina shape	Ovate	With the widest axis below middle and with margins symmetrically curved- egg shaped
	Ovate-elliptic	Ovate in shape, but the widest axis at the mid point
	Ovate-lanceolate	Much longer than the broad; widening above the base and tapering to the apex
	Elliptic-lanceolate	Oval in outline, widening near the middle and tapering to the apex
	Cordate	Heart-shaped, with a sinus and surrounded lobes at the base and ovate in general outline
Leaf base shape	Round	Margins forming a smooth arc
	Cordate	Lobes rounded, sinus depth 1/8 to ¼ distance to midrib point of blade
	Acute	Margin straight to convex forming a terminal angle 45^0 to 90^0
	Oblique	Slanting, unequal sided
Leaf margin	Entire	Without indentations or incisions on margins; smooth
	Wavy	Slightly folded or with insertion
Type of veining	Acrodromous	With two or more primary or strongly developed secondary veins diverging at or above the base of he blade and running in convergent arches towards the apex over some or all of the blade length
	Campylodromous	With several primary veins or their branches diverging at a close at or close to a single point and running in strongly developed, basally recurved arches which converge towards the apex, reaching it or not
	Eucamptodromous	With a single primary vein, the secondary veins curved upward, gradually diminishing distally within the margin, and interconnected by a series of cross veins without forming conspicuous marginal loops
Leaf texture	Glabrous coriaceous	Smooth; devoid of trichomes and leathery texture
	Glabrous membranous	Smooth; devoid of trichomes, thin and membrane like
	Glabrous sarcous	Smooth, devoid of hairs and fleshy
	Downy membranous	Thin and membrane like leaf covered with short, weak, soft trichomes
	Downy along the veins	Thin and membrane like leaves with short, weak trichomes only along the veins
Spike shape	Filiform	Thread like, usually flexuous
	Cylindrical	Long tubular or like a cylinder
	Globular	Round shaped
Type of hermaphroditism	Staminate flowers only	Only male flowers are present in the plant
	Pistillate flowers only	Only female flowers are present
	Bisexual flowers only	All the flowers of the plant are with stamen and pistil
	Predominantly male	Majority of flowers are staminate, but other types also present
	Predominantly female	Majority of flowers are pistillate, but other types also present

	Predominantly bisexual	Majority of flowers are bisexual, but other types also present
Flower arrangement	Free	Individual flowers not united with each other
	Fused laterally	All the flowers are fused with each other
Spike texture	Glabrous	Smooth, devoid of hairs
	Hirtellous	Spike with soft or minute hairs
Bract type	Sessile, oblong and adnate to rachis	Bract fused with the peduncle without a stalk, oblong shaped with free margin
	Peltate orbicular	Circular or disc shaped bract with a small connective at the center
	Cupular with decurrent base	Cup shaped bract with elongated base extending downward
	Deeply copular with decurrent base	Cup shaped bract with base extending downward
Fruit shape	Ovate	With an outline that of hen's egg, the broader end below the middle
	Round	Globular shape, with almost equal radius
	Oblong	Longer than the broad with the sides nearly or quite parallel most of their length

Source: Lawrence, 1951; Radford *et al.*, 1974

Molecular characterization

Isolation and purification of genomic DNA

Modified CTAB method (Ausubel *et al.*, 1995) was used to isolate DNA from *Piper*. The protocol used for extraction of DNA from *Piper* leaf tissues is as follows,

1. Grind 5 g of young leaves in liquid nitrogen with a mortar and pestle and add 25 ml of preheated (65^0C) CTAB buffer. Add 0.2% β-Mercaptoethanol prior to use.
2. Incubate at 60^0C for 30 minutes.
3. Extract with equal volume of chloroform : isoamyl alcohol (24:1) at 10,000 rpm for 10 minutes at room temperature.
4. Take the aqueous phase and add 2/3 rd volume of ice-cold isopropanol.
5. Incubate at -20^0C for 2 hours and centrifuge (10,000 rpm, 15 minutes at 4^0C).
6. Discard the supernatant and invert the tube on paper towel for few minutes.
7. Dissolve the pellet and add 1.5 ml of TE buffer at room temperature over night.
8. Add 10 μg/ml of RNase A and incubate at 37^0C for 30 minutes.

9. Add equal volume of Tris saturated phenol, mix it well and centrifuge at 10,000 rpm for ten minutes.

10. To the aqueous phase add equal volume of phenol: chloroform: isoamyl alcohol, (25:24:1), shake and centrifuge at 10,000 rpm for ten minutes.

11. Take the aqueous phase and add equal volume of chloroform: is amyl alcohol (24:1), shake and centrifuge at 10,000 rpm for ten minutes.

12. To the aqueous phase add one-tenth volume of 3M sodium acetate (pH 5.2) and 2.5 volumes of ethanol and incubate at -20^0C for one hour or at -70^0C for 30 minutes.

13. Centrifuge at 10,000 rpm for 10 minutes and wash the pellet in 70% ethanol (10,000 rpm for 5 minutes).

14. Air dry the pellet and dissolve in 1.5 ml TE and estimate the yield.

The composition of various stock solutions and buffers used are given in Tables 10 and 11.

Table 10. Composition of various stock solutions for DNA isolation (Sambrook *et al.*, 1989)

Solution	Method of preparation
1M Tris (pH 8.0) 500ml	Dissolve 60.55gm Tris base (Sigma) in 300 ml distilled water. Adjust pH to 8 by adding concentrated HCl. Adjust volume to 500ml. Dispense into reagent bottles and sterilize by autoclaving.
0.5M EDTA pH 8.0	Dissolve 93.05g of EDTA-disodium salt (Sigma) in 300 ml of water. Adjust pH to 8 by adding NaOH pellets. Adjust volume to 500 ml. Dispense into reagent bottles and autoclave.
5M NaCl 500 ml.	Weigh 146.1g NaCl (Merck) add 200ml of water and mix well. When the salts get completely dissolved, adjust the final volume to 500ml. Dispense into reagent bottles and autoclave.
3M Sodium acetate (pH5.2) 250 ml.	Dissolve 61.523g of anhydrous sodium acetate (Qualigens) in 200 ml of water and mix well. When dissolved completely adjust the pH of the solution to 5.2 with glacial acetic acid (99- 100%). Autoclave
Ethidium Bromide 10mg/ml, 100ml.	Add 1g Ethidium Bromide to 100 ml of distilled water. Keep on magnetic stirrer to ensure that the dye has dissolved completely. Dispense into amber coloured reagent bottle and store at 4°C.
70% ethanol, 500 ml	Take 360 ml. of ethanol; mix with 140 ml of distilled water. Dispense to reagent bottle and store at 4°C.

Chloroform: isoamyl alcohol (24:1),500 ml	Measure 450 ml of chloroform and 20 ml of isoamyl alcohol. Mixed and stored at room temperature
1M $MgCl_2$, 100ml	Weigh 20.33g of $MgCl_2$, dissolve in double distilled water, make up to 100 ml, autoclave.

Table 11. Composition of buffers used for DNA isolation (Sambrook *et al.,* 1989)

	Buffer	Method of preparation
1	CTAB Extraction Buffer : for 1 litre 100mM Tris HCl (pH 8.0) 20mM EDTA (pH 8.0) 1.4M NaCl 2%CTAB(w/v) Merck 0.2%B-mercapto ethanol.(v/v)- Merck	Measure 100ml Tris (1M), 280ml of NaCl, 40ml of EDTA (0.5M). Mix with about 400ml of hot distilled water, add 20g of CTAB to this. Adjust final volume to 1 liter. Dispense into reagent bottles and autoclave. Just before use, add 0.2% β-mercaptoethanol.
2	TE (0.1mM) buffer ...for 100ml 100mM Tris HCl (pH 8.0) 0.1mM EDTA (pH 8.0)	Take 1ml of Tris HCl (1M), 20ml of EDTA (0.5M). Mix with 99ml of sterile distilled water taken in a reagent bottle, mix thoroughly, autoclave.
3	TAE buffer 10x : for 1 liter	Weigh 48.4g of Tris base; add 20ml of EDTA (0.5M); 11.42ml of glacial acetic acid and around 150ml distilled water. Dissolve the salt and adjust volume to 1 liter. Autoclave
4	Gel loading buffer (6x) : for 100ml 0.25% Bromophenol blue (Sigma) 30% Glycerol (Merck)	Dissolve 0.25g of BPB in 99ml of 30% glycerol. Keep on magnetic stirrer for several hours to get the dye completely dissolved. Dispense to reagent bottles and keep at 4 °C

Quantification of DNA

The amount of DNA was estimated using Scanning Shimatzu Spectrophotometer. DNA shows a clear absorbance peak at 260 nm and the value of 1.0 OD_{260} is calculated equivalent to 50 μg/ml. DNA solution was considered pure if the value of OD_{260} : OD_{280} is 1.8. The DNA was visualized on 0.8% agarose gel for its quality and stored at –20^{0}C.

RAPD profiling

RAPD profiles are developed as per the method suggested by Williams *et al.* (1990) with minor modifications. The dNTPs, Taq polymerases and other chemicals are procured from Amersham Pharmacia Biotech, Sweden. Twenty seven arbitrary primers from Operon Technologies Inc. Alameda, California are used for PCR reaction. Each primer contains at least 60% -70% GC content and no self-complementary ends. The primers used and their base sequences are presented in Table 12.

Different combinations and concentrations of dNTPs, Taq polymerase $MgCl_2$ and other variables are tested for good and consistent amplification of genomic DNA. It was found that 30 ng DNA, 1x assay buffer, 150 µM dNTPs, 2.0 mM $MgCl_2$ and 1 U of Taq polymerase are optimal for generating good and consistent amplification products, at annealing temperature of 40^0C, hence used for developing RAPD profiles in pepper.

PCR machine used was PTC 100 Programmable Thermal Cycler, MJ Research, USA.

The reaction mixture for PCR reaction was prepared by mixing the following components in a 0.2 ml sterile thin walled microfuge tube.

		1x
1.	Sterile distilled water	11.75µl.
2.	10x PCR buffer	2.5µl.
3.	dNTPs (1 mM).................	3.75µl.
4.	Primer (5pmoles/µl)...........	2.0µl.
5.	$MgCl_2$,(10mM).................	1.5µl
6.	Taq polymerase (2U/µl)......	0.5µl
7.	Template DNA(30 ng/µl)....	3.0µl
	Total reaction volume	**25µl**

Table 12. Operon primers, which showed polymorphism, used for developing RAPD profiles

S. No.	Primer used	Sequence of the primer used	GC content (%)
1	OPA-03	5'AGTCAGCCAC3'	60
2	OPA-09	5'GGGTAACGCC3'	70
3	OPA-13	5'CAGCACCCAC3'	70
4	OPA-15	5'TTCCGAACCC3'	60
5	OPA-18	5'AGGTGACCGT3'	60
6	OPB-05	5'TGCGCCCTTC3'	70
7	OPB-07	5'GGTGACGCAG3'	70
8	OPB-14	5'TCCGCTCTGG3'	70
9	OPB-20	5'GGACCCTTAC3'	60
10	OPC-02	5'GTGAGGCGTC3'	70
11	OPC-07	5'GTCCCGACGA3'	70
12	OPC-09	5'CTCACCGTCC3'	70
13	OPC-13	5'AAGCCTCGTC3'	60
14	OPC-18	5'TGAGTGGGTG3'	60
15	OPC-20	5'ACTTCGCCAC3'	60
16	OPD-02	5'GGACCCAACC3'	70
17	OPD-03	5'GTCGCCGTCA3'	70
18	OPD-07	5' TTGGCACGGG3'	70
19	OPD-10	5'GGTCTACACC3'	60
20	OPD-13	5'GGGGTGACGA3'	70
21	OPD-15	5'CATCCGTGCT3'	60
22	OPE-02	5'GGTGCGGGAA3'	70
23	OPE-11	5'GAGTCTCAGG3'	60
24	OPE-14	5'TGCGGCTGAG3'	70
25	OPF-09	5'CCAAGCTTCC3'	60
26	OPF-10	5'GGAAGCTTGG3'	60
27	OPF-15	5'CCAGTACTCC3'	60

The optimized PCR reaction profile is given below:

Cycles: 3

Ist cycle:	94 °C for 2 minutes	
	37 °C for 1 minute	
	72 °C for 1 minute	Cycle repeats: 1
IInd cycle:	94 °C for 1 minute	
	37 °C for 30 seconds	
	72 °C for 1 minute	Cycle repeats: 30
IIIrd cycle:	94 °C for 1 minute	
	37 °C for 1 minute	
	72 °C for 15 minutes	Cycle repeats: 1

The PCR products are visualized in 2% Agarose gels and documented in BIORAD gel documentation system.

ISSR profiling

Nineteen ISSR primers (Table 13) are used for amplifying the genomic DNA. Amplification was carried out in 25-µl reaction volume containing 20-30 ng of genomic DNA, 10 pmoles of primer, 1 mM dNTPs, 2.5mM assay buffer and one unit of Taq DNA polymerase (Bangalore Genei). Amplification was done using a PTC 100 Thermal Cycler (MJ Research Inc.) programmed for initial denaturation at 94°C for 1 min, 32 cycles of 1 min. denaturation at 94°C, 50 sec annealing at 46°C and 2 min. extension at 72°C and final extension of 5 min at 72°C and then at 4°C for storage.

Table 13. ISSR primers used for PCR reaction.

No	Primer code	Sequence
1	ISSR-1	5'(CT)8AC3'
2	ISSR-2	5'(CT)8GC3'
3	ISSR-3	5'(CA)7GT3'
4	ISSR-4	5'(CA)7AG3'
5	ISSR-5	5'(CA)7GG3'
6	ISSR-6	5'(GT)6GG3'
7	ISSR-7	5' (CA)7AC3'
8	ISSR-8	5' (GA)6GG3'
9	ISSR-9	5' (GA)6CC3'
10	ISSR-10	5' (GT)6CC3'
11	ISSR-11	5' (CAC)3GC3'
12	ISSR-12	5' (GACA)3GG3'
13	ISSR-13	5' (CTC)8GC3'
14	ISSR-14	5' (GACA) 3'
15	ISSR-15	5'(AGTG)7G3'
16	ISSR-16	5'(AT)7G3'
17	ISSR-17	5'(TA)7A3'
18	ISSR-18	5' (GT)6GG3'
19	ISSR-19	5'(GATA)3CC3'

Assessment of variability

Similarity / differences between the genotypes are assessed using RAPD/ISSR polymorphism as estimated by Paired Affinity Indices (PAI). PAI was calculated by the formula

$$PAI = \frac{\text{No. of similar bands}}{\text{Total no. of bands}} \times 100$$

The PAI is expressed as percentage that indicates the percent of similarity between any two genotypes.

Statistical Analysis

All the characters are analyzed using the following analytical software's.

Morphological observations

Data generated from the morphological studies of wild species as well as the cultivars are used for cluster analysis. Unweighted Pair Group Method based on Arithmetic averages (UPGMA) was used for cluster analysis (Sokal and Michener. 1958).

Standardized character states are computed as:

$$X'ij = \frac{xij - \overline{xi}}{Si}$$

Where: X'ij = is the standardized character state code for character 'i' and OTU 'j', xij = row score, '$\overline{\text{Xi}}$' and 'Si' are the mean and standard deviation for the character respectively.

All the quantitative characters are converted into binary characters by replacing the standardized character states >= 0 with 0 and < 0 with 1 (Sokal and Sneath. 1963, Chandran, 1999). Binary pattern difference was used as the distance measure for this analysis.

Qualitative multi-state characters are those in which the several states cannot be arranged in some obvious order but still refer to unit character or logical grounds. If character is continuous variable multi-state coding is used and each can be expressed by a single numerical value as suggested by Sahu (1998), where each variable are converted in to a series of binaries *e.g. flower colours- red, yellow or white can be grouped in to three sequential presence or absence alternatives i.e. red or not, or yellow or not (this includes white which is not yellow....etc)*

All the qualitative characters are scored for its presence or absence (Samsudeen, 2003). Characters, which are present in all the samples with same level, are not included for further analysis.

Pair-wise genetic similarity measures between each OTUs are obtained from the binary matrix with the package Numerical Taxonomy and Multivariate Analysis System NTSYSpc version 2.02 (Rohlf, 1997), using the similarity for qualitative data (SIMQUAL) option. Two distance coefficients, both of which are appropriate for two-state data, are computed from the binary matrix: the Sokal and Michener's simple matching (SM) coefficient (Sokal and Michener, 1958) and the Jaccard (J) (1908) coefficient, which are defined as,

$$SM = \frac{a+d}{n}$$

$$J = \frac{a}{n-d}$$

Where 'a' is the number of traits common between OTU's x and y, d is the total number of traits observed. Dendrograms / phylograms are generated from similarity matrices using the Unweighted Pair –Group Method, Arithmetic Average (UPGMA) clustering procedure in the SAHN option, which is available in the NTSYS.

Molecular characterization

Cluster analysis

The binary data scored was used to construct a dendrogram. The genetic associations between varieties are evaluated by calculating the Jaccard's similarity coefficient for pair wise comparisons based on the proportions of shared bands produced by the primers (Jaccard, 1908). Similarity matrix was generated using the NTSYS-PC software, version 2.02 (Rohlf, 1997). The similarity coefficients are used for cluster analysis and dendrogram was constructed by the UPGMA (Sneath and Sokal, 1973).

Bootstrapping

Bootstrap analysis was performed using the Win Boot programme (Yap and Nelson. 1996), with 100 repetitive sampling of the RAPD and ISSR data to compute bootstrap *P* values.

Results

Fifteen *Piper* species collected from various parts of Western Ghats and 33 black pepper cultivars collected and conserved in Black Pepper Germplasm Conservatory were used for the study. Fifteen collections of wild forms of *Piper nigrum* and eight collections of *P. longum* collected from different locations were also used to study intra- species variability within these two economically important species.

Though both male and female types of each species were characterized, only observations recorded from female plants were used for the analysis, for realistic comparison. Similarly, six collections of the most popular variety cv. Karimunda and seven collections of cv. Kottanadan known for high quality were used to study the intra cultivar variability.

Geographical distribution of *Piper* species

Distribution and diversity of fifteen *Piper* species occurring in South India were studied based on the actual collection data using GIS. The graphical presentations of occurrence of *Piper* species at different elevations are given in Fig 3. The distribution and diversity index of different species of *Piper* are given in Table 14 and Figs. 4 and 5.

Distribution of the genus Piper in South India

The occurrence and distribution of various *Piper* species were analyzed using DIVA GIS and the patterns obtained are given in Fig. 3 and 4.

P. longum is the most widely distributed species among the *Piper* species with erect spikes. It occurs only at lower elevations at an altitude of 40 - 310 m in the foothills of all districts of Kerala. Species richness is maximum in Palghat, Malappuram and Idukki Districts and lowest in Kasaragod District. Among the *P. longum* collections, two clear morphological variants – one with bold spikes and another with light purple spikes were collected from Nilambur forests of Malappuram District and from Thenmala forests of Kollam District, respectively. Others are morphologically similar to each other.

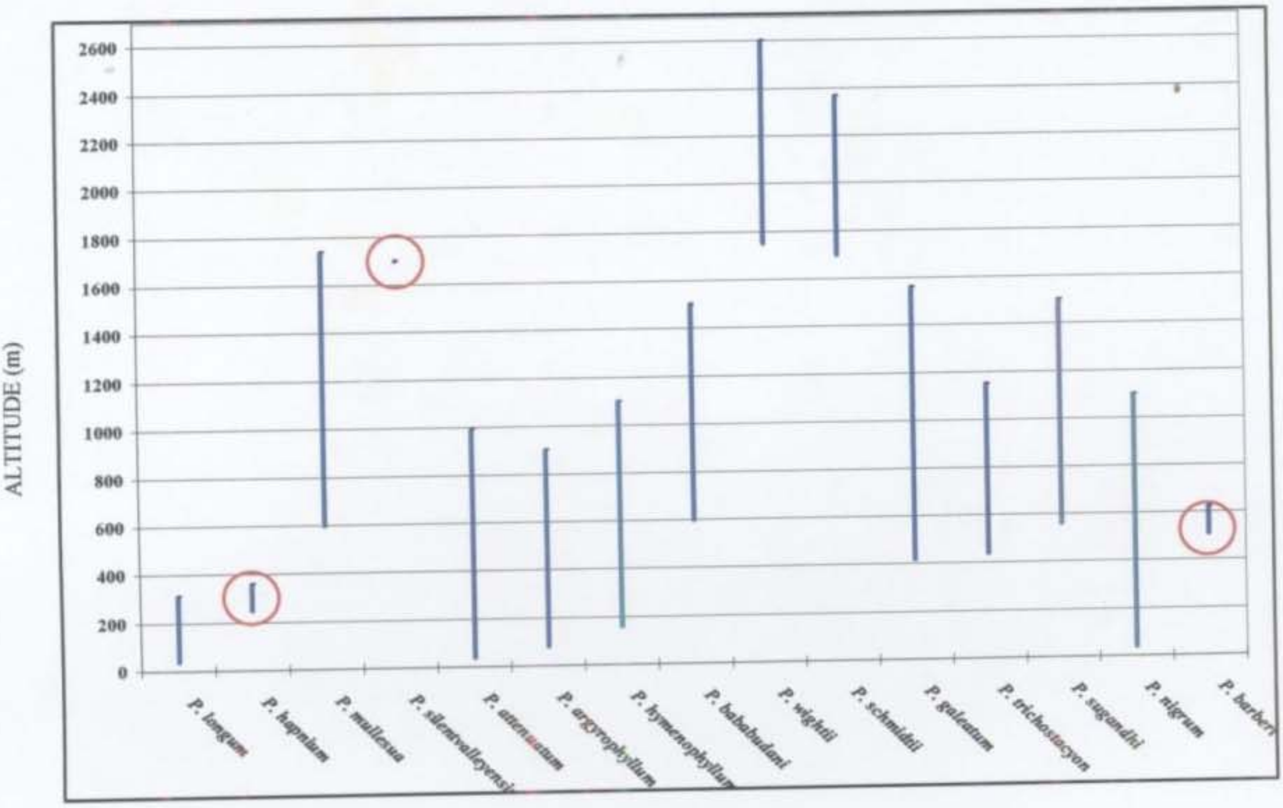


Fig. 3: Distribution of *Piper* species based on altitude.
The circled species shows their limited distribution

Distribution of *P. hapnium,* though morphologically close to *P. longum*, is limited and is confined to only Manalar regions of Kollam District at an elevation between 250 - 360 m.

P. mullesua is the only South Indian species with erect but globular female spikes occurring at an altitude between 600 - 1740 m in the states of Kerala, Karnataka and Tamil Nadu. The population density was at maximum in Naduvattom region in Tamil Nadu, Silent Valley forests in Kerala and Thalacauvery region in Karnataka. These regions can be considered as the ecological niches for *P. mullesua.*

P. silentvalleyensis, a unique species with erect spikes containing both male and female flowers in the same spike, is the rarest among the species of *Piper* and was collected from a single location at an elevation of 1700 m at Paikara of Nilgiri District. This species, unless protected, will become extinct very soon.

P. attenuatum, P. argyrophyllum and P. hymenophyllum are the *Piper* species with pendulous spikes and adnate bracts with free margins. Among these three, *P. attenuatum* is the most widely distributed and occurs in all the forest regions of

Kerala, Karnataka and Tamil Nadu at an elevation of 40 - 990 m. Though this species is found at high elevations like Munnar in Kerala, its population is maximum in the lower elevations. The species richness was maximum at Silent Valley of Palghat District, Neyyar, Peppara areas of Thiruvananthapuram District and nearby forests at Tirunelveli District (Tamil Nadu), which can be considered its ecological niches.

P. argyrophyllum is morphologically similar to *P. attenuatum* but differs from it in that; the leaves are five nerved and slightly pubescent along the veins. The shoot tips are also pubescent. This species is found occurring at an elevation of 80 - 900 m. Species richness was maximum in Malappuram District followed by Wayanad and Idukki in Kerala, Kodagu District in Karnataka and Tirunelveli District in Tamil Nadu.

P. hymenophyllum is the most hirsute species among the three mentioned earlier. It is found occurring at an elevation of 160 - 1100 m. The species is very much similar to *P. attenuatum* except for its hirsute nature on the leaves and stem. This species is widely distributed in the wet evergreen forests of Kerala, Karnataka and Tamil Nadu at medium elevations. Species richness was maximum in Kodagu District of Karnataka followed by Wayanad and Palghat Districts of Kerala.

P. schmidtii and *P. wightii* are two species occurring only at higher elevations. The distribution of *P. wightii* ranged from 1750 - 2600 m while that of *P. schmidtii* is from 1700 - 2360 m. They are extensively distributed in the Shola forests of Nilgiri District of Tamil Nadu, which can be considered as the area of maximum diversity for these species. *P. schmidtii* co-exists with *P. wightii* generally but its population gradually decreases as the elevation increases to above 2500 m. They were also distributed sparsely in Silent Valley (Manilal, 1988) and Munnar regions in Kerala.

The maximum population density and diversity of *P. wightii* is in Ootacamund and Kodai regions of Tamil Nadu. *P. schmidtii* was found to occur though in lesser population density in lower parts of Ootacamund and Kodai hills intermingled with *P. wightii*. Only *P. wightii* is seen in the upper parts of the regions. These species, though occur intermingled, are clearly distinct from each other in almost all morphological characters and no intermediate forms were observed.

Table 14. Geographical information of the area surveyed and distribution of diversity

State	Geographical area	Districts covered	Altitude range (m)	Latitude (N)	Longi tude (E)	Diversity distributed
	Southern Western Ghats	Pathanamthi-tta, Kollam and Trivandrum	70 – 650	$8^{0}57'$- $9^{0}48'$	$77^{0}30'$- $77^{0}10'$	*P. longum* *P. hapnium* *P. mullesua* *P. attenuatum* *P. argyrophyllum* *P. hymenophyllum* *P. galeatum* *P. trichostachyon* *P. sugandhi* *P. nigrum* *P. barberi*
Kerala	High ranges, Nelliampathy and Palghat Hills, Silent Valley and Siruvani hills	Idukki and Palghat	100 -2100	$9^{0}50'$- $11^{0}39'$	$77^{0}05'$- $77^{0}28'$	*P. longum* *P. mullesua* *P. argyrophyllum* *P. attenuatum* *P. argyrophyllum* *P. hymenophyllum* *P. schmidtii* *P. wightii* *P. galeatum* *P. trichostachyon* *P. sugandhi* *P. nigrum*
	Bhramagiris and Kottiyur hills	Wayanad and Kannur	100-1500	$11^{0}53'$- $11^{0}68$	$75^{0}91'$- $76^{0}40'$	*P. longum* *P. mullesua* *P. argyrophyllum* *P. attenuatum* *P. argyrophyllum* *P. hymenophyllum* *P. galeatum* *P. trichostachyon* *P. sugandhi* *P. bababudani* *P. nigrum*
Karnataka	Coorg hills	Coorg	490-630	$11^{0}89'$ – $12^{0}45'$	$75^{0}48$ – $75^{0}68$	*P. mullesua* *P. attenuatum* *P. argyrophyllum* *P. hymenophyllum* *P. galeatum* *P. trichostachyon* *P. sugandhi* *P. bababudani* *P. nigrum*

	Kuderemukh, Agumbe and Sirsi hills	DK, Chickmagalur, Hassan and Uttar Kannada	210-580	$12^{0}69'$ – $12^{0}72'$	$75^{0}20'$– $75^{0}44'$	*P. attenuatum* *P. argyrophyllum* *P. hymenophyllum* *P. galeatum* *P. trichostachyon* *P. sugandhi* *P. nigrum*
Tamil Nadu	Nilgiri hills	Nilgiri	210-2350	$11^{0}18'$ - $11^{0}60'$	$76^{0}32'$ – $76^{0}42'$	*P. mullesua* *P. silentvalleyensis* *P. argyrophyllum* *P. attenuatum* *P. argyrophyllum* *P. hymenophyllum* *P. galeatum* *P. trichostachyon* *P. schmidtii* *P. wightii* *P. nigrum*
	Kannikatti, Courtallam and KMTR	Tirunelveli	480 - 930	$8^{0}69'$ – $9^{0}03'$	$77^{0}31'$ – $77^{0}38'$	*P. mullesua* *P. argyrophyllum* *P. attenuatum* *P. argyrophyllum* *P. hymenophyllum* *P. galeatum* *P. trichostachyon* *P. nigrum* *P. barberi*

P. galeatum and *P. trichostachyon* are clearly separated in floral morphology from the rest of South Indian *Piper* in that they have stalked flowers with bracts fused to form a receptacle from which the flower arises. Though these species broadly resemble *P. nigrum* in other characters, they differ from it in leaf and fruit characters. *P. galeatum* is a hardy vine growing to great heights occurring generally in medium to high elevation in the forests of Western Ghats. It is distributed in Kerala, Karnataka and Tamil Nadu at an altitude of 420 - 1560 m. Species richness was found maximum in Wayanad, Idukki and Silent Valley regions of Kerala and Kodagu District of Karnataka.

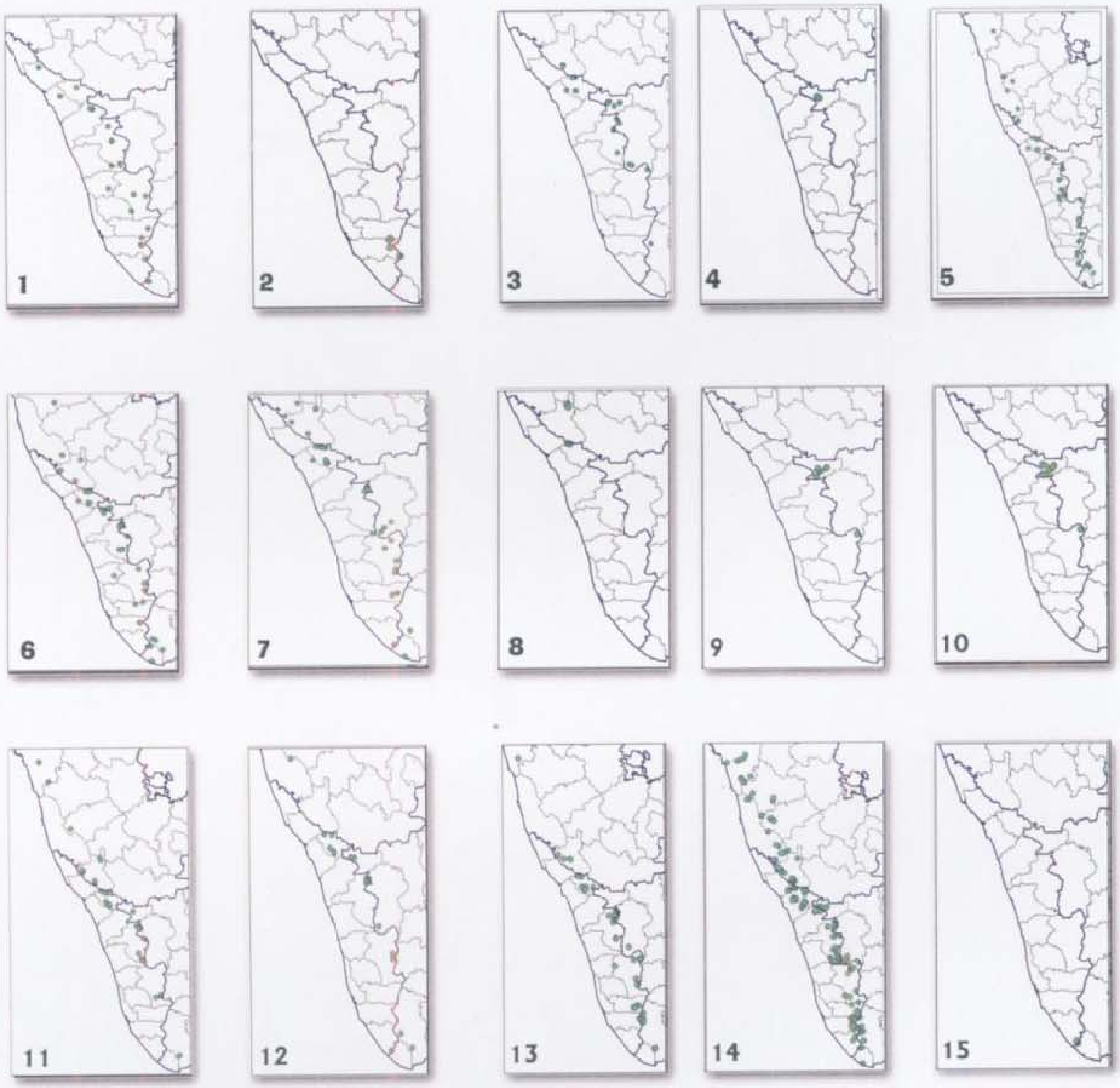


Fig. 4. Distribution of *Piper* species in South India.

1 *Piper longum,* 2 *P. hapnium,* 3 *P. mullesua,* 4 *P. silentvalleyensis,* 5 *P. attenuatum,* 6 *P. argyrophyllum,* 7 *P. hymenophyllum,* 8 *P. bababudani,*9 *P. wightii,* 10 *P. schmidtii,* 11 *P. galeatum,* 12 *P. trichostachyon,* 13 *P. sugandhi,* 14 *P. nigrum* and 15 *P. barberi*

P. sugandhi closely resembles *P. nigrum*, but for the slightly stalked flowers. It is found distributed among the populations of *P. trichostachyon*, *P. galeatum* and wild forms of *P. nigrum* at an altitude between 560 - 1500 m. Species richness was maximum in Wayanad and Idukki Districts of Kerala. Good population was located at Chickmagalur District of Karnataka also.

P. bababudani is similar to *P. sugandhi* in general morphology but with fleshy peduncle and has limited distribution. This species was originally reported from Bababudan hills in Karnataka and could be collected only from two locations viz. Garwale forest of Kodagu District and from the Thirunelly forests (Pakshipathalam) of Wayanad District and can be considered as endangered. Its distribution ranged from 600 - 1500 m.

The Western Ghats region of South India is considered as the center of origin of *P. nigrum* where the wild forms still exists in plenty. Among the species of *Piper, P. nigrum* has the maximum diversity, adaptability and density and occurs at almost all areas of this region from sea level (40 m) to an altitude of 1100 m. Occurrence of wild forms of *P. nigrum* at elevations above 1100 m was not noticed. However, the cultivation of black pepper was prevalent even up to an elevation of 2500 m. The distribution of wild forms of *P. nigrum* though abundant in almost all regions of Western Ghats, is maximum in Palghat, Idukki and Pathanamthitta Districts of Kerala and Hassan District and Jog falls region of Karnataka.

P. barberi is a unique species of *Piper* and differs from rest of the species of Southern India in the reticulate venation of leaves and unusually long peduncle. It is an endangered species having very limited distribution and could be collected only from a few locations viz. Anamalai forests of Coimbatore and Kannikatti forests of Tirunelveli in Tamil Nadu at an elevation of 520-600 m. Even in these locations, only one or two plants were found making this species highly endangered along with *P. hapnium*, *P. silentvalleyensis* and *P. bababudani*, which needs to be given the highest priority for conservation, multiplication and reintroduction in their original habitats.

The community composition, species richness, relative abundances of different species and species diversity in a community were represented using Shannon diversity index (H).

Studies using Shannon's diversity index (Fig. 5) indicated that the Western Ghats region of South India could be divided into seven, based on relative abundance of different species and species diversity in a community.

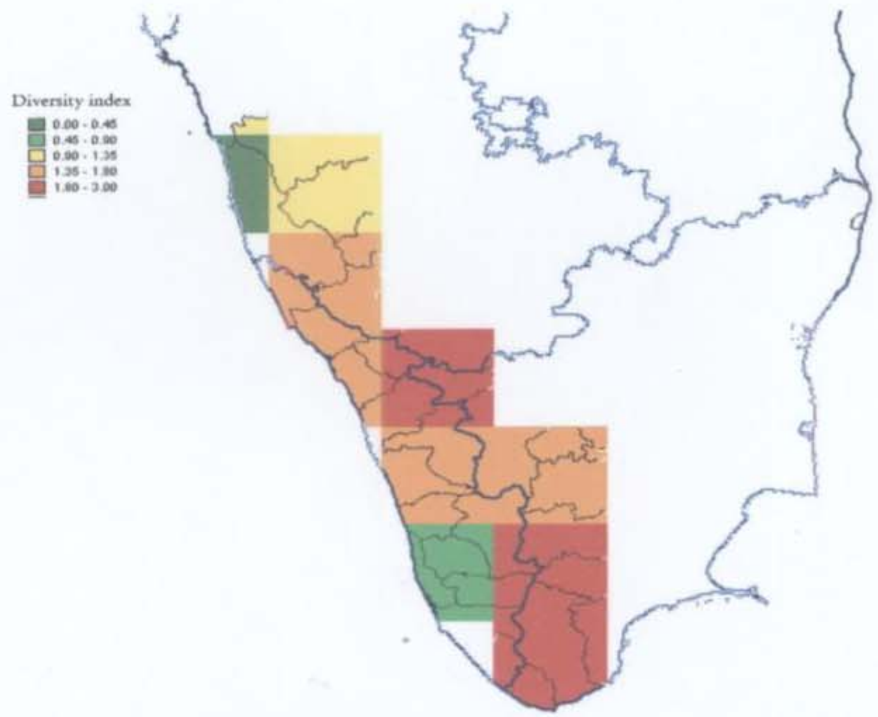


Fig. 5. Diversity indices of distribution of *Piper* species

Shannon's (Beals *et al.*, 1998) index (rage 0.45-3.0) increases from the North Kanara in Karnataka to the hilly borders between Kerala and Tamil Nadu. It again declines towards Southern Kerala. However, at the Southern tip, diversity again reaches highest levels. Low levels of diversity were found in the coastal regions. The hilly regions of Kerala and Tamil Nadu are the two regions with maximum diversity – especially the mountainous regions between the states. These may be the possible centres of origin for the South Indian species of *Piper*.

Taxonomy

The genus *Piper* belongs to the Family Piperaceae under the sub Class Monochlamydeae in the series Microembryeae where the floral parts are reduced to the essential parts. Hence, the classification and taxonomy of *Piper* and its species are heavily dependant upon very few morphological/floral characters. The earlier workers used characters like plant habit, pubescence, leaf shape, texture and venation in juvenile and mature forms, orientation of the spike, length of peduncle, nature of bract and fruit colour as key distinguishing characters in both male and female types to identify different species (Hooker, 1886; Kanjilal *et al.*, 1940; Gamble, 1925).

The description of fifteen different species of *Piper* occurring in Southern India based on the above said characters is given below. The important taxonomic features of each species are also presented in Figures 6-20.

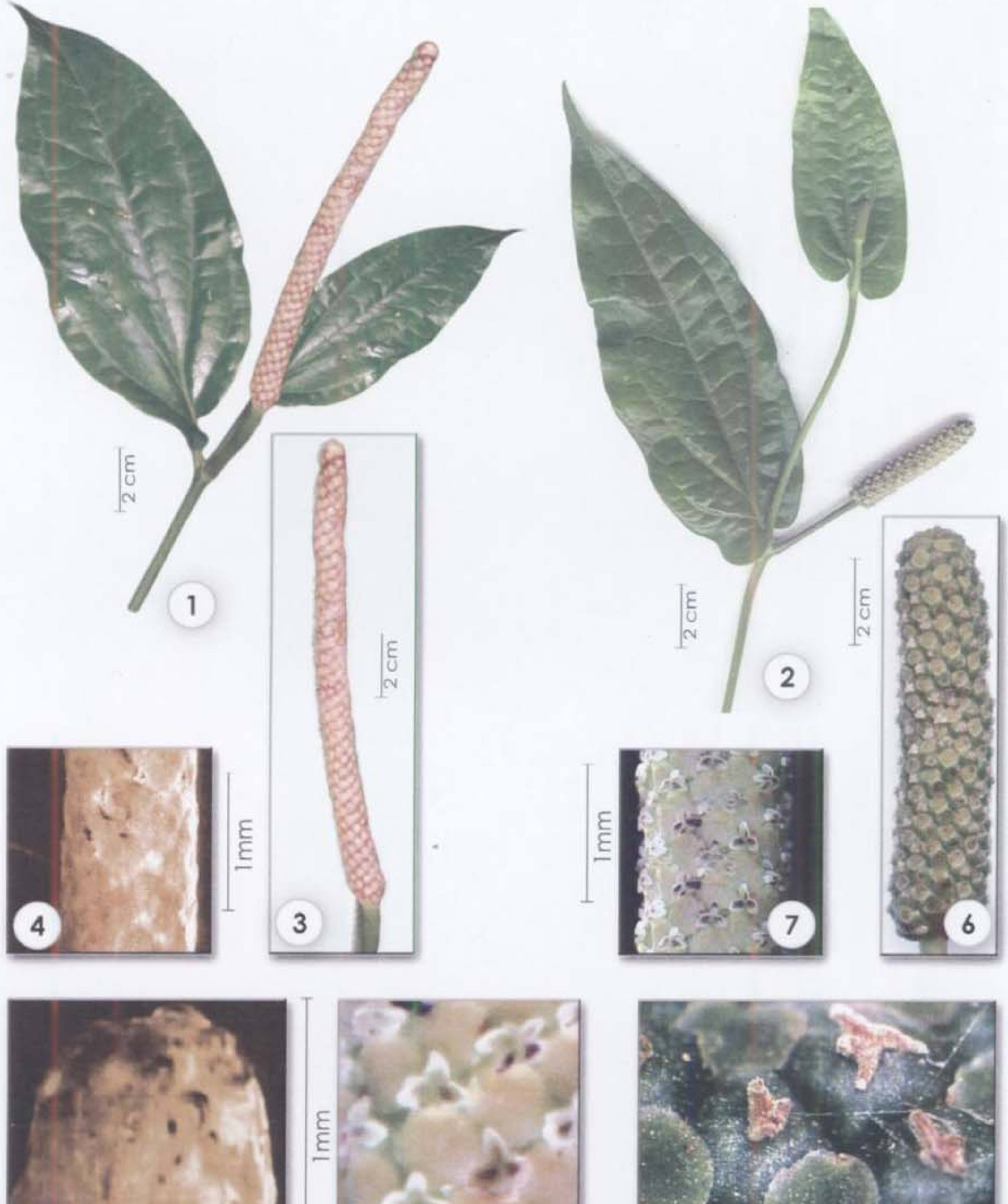


Fig. 6. *Piper longum* Linn.

1. Branch with male spike; 2. Branch with fruiting spikes; 3. Male spike; 4. Male spike-enlarged 5. Portion of male spike with stamen and bracts; 6. Female spike; 7. Portion of female spike enlarged; 8. Bracts and stigma; 9. Mature round berries.

Piper longum Linnaeus 1753 -- *Sp. Pl.* 29. (IK)

Habitat: Growing wild in the low-lying forests.

Habit: A slender, perennial, creeping, under shrub, dioecious. Vegetative branches creeping and spreading on the ground, fruiting branches erect young branches puberulous, hairs minute, multi-cellular, deciduous, older branches very glabrous

Leaves: Petiolate, distinctly dimorphic, those on creeping shoot cordate, glabrous, petiole long up to 6.5 cm, grooved; length up to 12.5 cm and width up to 9 cm, leaves on the fruiting branches oblong, lanceolate, base unequally cordate, with pronounced auricle, tip acuminate, length up to 9 cm and width up to 7 cm, 3 – 4 pairs of lateral ribs arise right from the base, lower side puberulous or downy when young, petiole very short.

Inflorescence: Catkin, cylindrical, erect, female spikes up to 6.0 cm in length, creamy white or yellowish white when young, peduncle about 1 – 2 cm long, downy; male spike much longer, about 4.0 – 10.0 cm long, yellow on maturity. Bracts peltate, orbicular, glabrous.

Flowers: Bracteate, incomplete, unisexual and laterally fused. Calyx and corolla absent.

Androecium: Stamens 3 – 4, free.

Gynoecium: Carpel single, ovary obovate, style absent, stigma 3 – 4 lobed, short, papillate.

Fruits: Very small, fused laterally, spicy and pungent. Seeds very small. Fruits on ripening turn from green to black, deciduous.

Occurrence:

Kerala: *Idukki Dist.* - Cheruthoni, Moozhiyar, Pampadumpara; *Kannur Dist.* – Alakode; *Kollam Dist.*- Aryankavu, Thenmala; *Kottayam Dist.*- Kuttikanam; *Kozhikode Dist.*- Peruvannamuzhi; *Malappuram Dist.*- Nadukani, Nilambur; *Palghat Dist.*- Dhoni, Karapara, Mukkali, Parambikulam WLS; *Pathanamthitta Dist*-Ettathanam; *Wayanad Dist.*- Tirunelli

Tamil Nadu: *Tirunelveli Dist.*- Courtallam, Shenkottai, KMTR (Kallakad Mundanthurai Tiger Reserve)

Altitude range: 40- 310 m MSL.

Flowering and fruiting: May- June, off-season flowering common. Fruits mature in Dec-January.

61a

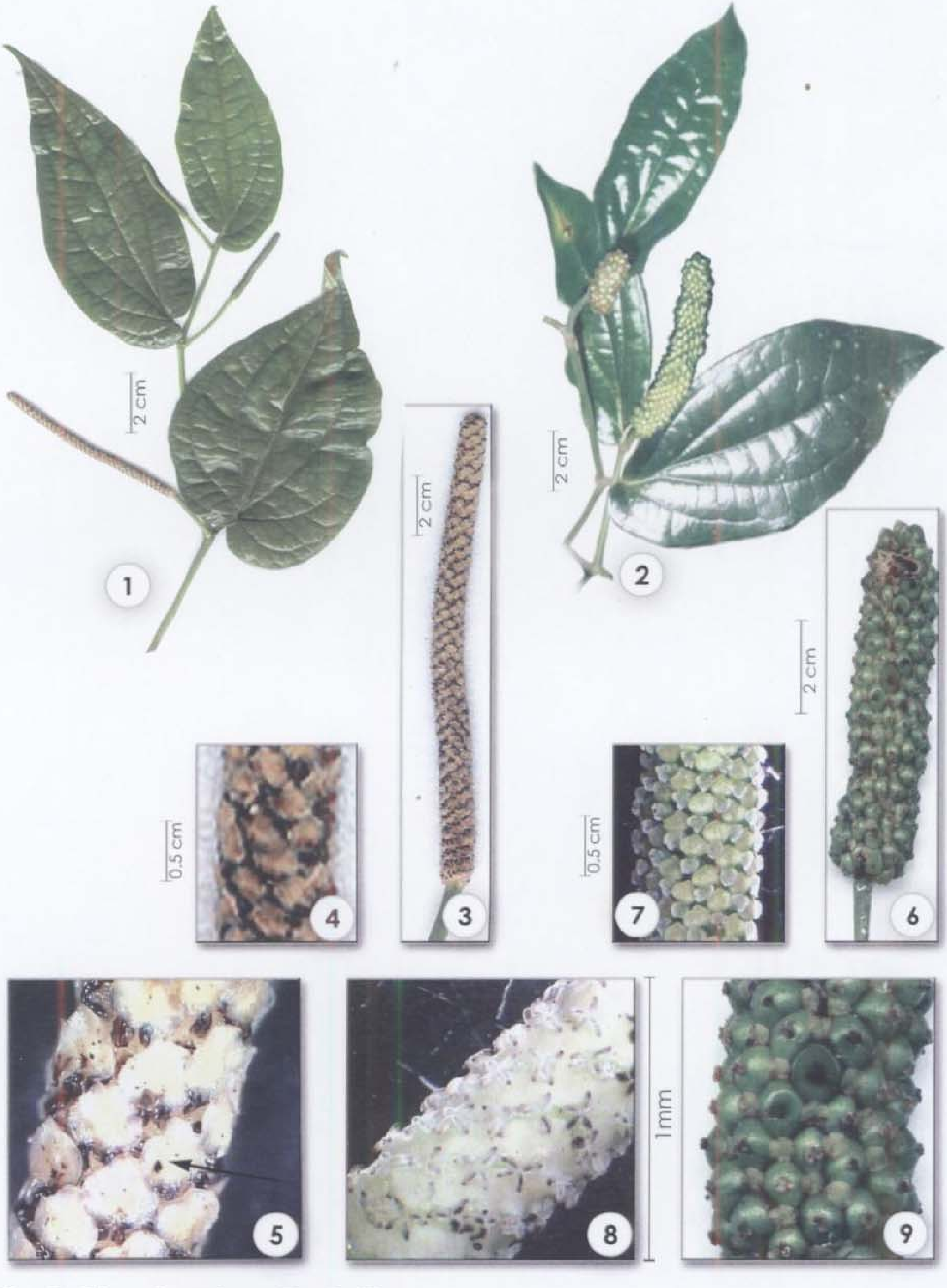


Fig. 7. *Piper hapnium* Buch-Ham.

1. Branch with male spike; 2. Branch with fruiting spikes; 3. Male spike; 4. Male spike-enlarged 5. Portion of male spike with stamen and bracts; 6. Female spike; 7. Portion of female spike enlarged; 8. Bracts and stigma; 9. Mature round berries.

Piper hapnium Francis Buchanan-Hamilton 1832. -- in *Wall.* Cat. n. 6650 D. (IK)

Habitat:	An endangered species occurring about 100 m to 400 m MSL of Western Ghats.
Habit:	Habit: A slender scandent dioecious climber, branchlets delicately puberulous.
Leaves:	Petiolate. Leaves on the runners broadly cordate, equal sided, palmately ribbed, tip acute – acuminate, on the fruiting branches elliptic or oblong lanceolate, slightly puberulous along the ribs and veins on the ventral side, about 8 cm long, 5 cm broad, 2-3 pairs of prominent lateral ribs, base unequal, petioles puberulous.
Inflorescence:	Catkin, female spikes cylindrical, erect, 4 – 5.5 cm long, shining white, peduncle puberulous; mature spikes green, often curved. Bracts peltate, pedicelled, orbicular, glabrous above.
Flowers:	Bracteate, incomplete, actinomorphic, unisexual and laterally fused. Calyx and corolla absent.
Androecium:	Stamens 3 – 4, free.
Gynoecium:	Carpel single, ovary obovate, style absent, stigma 3 – 4 lobed, short, papillate.
Fruits:	Very small, fused laterally, spicy and pungent. Seeds very small. Fruits on ripening turn from green to black, deciduous.
Occurrence:	
Kerala:	*Kollam Dist.* – Achankovil, Manalar, Palaruvi, Shenthuruni.
Altitude range:	250 - 360 m MSL.
Flowering and fruiting:	June- August. Fruits mature during Dec-January.

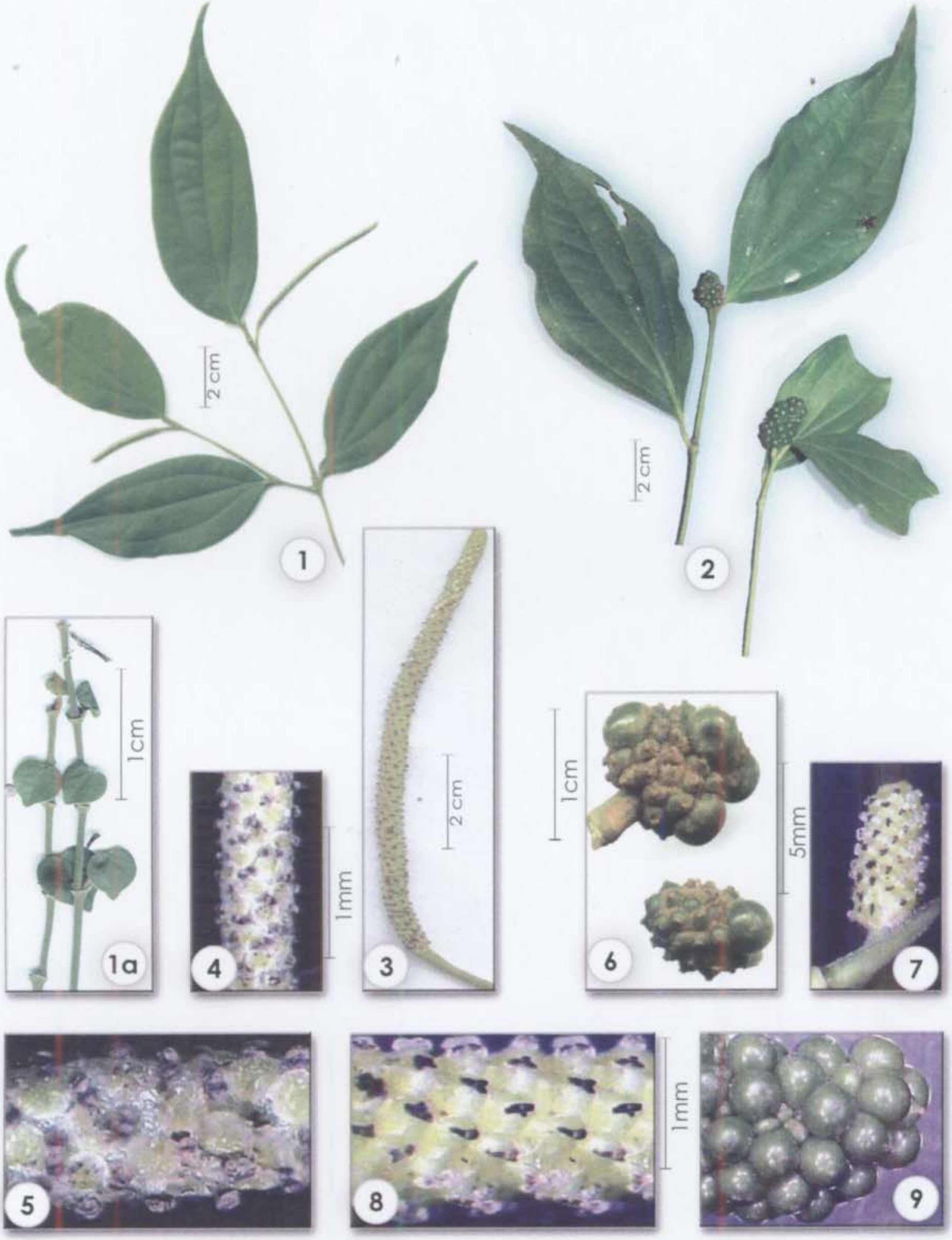


Fig. 8. *Piper mullesua* Buch-Ham.

1. Branch with male spike; 1-a Young shoot tip with ivy-like leaves; 2. Branch with fruiting spikes; 3. Male spike; 4. Male spike-enlarge; 5. Portion of male spike with stamen and bracts; 6. Female globose spikes; 7. Female spike enlarged; 8. Bracts and stigma; 9. Mature round berries.

Piper mullesua Francis Buchanan-Hamilton 1825 – *Prodromus* . Fl. Nepal. 20. (IK)

Habitat: Generally distributed in wild in the high altitude areas of shola forests.

Habit: A slender, extensively branching climber, branches glabrous; juvenile shoots puberulous or glabrous. The juvenile shoots often have crisp hairs, which are deciduous; such shoots sometimes coloured like pink.

Leaves: Petiolate. Very small ivy-like or cordate; leaves on the flowering shoots small, coriaceous, elliptic, approximately 13 × 4 cm; base acute and often oblique, tip acuminate, two pairs of prominent ribs, lower one from the base, upper one 1-2 cm above the base; veins prominent on the ventral side.

Inflorescence: Catkin. Spikes filiform in male, 3- 5 cm long; female globose or oblong, about 1 cm long. Peduncle short, less than 0.5 cm, bracts orbicular, peltate and pedicelled.

Flowers: Bracteate, incomplete, actinomorphic and unisexual. Calyx and corolla absent.

Androecium: Stamens two, filaments short, anther lobes single, reniform, dorsifixed; pollen sacs two, dehiscing by longitudinal slits.

Gynoecium: Carpel single, ovary ellipsoid, style absent, stigma 3 lobed, minute papillate.

Fruits: Very small, almost ellipsoidal, spicy and mildly pungent, turns from green to black on ripening.

Occurrence:

Kerala: *Idukki Dist.*- Munnar; *Kozhikode Dist.*- Kakkayam; *Palghat Dist.*- Silent Valley, Siruvani. *Wayanad Dist.*- Choorathodu, Sugandhagiri.

Tamil Nadu: *Nilgiri Dist.* - Ooty, Kotagiri, Naduvattom; *Tirunelveli Dist.*- Kodairdam; *Coimbatore Dist.*- Valparai .

Karnataka *Chickmagalur Dist.* - Kuderemukh. *Kodagu Dist.* - Virajpet, Thalacauvery.

Altitude range: 600 - 1740 m MSL.

Flowering and fruiting: April- July. Off-season flowering is very common. Fruits mature during Jan- March period.

65a

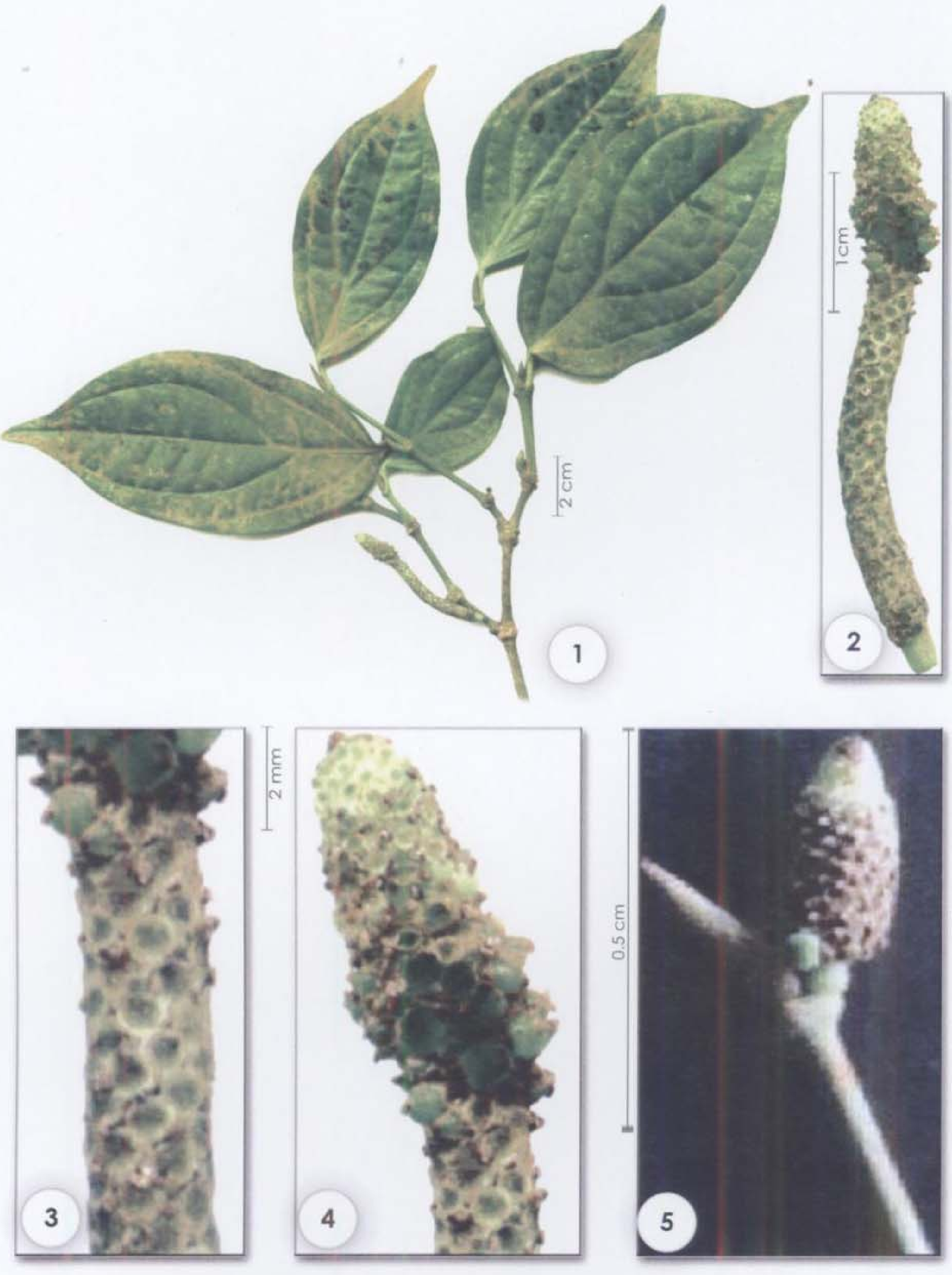


Fig. 9. *Piper silentvalleyensis* Ravindran and Asokan

1. Plant habit with bisexual spike; 2. A spike showing immature berries at the top; 3 A portion of spike with bracts and stamen; 4 A portion of spike showing small berries; 5. A bisexual spike with two berries.

Piper silentvalleyensis P. N. Ravindran, M. K. Nair & R. Asokan Nair 1987 -- in *J. Econ. Taxon. Bot.*, 10(1): 167.

Habitat:	A very rare species found wild only in high elevation areas.
Habit:	A perennial, slender climber, stem about 0.5-1.0 cm thick, swollen at the nodes, branches terete, entirely glabrous, petiole short, about 3-6 mm grooved, sheaths minutely pubescent. Only bisexual wild species is reported so far from the Western Ghats.
Leaves:	Petiolate. Alternate, ovate to ovate- elliptic, somewhat coriaceous, lamina 5-8.5 cm long and 2.0-3.5 cm broad, glabrous on both sides, base acute, more or less asymmetric, tip caudate-acuminate, lamina prominently ribbed, lateral ribs two pairs, first from the base and the second about 0.5 cm above the base.
Inflorescence:	Spikes 2.5 -5.5 cm long, erect and flexuous, peduncle very short, 0.1-0.3 cm long; glabrous, furrowed when dry, never longer than petiole, bracts orbicular, peltate, stalked, about 0.07 cm in diameter.
Flowers:	Bisexual, incomplete, and actinomorphic.
Androecium:	Stamens two, very short, anthers 2-lobed, reniform, attached transversely at the tip of the filament, dehiscing by longitudinal slit.
Gynoecium:	Ovary globoid, style absent, stigma minute, 3-lobed.
Fruits:	Very small, mature one about 0.1 cm across, obovate with striations, spicy and mildly pungent
Occurrence:	
Kerala:	*Palghat Dist.* - Silent Valley forests.
Tamil Nadu:	*Nilgiri Dist.*- Paikara
Altitude:	1700 m MSL.
Flowering and fruiting:	Dec- February

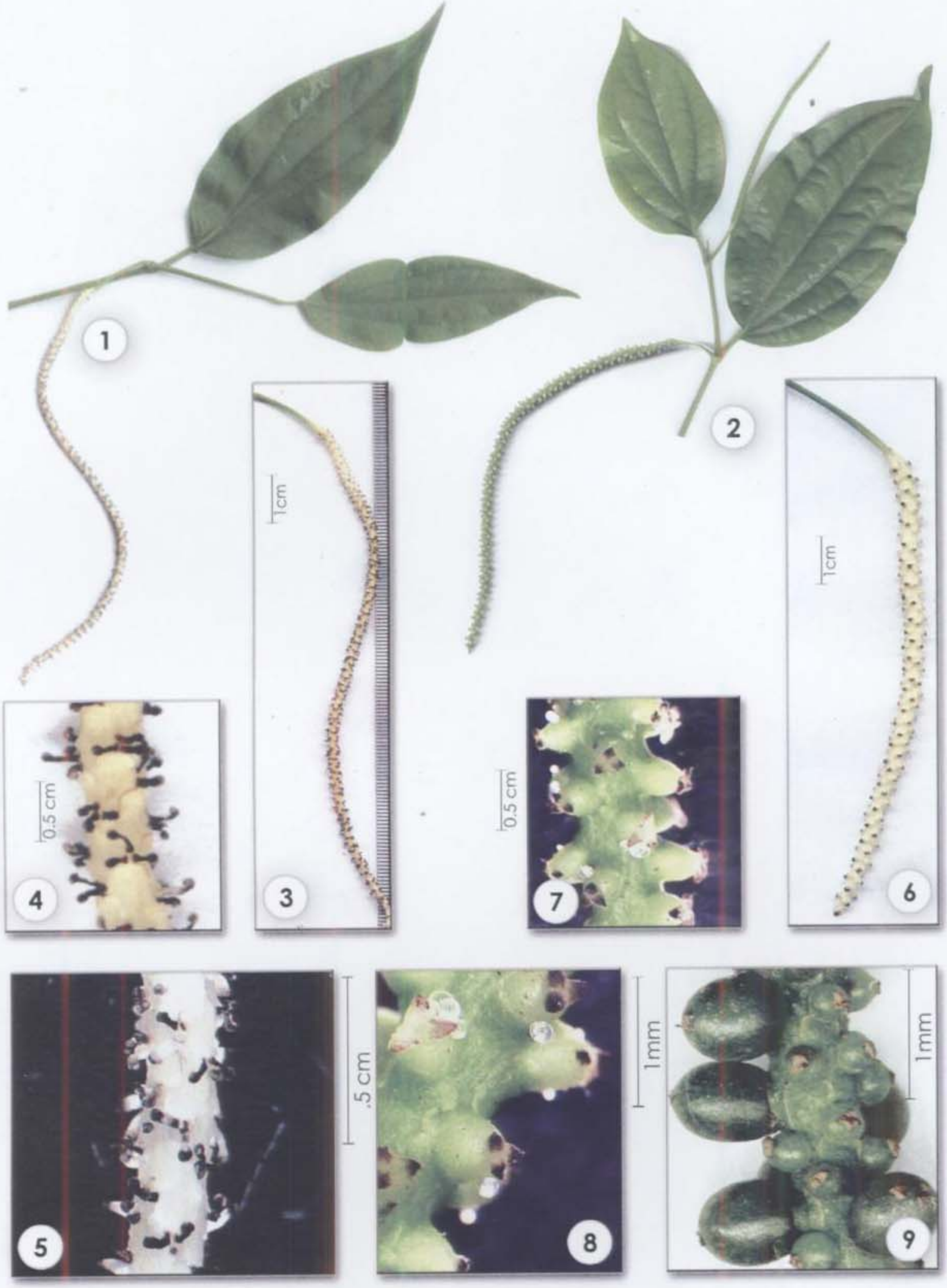


Fig. 10. ***Piper attenuatum*** **Ham.Ex. Wall.**

1. Branch with male spike; 2. Branch with fruiting spikes; 3. Male spike; 4. Male spike-en larged; 5. Portion of male spike with stamen and bracts; 6. Female spike; 7. Portion of female spike enlarged; 8. Bracts and stigma; 9. Mature conical berries.

Piper attenuatum Francis Buchanan-Hamilton ex Nathaniel Wallich 1843. -- *Cat. n.* 6642 B. (IK)

Habitat:	A very common wild species found in almost all the forests of Western Ghats both in evergreen and semi evergreen nature, except for the high altitude area.
Habit:	Scandent, slender climber, main stem rarely exceeds 2.5 cm in diameter. Orthotropic shoot tip light green in colour.
Leaves:	Simple, petiolate, thin, broadly ovate to ovate, some times cordate in the runner shoots. About 9.5 to 11.5 cm long and 4 to 5.5 cm broad, in equilateral, glabrous, petiole grooved, base attenuate and tip acuminate, 7-ribbed, from the base, the outer pair reaching only half to two third of the leaf and the others reaching almost to the leaf tip.
Inflorescence:	Spike thin, filiform and Pendant. ♀ spikes 7-15 cm long, ♂ spikes 8-18 cm long. Peduncle 1.8 to 2.0 cm long. Bractetae, bracts sessile, adnate to rachis, obovate to elliptic, margins free, glabrous.
Flowers:	Incomplete, unisexual, zygomorphic.
Androecium:	Stamens three rarely four, dithecous, dehiscing longitudinally.
Gynoecium:	Style absent, ovary single, oblong, stigma mostly four lobed, papillate, ovule solitary, erect.
Fruits:	Berry oblong, mature ones round to oblong, 0.2 to 0.4 cm; directly turns to black on ripening, deciduous, taste bitter.
Occurrence:	
Kerala:	*Idukki Dist.*- Pampadumpara; *Kollam Dist.*- Kulathupuzha, Thenmala; *Kozhikode Dist.*- Kakkayam, Peruvannamuzhi; *Malappuram Dist.*- Nilambur, Vazhikadavu; *Palghat Dist.*- Dhoni, Malampuzha, Nelliampathy, Parambikulam WLS, Silentvalley; *Pathanamthitta Dist.*- Moozhiyar, Sabarimala; *Thiruvananthapuram dist.*- Neyyar, Peppara; *Thrissur Dist.*- Vazhachal; *Wayanad Dist.*- Sugandhagiri, Thirunelly.
Tamil Nadu:	*Tirunelveli Dist.*- Kodaiar, Kannikatti, KMTR.
Karnataka	*Dakshina Kannada Dist.*- Nettana; *Chikmagalur Dist.*- Balankoppa, Kuderemukh, Mudibe, Sringeri; *Shimoga Dist.*- Akumbe, Sirsi.
Altitude range:	40-990 m MSL.
Flowering and fruiting:	May – June, fruit ripen in December – January. Off-season flowering common.

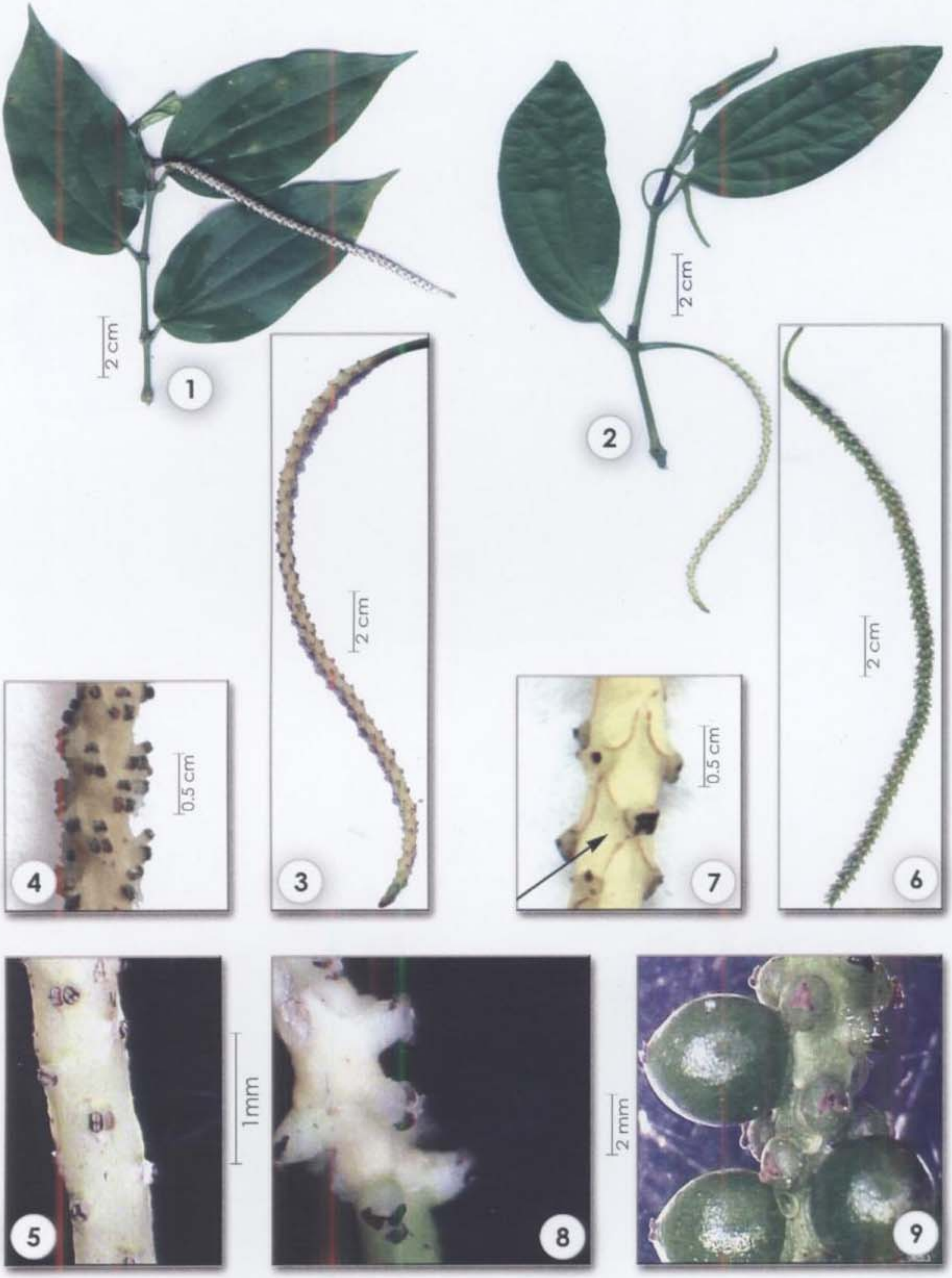


Fig. 11. *Piper argyrophyllum* Miq.

1. Branch with male spike; 2. Branch with fruiting spikes; 3. Male spike; 4. Male spike-enlarged; 5. Portion of male spike with stamen and bracts; 6. Female spike; 7. Portion of female spike enlarged; 8. Bracts and stigma; 9. Mature conical berries.

Piper argyrophyllum Friedrich Anton Wilhelm Miquel 1843 -- *Syst. Pip.* 330. (IK)

Habitat: Found in semi and evergreen forests of Western Ghats.

Habit: A dioecious, scandent, climbing shrub, perennial, main stem and branches glabrous, young shoots pubescent. Externally similar to *P. attenuatum,* but differs from it in having 5-nerved (ribbed) nature of leaf base and shorter greenish white fruiting spike and silvery scales on the underside of the leaves.

Leaves: Leaves simple, alternate, petiolate, thin papery when dry, ovate to elliptic, base round to oblique, cordate in runner shoots, up to 14 cm in length and 8 cm in width, tip acuminate, 5- ribbed at the base, the outer pair of ribs running to two third of the leaf, the inner ones reaching the tip, glabrous or pubescent, younger leaves often minutely hairy, especially along the veins on the lower side of the leaf, silvery scales present on the lower side, petiole about 1 – 1.5 cm, grooved, glabrous or minutely pubescent.

Inflorescence: Spike thin, filiform, pendulous, length highly variable, male spikes 8 – 20 cm, female 5 – 10 cm, glabrous or pubescent. Bracteate, bracts sessile, adnate and almost confluent with the rachis, obovate to elliptic.

Flowers: Incomplete, unisexual and zygomorphic.

Androecium: Stamens three, anther dithecous.

Gynoecium: Carpel single, style absent, ovary oblong, stigma 4 lobed, rarely 3 lobed, short, recurved and papillate.

Fruits: Ovate, becomes spherical in full maturity, on ripening turns lack directly from green, deciduous, taste bitter.

Occurrence:

Kerala: *Idukki Dist.*- Kumali, Pampadumpara, Rajamala; *Kollam Dist.*- Kulathupuzha, *Kozhikode Dist.*- Kakkayam; *Malappuram Dist.*- Vazhikadavu; *Palghat Dist.*- Muthikulam, Nelliampathy, Silentvalley; *Pathanamthitta Dist.*- Chalakkayam, Plapally; *Thiruvananthapuram Dist.*- Neyyar, Peppara; *Thrissur Dist.*-Chimmony; *Wayanad Dist.*- Mananthavady, Poovattanmoola, Sugandhagiri, Tirunelli

Tamil Nadu: *Coimbatore Dist.* - Valayar, Valparai; *Nilgiri Dist.*- Gudallur, Nadukani; *Thirinelveli Dist.*- Kodaiyar, Shenkottai, Varattayar.

Karnataka	*Dakshina Kannada Dist.*-Nettana; *Shimoga Dist.*- Kannangi; *Kodagu Dist.*- Thalacauvery, Virajpet.
Altitude range:	80 – 920 m MSL
Flowering and fruiting:	May – June, fruiting December - January, off-season flowering common.

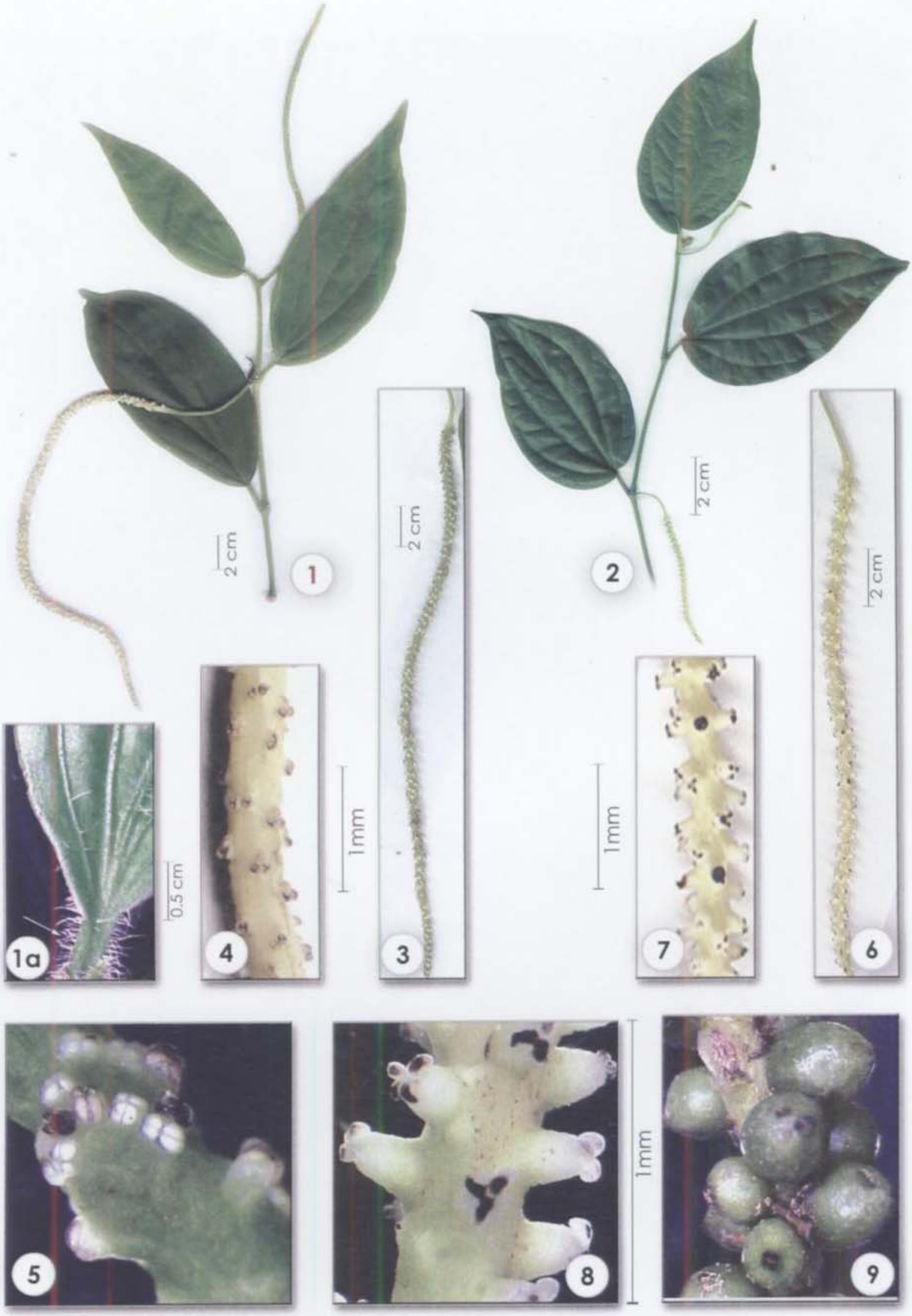


Fig. 12. *Piper hymenophyllum* (Miq.) Wight

1. Branch with male spike; 1-a Portion of leaf with hairs; 2. Branch with fruiting spikes; 3. Male spike; 4. Male spike-enlarged; 5. Portion of male spike with stamen and bracts; 6. Female spike; 7. Portion of female spike enlarged; 8. Bracts and stigma; 9. Mature conical

Piper hymenophyllum (Miquel) Wight 1853 -- in *Icon. Pl. Ind. Orient.* (Wight) 4 (t. 1942). (IK)

Habitat: Distributed in the medium to moderately high altitude wet forests of Western Ghats.

Habit: Scandent, slender climber dioecious, having prominently pubescent branchlets and leaves, hairs more pronounced on the young shoots. Orthotropic shoot tip light green in colour.

Leaves: Petiolate, simple, alternate, thin and hairy, sometimes thinly coriaceous; shape and size much variable, ovate- ovate elliptic, or elliptic lanceolate. Leaves on the lateral shoots vary in size, length up to 11 cm and width up to 8.5 cm, base acute or obtuse; cordate or semi-cordate in the case of juvenile shoots; tip acuminate; 2-3 pairs of lateral ribs arising from the base or near to it; both sides pubescent, petiole grooved, long up to 1.3 cm in the leaves of plagiotropic shoots and up to 4 cm long in the leaves of orthotropic shoots.

Inflorescence: Spike thin filiform, male spike 5-13 cm long, female spike 6-16 cm long, lengthening in maturity, peduncle pubescent, bracts adnate to the rachis, obovate to elliptic in shape.

Flowers: Incomplete, unisexual.

Androecium: Stamens two to three, anther dithecous.

Gynoecium: Style absent, ovary oval, stigma 3-4 lobed recurved and papillate.

Fruits: Fruits oval, mature ones often becomes spherical, dark green on ripening turns black; taste bitter.

Occurrence:

Kerala: *Idukki Dist.* - Adimali, Kannimala, Kumaly, Munnar, Pampadumpara; *Kozhikode Dist.*- Kakkayam; *Palghat Dist.*- Pathenthodu, Sholayar, Silent Valley, Siruvani, Varadimalai; *Thiruvananthapuram Dist.*- Peppara; *Wayanad Dist.*-Choorathodu, Sugandhagiri, Thirunelly.

Tamil Nadu: *Nilgiri Dist.* – Naduvattom; *Tirunelveli Dist.* – Kodairdam; *Coimbatore Dist.* – Valparai; *Kanyakumari Dist.*- Brymoore.

Karnataka *Kodagu Dist.* - Mathapuram, Virajpet, Thalacauvery; *Dakshina Kannada Dist.* - Subramanya.

Altitude range: 160 – 1100 m MSL

Flowering and fruiting: May- July. Off-season flowering common. Fruits ripen in Jan- March.

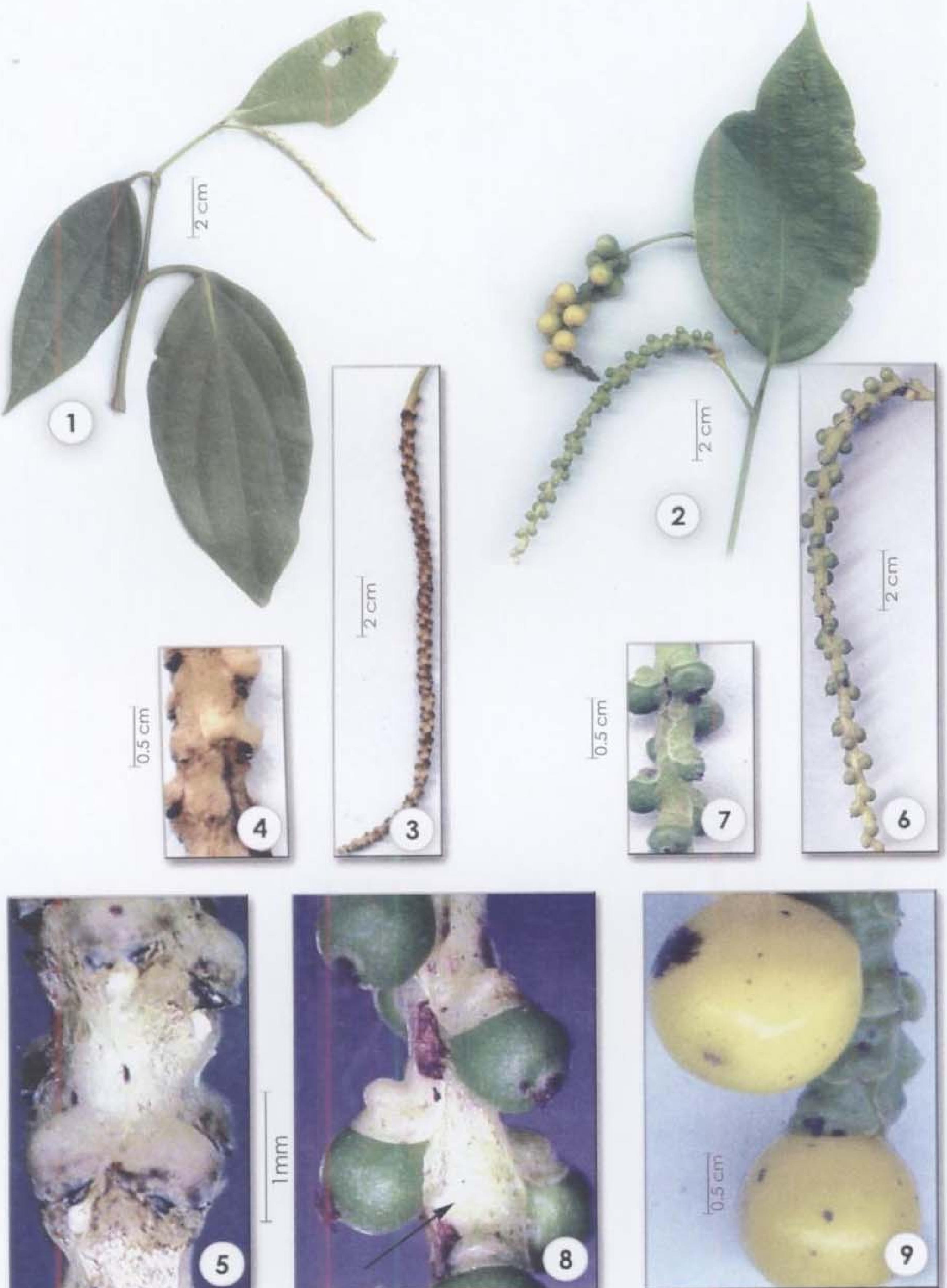


Fig. 13. *Piper bababudani* **Rahiman.**
1. Branch with male spike; 2. Branch with fruiting spikes; 3. Male spike; 4. Male spike-enlarged 5. Portion of male spike with stamen and bracts; 6. Female spike; 7. Portion of female spike enlarged; 8. Bracts and stigma; 9. Mature round berries.

Piper bababudani Rahiman sp. nova. PhD Thesis, 1981.

Habitat:	Located in Bababudin hills and Garwale forests of Karnataka and Thirunelly forests of Kerala.
Habit:	Thick stemmed vigorous vine, dioecious, branches right from the ground level, profuse foliage.
Leaves:	Petiolate, alternate, rounded-ovate to ovate, up to 18.5 cm long and 9.0 cm broad, coriacious, glabrous, dorsal side green and glauccus, ventral side light coloured, base obtuse, tip acuminate, 7 nerved, ribs prominent, anterior most pair starts about two- three cm above the base, rest from the base or near to it.
Inflorescence:	Spike filiform, fleshy, pendulous and white in colour. Male spike up to 10.0 cm long. Flowers arranged in irregular fascicles or spiral, bracts oblong with decurrent base, deeply cupular, adnate to the rachis.
Flowers:	Unisexual, incomplete.
Androecium:	Stamens two, filaments very short, anthers split longitudinally.
Gynoecium:	Carpel single, ovary spherical, style absent, stigma 4-lobed and papillate.
Fruits:	Spherical, bold, turns yellow to orange red while ripening. Pungent in taste.
Occurrence:	
Kerala:	*Wayanad Dist.*-Pakshipathalam (Thirunelly).
Karnataka	*Kodagu Dist.* - Garwale forests.
Altitude range:	600 – 1500 m MSL.
Flowering and fruiting:	May- July, sometimes in Dec-Jan and fruits mature at Feb- March.

Fig. 14. *Piper wightii* Miq.

1. Branch with male spike; 2. Branch with fruiting spikes; 3. Male spike; 4. Male spike-enlarged; 5. Portion of male spike with stamen and bracts; 6. Female spike; 7. Portion of female spike enlarged; 8. Bracts and stigma; 9. Mature round berries.

Piper wightii Miquel 1846 - in Hook. *Lond. Journ. Bot. v.* 552. (IK)

Habitat:	Occurring only in the high altitude shola forests of Western Ghats
Habit:	Perennial climber, dioecious, vigorous, occur at elevation above 1500 m only, rooting ivy- like at first, later climbing up on trees, often grow to 10 – 12 m height, orthotropic shoot tip green.
Leaves:	Petiolate, leaf shape ovate, lanceolate, cordate, base round, acute, cordate etc, size approximately 9 × 6 cm, glabrous, tip acuminate, ribbed, margin even or slightly wavy, often curved outwards, ventral side with sparse silvery scales, petiole grooved, 1-5 cm long.
Inflorescence:	Spike filiform, pendant, up to 12.5 cm long, sometimes reach about 15 cm, peduncle up to 3.5 cm, flower sessile, bracts oblong, overlapping with the successive bract, adnate to the rachis.
Flowers:	Unisexual, incomplete.
Androecium:	Stamen 2-3, stalked, filaments thick.
Gynoecium:	Ovary conical, stigma 4 lobed, persistent, style absent.
Fruits:	Conical, but become spherical at maturity, turns yellow and then red when ripen.
Occurrence:	
Kerala:	*Idukki Dist.*-Mannavanchola (Munnar).
Tamil Nadu:	*Nilgiri Dist.*-Dodabettai, Kotagiri, Ooty, Paison Valley, Paikara
Altitude range:	1750- 2700 m MSL.
Flowering and fruiting:	July- August, fruits ripen in Feb- March.

18-14

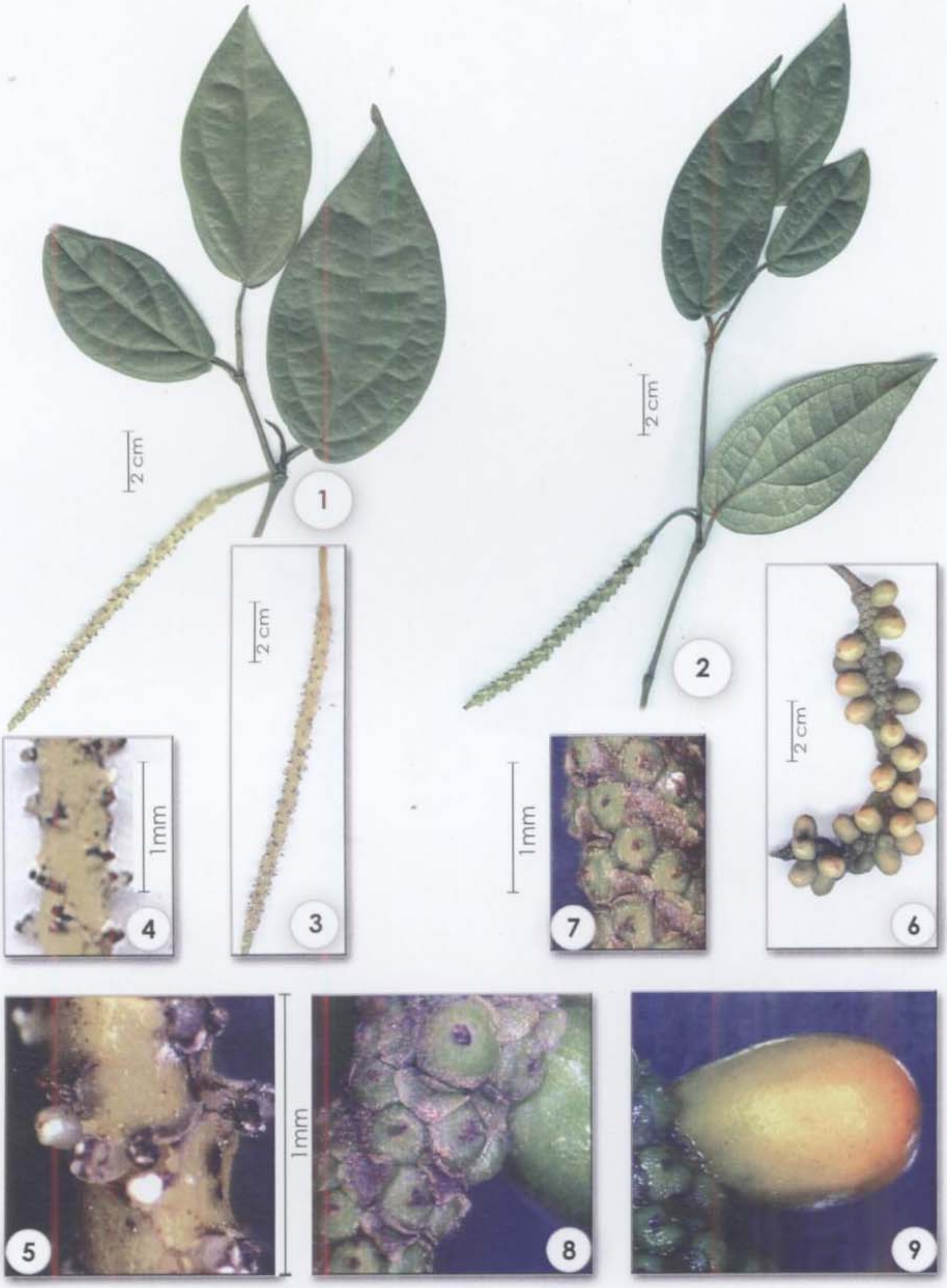


Fig. 15. ***Piper schmidtii*** **Hook.**

1. Branch with male spike; 2. Branch with fruiting spikes; 3. Male spike; 4. Male spike-enlarged; 5. Portion of male spike with stamen and bracts; 6. Female spike; 7. Portion of female spike enlarged; 8. Bracts and stigma; 9. Mature oblong berries.

Piper schmidtii Hooker .f. 1886 -- *Fl. Brit. Ind.* v. 89. (IK)

Habitat:	Distributed in the high altitude area of wet forests of Western Ghats.
Habit:	Perennial, dioecious, woody climber, climbing on trees and covering their trunks and branches, found at elevations above 1500 m. Orthotropic shoot tip purple in colour.
Leaves:	Very thick and coriaceous, venation very prominent; leaves small in mature plants, ovate to ovate–elliptic, base round or acute, tip acuminate, entirely glabrous, ribs very prominent in lower side with purple colour, lateral ribs two pairs, first from the base, second about 1.0 cm above the base, placed unequally; leaves about 9×4 cm in size, larger in the young vines.
Inflorescence:	Spikes filiform, pendant, female spike thick, 6-16 cm, male spikes thinner, up to 15 cm in length; bracts peltate, with raised free margins.
Flowers:	Unisexual, incomplete.
Androecium:	Stamen two, stalked, filaments thick, anther opens by longitudinal slits.
Gynoecium:	Ovary oblong, ovule solitary, style absent, stigma four lobed, papillous.
Fruits:	Conical to ovate, turns yellow and to orange red while ripening
Occurrence:	
Kerala:	*Idukki Dist.* - Mannavanchola (Munnar). *Palghat Dist.* - Silent Valley.
Tamil Nadu:	*Nilgiri dist.* -Kotagiri, Ooty, Paison Valley, Paikara
Altitude range:	1750-2300 m MSL.
Flowering and fruiting:	July- August, fruits ripen in Feb- March.

Fig. 16. *Piper galeatum* C.DC.

1. Branch with male spike; 2. Branch with fruiting spikes; 3. Male spike; 4. Male spike-enlarged; 5. Portion of male spike with stamen and bracts; 6. Female spike; 7. Portion of Female spike enlarged; 8. Bracts and stigma; 9. Mature oblong berries.

Piper galeatum Anne Casimir de Candolle 1869 -- in *DC. Prod.* xvi. I. 242. (IK)

Habitat: Generally found at medium elevations of 500 – 800 m in the shola forests, but some times occur at an elevation up to 1560 m MSL.

Habit: A stout woody climber, Dioecious.

Leaves: Petiolate, alternate, coriaceous, usually elliptic-lanceolate to lanceolate, upto 10.5 cm long and 4.0 cm broad. In male, plants are usually smaller and narrower. Leaves on the main stem are much larger with cordate base, blade almost equilateral. Base acute, two pairs of lateral ribs from the base, the third pair about 1-2 cm above the base and often placed unequally. Nerves and nervules are more prominent in the lower side.

Inflorescence: Spike filiform, Pendant, young ones green or pale purple, mature pale yellowish white, glabrous, peduncle short, peduncle glabrous and short. Male spike is longer than the female and 10-15 cm in length. Bracteate, bract prominent, connate, forming a fleshy cup or boat shaped structure, shortly stipitate and recurved, glabrous.

Flowers: Incomplete, unisexual and slightly stipitate.

Androecium: Stamens two, short, anther lobes two.

Gynoecium: Carpel single, ovary obovate, stigma 3-4 lobed.

Fruits: Green, on ripening turns bright yellow and then to orange red. Oblong or spherical, initially bitter in taste and slightly pungent later.

Occurrence:

Kerala: *Idukki Dist.* - Anavilasam, Kumaly, Peerimedu; *Palghat Dist.*- Nelliampathy, Pathenthodu, Parambikulam WLS, Silentvalley; *Wayanad Dist.* - Choorathodu, Pakshipathalam, Sugandhagiri, Thirunelly.

Tamil Nadu: *Coimbatore Dist.* - Valayar, Valparai; *Tirunelveli Dist.*- Puliyarai, *Nilgiri Dist.*- Naduvattom.

Karnataka *Chickmagalur Dist.* - Samse forest; *Shimoga Dist.* - Adakatte, Akumbe; *Kodagu Dist.*- Bagamandala, Coorg, Garwale, Makutta, Varaharitha, Virajpet; *Uttar Kannada Dist.*- Bhandale, Jog falls.

Altitude range: 420 – 1520 m MSL.

Flowering and fruiting: May- July, off-season flowering occurs. Fruit mature in Jan- March.

82. A

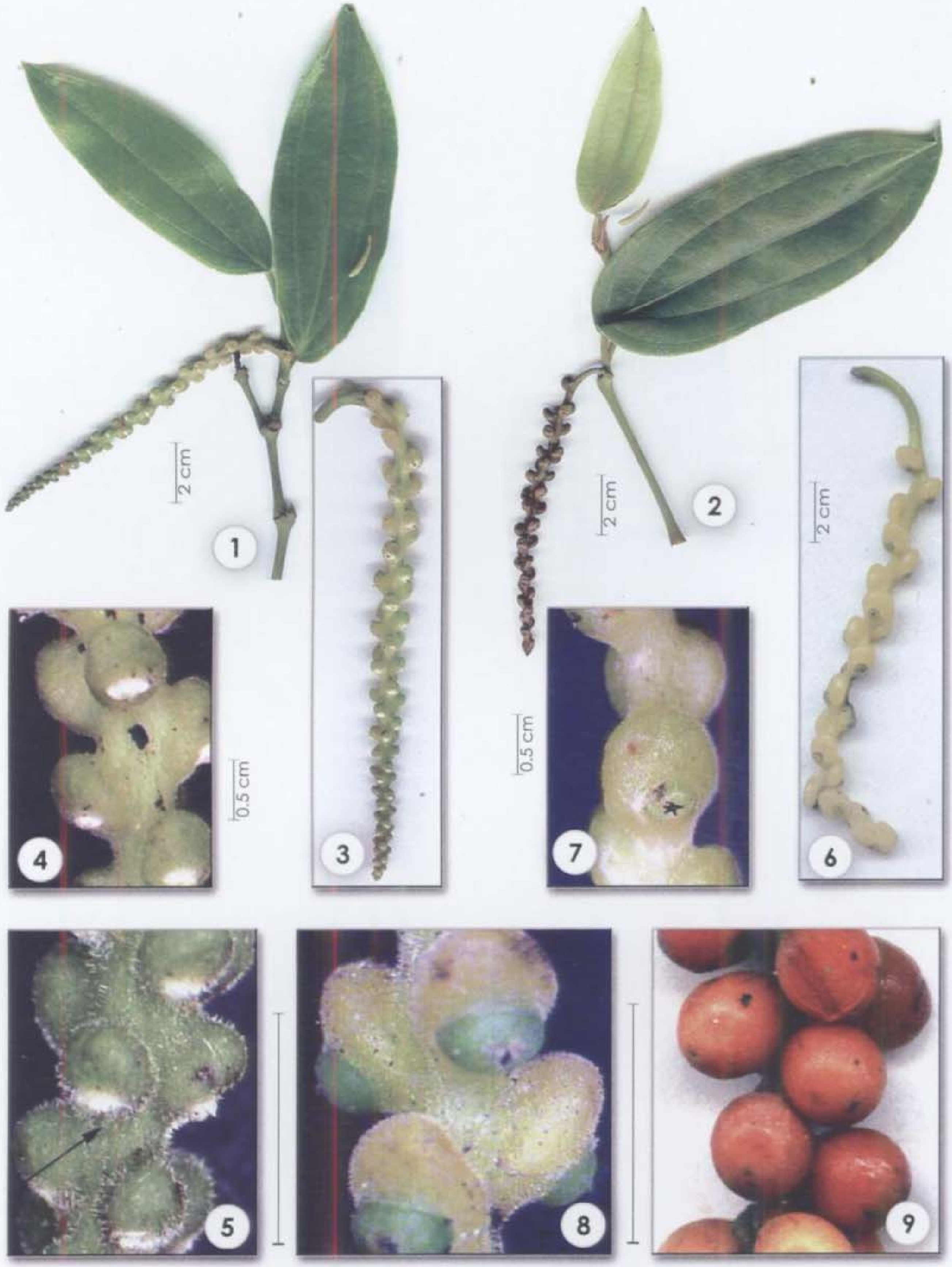


Fig. 17. *Piper trichostyachyon* (Miq.) C.DC.

1. Branch with male spike; 2. Branch with fruiting spikes; 3. Male spike; 4. Male spike-enlarged; 5. Portion of male spike with stamen and bracts; 6. Female spike; 7. Portion of Female spike enlarged; 8. Bracts and stigma with prominent trichomes; 9. Mature round berries.

Piper trichostachyon (Miquel) Anne Casimir de Candolle 1869 -- in *DC. Prod.* xvi. I. 242. (IK)

Habitat:	Found occurring in the medium to high elevation areas of shoal forests of Western Ghats.
Habit:	A perennial, stout woody climber growing to a height of 10 – 12 m, common at elevations up to about 1150 m, orthotropic shoot tip purple. Stem may grow to a thickness of more than 6.0 cm covered with thick cork in old vines. Usually branches much above the ground level. Very similar to *P. galeatum.*
Leaves:	Petioled, alternate, thick, coriaceous, glabrous, elliptic to elliptic-lanceolate, rarely obovate, much variable in size, length ranges from 8 – 18 cm, breadth ranges from 6 – 14 cm, size larger in young plants, much smaller in older vines and in male vines, base round or acute, tip acuminate, margins often recurved. Leaves on the orthotropic shoots more or less cordate, ribs 2 – 3 pairs, the upper most arises 1 – 2 cm above the leaf base.
Inflorescence:	Spike filiform, minutely hairy, male spike about 4-10 cm, female 4-9 cm, lengthens in maturity; peduncles glabrous, bracts decurrent, connate, forming a fleshy cup or boat shaped structure.
Flowers:	Incomplete, unisexual.
Androecium:	Stamens two, short, dithecous.
Gynoecium:	Carpel one, style absent, stigma 3-4 lobed, lobes short papillate.
Fruits:	Fruits bold, spherical or oblong, taste bitter first, pungent later; colour changes from green to yellow and then to orange red on ripening.
Occurrence:	
Kerala:	*Idukki Dist.*- Myladumpara, Pampadumpara; *Palghat Dist*- Silent Valley, Varadimalai; *Wayanad Dist.*- Sugandhagiri, Thirunelly.
Tamil Nadu:	*Coimbatore Dist.*-Valparai; *Nilgiri Dist.*-Gudallur; *Tirunelveli Dist.*- Brymoore, Courtallam, Varattayar.
Karnataka	Karnataka: *Chickmagalur Dist.*- Kuderemukh; *Kodagu Dist.*- Coorg, Thalacauvery; *Shimoga Dist.* – Akumbe.
Altitude range:	420 – 1150 m MSL.
Flowering and fruiting:	May- July, off-season flowering occurs. Fruit mature in Jan- March.

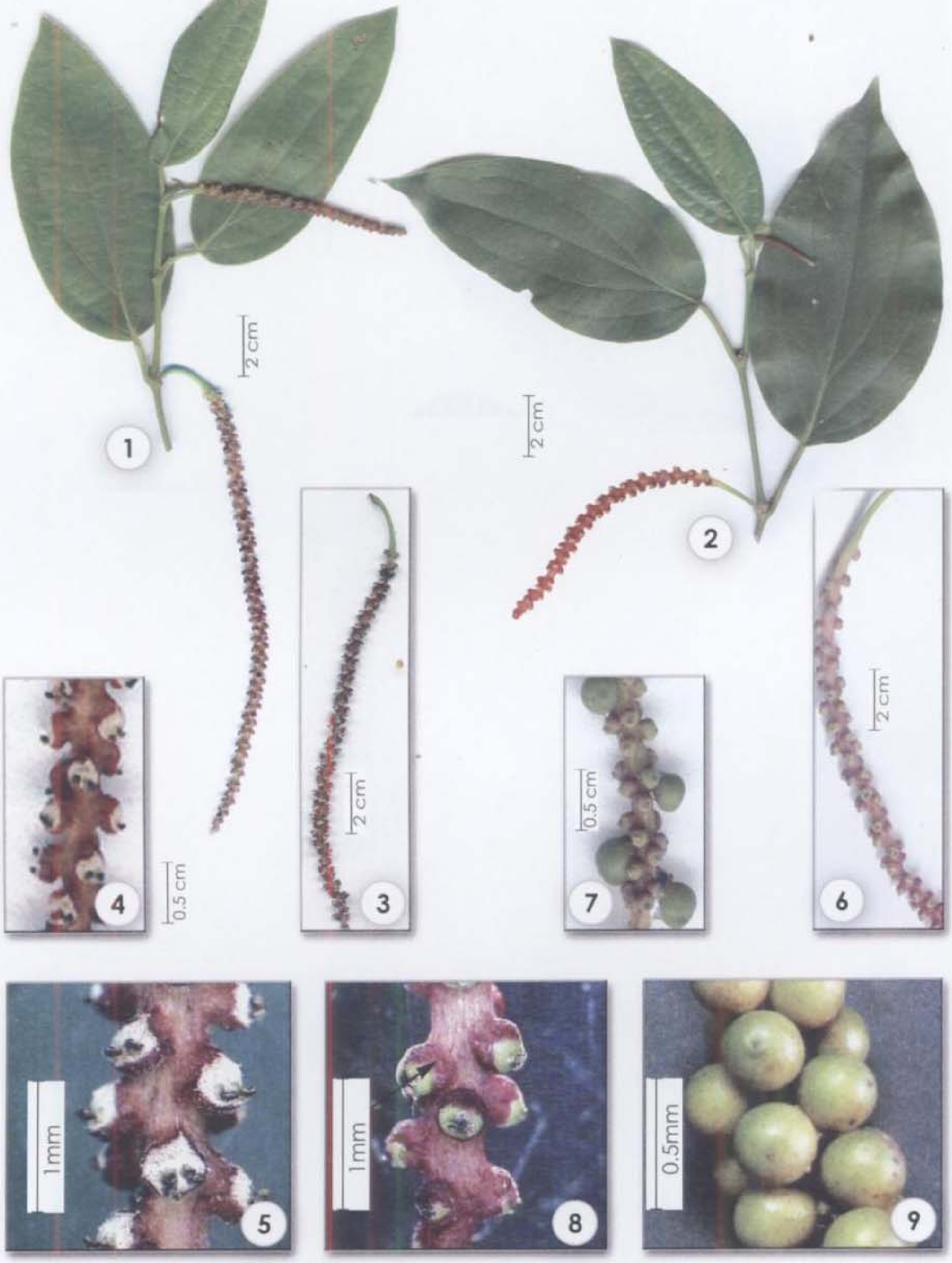


Fig. 18. ***Piper sugandhi*** **Ravindran , Babu et Naik.**

1. Branch with male spike; 2. Branch with fruiting spikes; 3. Male spike; 4. Male spike-enlarged; 5. Portion of male spike with stamen and bracts; 6. Female spike; 7. Portion of female spike enlarged; 8. Bracts and stigma; 9. Mature round berries.

Piper sugandhi Ravindran, Babu et Naik *J. Spices & Aromatic Crops*, 2: 26-33, 1993).

Habitat: Distributed generally in the high elevation area of Western Ghats, especially in the evergreen forests.

Habit: A vigorous woody climber, dioecious and perennial, reaching to a height of 10 m or more; branches terrete, swollen at the nodes, glabrous, orthotropic shoot tips light purple to dark purple.

Leaves: Petiolate, alternate, glabrous, coriaceous, glabrous and dorsal shiny, ovate to ovate –lanceolate, acuminate, base round to acute and often oblique, margins even or slightly wavy, 5-13 cm long and 3-8 cm broad in the female, prominently 5-7 ribbed, more conspicuous on the lower side, the basal pair of ribs sub-opposite, others alternate, petiole 2-8 cm long, grooved, margin modified as sheaths, sheaths caduceus.

Inflorescence: Spike filiform, Pendant, 10 -14 cm long; female spikes slightly thicker than male spikes, 5-10 cm long. Flowers held at right angles to the rachis, stipitate, bracteate, and greenish purple to purple in colour, bracts cupular with free margins.

Flowers: Unisexual, incomplete and stipitate.

Androecium: Stamens two, filaments short and thick, embedded in the cupular bract, anthers projecting out at maturity; dithecous, dehiscing by apical longitudinal slits.

Gynoecium: Ovary spherical, subtended by a copular bract, stigma sessile, 3-4 lobed, lobes short and papillate.

Fruits: Fruit oblong, bold, 0.8 – 1.0 cm in diameter, less pungent than black pepper, turns yellow and then red on ripening.

Occurrence:

Kerala: *Idukki Dist.*- Aruvikadu (Munnar), Kumali, Kadalar, (Munnar), Pampadumpara, Vandanmedu; *Kozhikode Palghat Dist.*- Muthikulam, Nelliampathy, Pathenthodu, Silentvalley, Siruvani, Varadimalai; *Pathanamthitta Dist*- Moozhiyar; *Wayanad Dist.*- Ambalavayal, Choorathodu, Pakshipathalam, Sugandhagiri.

Tamil Nadu: *Coimbatore Dist.*- Valparai; *Tirunelveli Dist.*- Varattayar, Upper Kodair dam, Puliyarai.

Karnataka	*Kodagu Dist.* - Bellamvetty, Moornad, Thalacauvery, *Uttar Kannada Dist.* - Gerosappa.
Altitude range:	560-1500 m MSL.
Flowering and fruiting:	February to April and fruits ripened during Dec to January.

Allied to *P. nigrum* L. but differs from it in having stipitate flowers and deeply cupular bract. Allied to *P. galeatum* (Miq.) C.D.C, but differs from it in the nature of bracts and in having pungent fruits as in black pepper. Also allied to *P. trichostachyon* (Miq.) C.D.C, but differs from it having stipitate flowers, nature of bract and in having pungent fruits.

Piper nigrum Linnaeus 1753 -- *Sp. Pl.* 28. (IK)

Habitat:	Very common in the evergreen and semi evergreen forests of Western Ghats and in the adjoining areas, almost from sea level up to an elevation of 1100 m MSL.
Habit:	A vigorous vine, old stem thick and rough, branches numerous; runner shoots arise from the base with profuse foliage. Climbing over the trees by twining and striking nodes at the nodes, ascends to a height of more than 10 meter, branches emerges right from the ground level.
Leaves:	Leaves simple, alternate, petiolate, thick, coriaceous, glabrous, shape much variable, commonly ovate elliptic or elliptic-lanceolate, cordate; leaf margin even or wavy, size ranges from 10-20 cm in length and 5-15 cm in width, base round, acute or cordate, tip acuminate, lateral ribs two or three pairs, prominent, the uppermost one 1-2.5 cm above the leaf base, upper surface dark green to light green, lower surface light green; petiole ranges from 0.9-6 cm in length, grooved.
Inflorescence:	Spike filiform; Pendant, young ones green or whitish green or light purple; mature ones green, pale purple or pale yellow. Upto 16 cm long in male and 13 cm long in female.
Flowers:	Unisexual in wild but bisexual in cultivated forms. Bracteate, bracts oblong, decurrent, sessile with free upper margin, develop in to a free shallow cup in female spikes, bracts glabrous.
Androecium:	Stamens 2, anther dithecous.
Gynoecium:	Carpel single, ovary spherical, style absent, stigma 3-5 lobed.
Fruits:	Usually globose, green when young, changes to red on ripening, seed mostly spherical, pungent or bitter.
Occurrence:	
Kerala:	*Idukki Dist.*-. Adimali, Anavilasam, Kadalar, Kuttikkanum, Marayoor Munnar; *Kannur Dist.*- Ampayithodu. Kolayadu, Kootupuzha Manjalampuzha; *Kollam Dist.*- Achankovil, Kottavasal, Manalar, Shenthurni; *Kottayam Dist.*- Kuttikayam; *Kozhikode Dist.*- Ampalapara, Kakkayam, Peruvannamuzhi Tusharagiri; *Malappuram Dist.*- Nadugani, Nilambur, *Palghat Dist.*- Attapadi, Karapara, Malampuzha, Muthikulam, Nelliampathy, Parambikulam , Shekkal mudi, Sholayur, Silentvalley, Siruvani;

	Pathanamthitta Dist.- Anamughi, Ettathanum, Moozhiyar, Sabarimala, Vazhaperiyar; *Thiruvananthapuram Dist.* - Bonacaurd; *Thrissur Dist.* - Charpa, Peringal Sholayar, Vazhachal; *Wayanad Dist.*- Choorathodu, Sugandhagiri, Thirunelli, Vythiri.
Tamil Nadu:	*Coimbatore Dist.*- Valayar, Valparai; *Kanyakumari Dist.*- Brymore; *Nilgiri Dist.*- Gudallur Nadukani; *Tirunelveli Dist.*- Courtallam, Kannikkatti, Kariyar dam, KMTR.
Karnataka	*Chickmagalur Dist.*-Balankoppa, Kuderemukh, Samse forest, Sringeri; *Dakshina Kannada Dist.*- Belinellai, Kollur, Nettana Subramanya, Sullia; *Shimoga Dist.*- Adakatte, Akumbe, Bindur Kannangi, Kudajadri, Siddapura; *Kodagu Dist.*- Bagamandala, Coorg, Garwale, Makutta, Mathapuram, Thalacauvery, Varaharitha, Virajpet; *Uttar Kannada Dist.*- Bhandale, Gerosappa, Jog falls, Kansur, Khulse, Kumpta.
Altitude range:	40-1100 m MSL.
Flowering and fruiting:	May-June, Fruits mature in Jan- Feb. Off season flowering occurs in male plants.

Fig. 20. ***Piper barberi*** **Gamble**

1. A branch wioth female spike; 2. A single spike; 3. A portion of spike enlarged; 4. Spike showing bracts and stigma; 5. Immature berries; 6. Mature red berries.

Piper barberi Gamble. 1924 in *Kew Bulletin.*, 387.

Habitat: Distributed in the high elevation forests of Southern Western Ghats.

Habit: A very distinct species among the South Indian *Piper* having reticulated veined leaves and spikes borne on slender, long dangling peduncle. A perennial climber, glabrous, dioecious, branching dimorphic, juvenile shoots slender with persistent scale leaves, wiry; orthotropic shoots with small leaves.

Leaves: Petiolate. 5-7 cm long, 2-3 cm broad, fruiting branches with leaves 8-18 cm long, 3-6 cm broad, glabrous, lanceolate, tip acuminate, base unequally acute, pinnately reticulate.

Inflorescence: Male spikes narrow, 7-10 cm long, female spikes 4-7 cm, cylindrical, pendulous, borne on long, slender peduncle, bracts peltate, orbicular.

Flowers: Ovary 0.5 – 1.0 mm, sessile, 1- celled, 1-ovuled, stigma 3-lobed, papillate, style absent.

Androecium: Fruit fleshy drupe, 5-6 mm across, red when ripe; seeds 2-3 mm, ovoid.

Gynoecium: Ovary 0.5 – 1.0 mm, sessile, 1- celled, 1-ovuled, stigma 3-lobed, pappilate, style absent.

Fruits: Fleshy drupe, 5-6 mm across, red when ripe, seeds 2-3 mm, ovoid.

Occurrence:
Tamil Nadu: *Coimbatore Dist.*- Anamalai. *Tirunelveli Dist.*- Kannikatti.

Altitude range: 500- 520 m MSL

Flowering and fruiting: June- July. Fruits mature at Jan- February.

No similarity to any other known South Indian species. Listed as an endangered species in the Red Data Book published by Botanical Survey of India.

Characterization of *Piper* species

The male and female types of each of the species were characterized for various morphological and reproductive characters listed in Table 4 and represented in tabular format (Tables 15. 1 to 15.15) with photographs of habit of the plant and spikes, followed by a morpho-taxonomic description of the plant based on the IPGRI descriptor (IPGRI, 1995). Each of the species were re-examined for the discriminative characters for cluster analysis and for studying the interspecies relationships.

Extensive inter-specific variation was observed in most of the characters studied. The observations recorded for qualitative and quantitative characters are given in Table 16; coded descriptive states of the traits recorded for cluster analysis are given in Table 17. Characterizations of different species for important discriminative characters, for both qualitative and quantitative traits, are given below.

Inter species variability

The variability observed between species for both morphological and reproductive characters are represented in Figs. 6-20.

Morphological characters

Plant growth habit

All the *Piper* species occurring in Western Ghats region are climbers except *P. longum* having prostrate growth habit.

Type of branching

Piper produces lateral branches or bearing branches where it bears its inflorescence. The branching pattern of lateral branches are either dichotomous (dimorphic) or it may have more than two secondary branches from one node (polymorphic). *P. longum, P. hapnium, P. mullesua, P. silentvalleyensis, P. attenuatum, P. argyrophyllum* and *P. nigrum* were having the habit of dimorphic type of branching nature whereas the rest of them were of polymorphic branching type.

Shoot tip colour

The shoot tip colour ranged from greenish yellow to dark purple among the species studied. The colour of the shoot tip was greenish yellow in *P. longum, P.*

hapnium, P. attenuatum, P. argyrophyllum, P. hymenophyllum and *P. wightii*. It was light purple in *P. mullesua, P. silentvalleyensis, P. nigrum* and *P. barberi* where as shoot tip colour was dark purple in the species *viz. P. bababudani, P. schmidtii, P. galeatum, P. trichostachyon* and *P. sugandhi.*

Runner shoot production

In the wild habitat, the predominant mode of multiplication and spread is through runner shoots. The production of runner shoots will be more when the vine is in juvenile stage and correspondingly decrease as the vine becomes older. However, species differ in their ability to produce runner shoots, which have a direct bearing on the spread and survival of the species. The capacity to produce runner shoots was less in *P. hapnium, P. silentvalleyensis, P. galeatum, P. trichostachyon* and *P. barberi* where as in other species the rate of runner shoot production was relatively high.

Holding capacity

Holding capacity was weak in two species *viz. P. hapnium* and *P. barberi.* All others were having strong nature of holding capacity.

Adventitious root production

Adventitious root production is having an impact on the holding capacity of the plant. Adventitious root production was less in *P. hapnium* and *P. barberi.*

Lateral branch habit

Lateral branches were erect in six species *viz. P. longum, P. hapnium, P. hymenophyllum, P. bababudani, P. schmidtii* and *P. nigrum.* It was horizontal in position in species like *P. mullesua, P. silentvalleyensis, P. attenuatum, P. argyrophyllum, P. wightii, P. galeatum, P. trichostachyon, P. sugandhi* and *P. barberi.* None of the species was having lateral branches in hanging position.

Table 15. 1 Morpho-taxonomic description of *Piper longum* L.

1. *Passport details*	
1.1 Name of the species:	***Piper longum***
1.2 Accession number:	**0479**
1.3 IC number:	318194
1.4 Place of collection:	Dhoni, Palghat
2. *Morphological descriptors*	
2.1 Plant growth habit:	Trailing
2.2 Branching type:	Dimorphic
2.3 Shoot tip colour:	Greenish yellow
2.4 Runner shoot production:	Many
2.5 Holding capacity:	Strong
2.6 Adventitious root production:	Many
2.7 Lateral branch habit:	Erect
2.8 Lateral branch length:	27.5
2.9 Number of nodes per lateral branch:	15.0
2.10 Leaf petiole length (cm):	0.9
2.11 Leaf length (cm):	11.8
2.12 Leaf width (cm):	5.5
2.13 Leaf lamina shape:	Elliptic- lanceolate
2.14 Leaf base shape:	Oblique
2.15 Leaf margin:	Wavy
2.16 Type of veining:	Campylodromous
2.17 Leaf texture:	Glabrous membranous
2.18 Leaf hairiness:	Absent

3. *Reproductive characters*	
3.1 Spike orientation:	Erect
3.2 Spike shape:	Cylindrical
3.3 Spike colour:	Light yellow
3.4 Spike length (cm):	2.1
3.5 Type of hermaphroditism:	Pistillate flowers only
3.6 Peduncle length (cm):	1.5
3.7 Number of spikes per lateral branches:	5.0
3.8 Flower arrangement:	Fused laterally
3.9 Spike texture:	Glabrous
3.10 Bract type:p	Peltate orbicular
3.11 Flower nature:	Sessile
3.12 Fruit shape:	Round
3.13 Fruit taste:	Pungent
3.14 Fruit size:	Very small
3.15 Fruit colour while ripening:	Green to black
Male plant	
3.16 Spike length (cm):	3.2
3.17 Number of stamens:	2
3.18 Filament length:	Intermediate

♂ spike

♀ spike

Table 15. 2 Morpho-taxonomic description of *Piper hapnium* Buch-Ham.

1. *Passport details*

1.1 Name of the species:	***P. hapnium***
1.2 Accession number:	**5501**
1.3 IC number:	371075
1.4 Place of collection:	Manalar, Achankovil

2. *Morphological descriptors*

2.1 Plant growth habit:	Climbing
2.2 Branching type:	Polymorphic
2.3 Shoot tip colour:	Greenish yellow
2.4 Runner shoot production:	Many
2.5 Holding capacity:	Weak
2.6 Adventitious root production:	Few
2.7 Lateral branch habit:	Horizontal
2.8 Lateral branch length:	28.1
2.9 Number of nodes per lateral branch:	15.0
2.10 Leaf petiole length (cm):	2.2
2.11 Leaf length (cm):	8.8
2.12 Leaf width (cm):	4.1
2.13 Leaf lamina shape:	Elliptic- lanceolate
2.14 Leaf base shape:	Oblique
2.15 Leaf margin:	Wavy
2.16 Type of veining:	Campylodromous
2.17 Leaf texture:	Downy along the veins
2.18 Leaf hairiness:	Mainly along the veins

3. *Reproductive characters*

3.1 Spike orientation:	Erect
3.2 Spike shape:	Cylindrical
3.3 Spike colour:	Light yellow
3.4 Spike length (cm):	5.5
3.5 Type of hermaphroditism:	Pistillate flowers only
3.6 Peduncle length (cm):	2.2
3.7 Number of spikes per lateral branches:	3.0
3.8 Flower arrangement:	Fused laterally
3.9 Spike texture:	Glabrous
3.10 Bract type:	Peltate orbicular
3.11 Flower nature:	Sessile
3.12 Fruit shape:	Round
3.13 Fruit taste:	Pungent
3.14 Fruit size:	Very small
3.15 Fruit colour while ripening:	Green to black

Male plant

3.16 Spike length (cm):	3.5
3.17 Number of stamens:	2.0
3.18 Filament length:	Short

♂ spike ♀ spike

Table 15. 3 Morpho-taxonomic description of *Piper mullesua* Buch- Ham.

1. *Passport details*

1.1 Name of the species:	***Piper mullesua***
1.2 Accession number:	**5405**
1.3 IC number:	Not allotted
1.4 Place of collection:	Naduvattom, Nilgiris

2. *Morphological descriptors*

2.1 Plant growth habit:	Climbing
2.2 Branching type:	Dimorphic
2.3 Shoot tip colour:	Light purple
2.4 Runner shoot production:	Many
2.5 Holding capacity:	Weak
2.6 Adventitious root production:	Few
2.7 Lateral branch habit:	Horizontal
2.8 Lateral branch length:	32.0
2.9 Number of nodes per lateral branch:	19.0
2.10 Leaf petiole length (cm):	0.6
2.11 Leaf length (cm):	8.1
2.12 Leaf width (cm):	2.8
2.13 Leaf lamina shape:	Ovate
2.14 Leaf base shape:	Round
2.15 Leaf margin:	Entire
2.16 Type of veining:	Acrodromous
2.17 Leaf texture:	Glabrous membranous
2.18 Leaf hairiness:	No hairs

3. *Reproductive characters*

3.1 Spike orientation:	Erect
3.2 Spike shape:	Globose
3.3 Spike colour:	Green
3.4 Spike length (cm):	1.0 cm
3.5 Type of hermaphroditism:	Pistillate flowers only
3.6 Peduncle length (cm):	2.3
3.7 Number of spikes per lateral branches:	18
3.8 Flower arrangement:	Free
3.9 Spike texture:	Glabrous
3.10 Bract type:	Peltate orbicular
3.11 Flower nature:	Sessile
3.12 Fruit shape:	Round
3.13 Fruit taste:	Spicy
3.14 Fruit size:	Very small
3.15 Fruit colour while ripening:	Green to black

Male plant

3.16 Spike length (cm):	4.2
3.17 Number of stamens:	Two
3.18 Filament length:	Intermediate

♂ spike

♀ spike

Table 15. 4 Morpho-taxonomic description of *Piper silentvalleyensis* Ravindran & Asokan

1. *Passport Details*	
1.1 Name of the species:	***Piper silentvalleyensis***
1.2 Accession number:	**5407**
1.3 IC number:	Not alloted
1.4 Place of collection:	Paikara, Nilgiris
2. *Morphological descriptors*	
2.1 Plant growth habit:	Climbing
2.2 Branching type:	Polymorphic
2.3 Shoot tip colour:	Greenish yellow
2.4 Runner shoot production:	Few
2.5 Holding capacity:	Strong
2.6 Adventitious root production:	Many
2.7 Lateral branch habit:	Horizontal
2.8 Lateral branch length:	32.1
2.9 Number of nodes per lateral branch:	18.0
2.10 Leaf petiole length (cm):	0.6
2.11 Leaf length (cm):	5.18
2.12 Leaf width (cm):	2.1
2.13 Leaf lamina shape:	Ovate
2.14 Leaf base shape:	Round
2.15 Leaf margin:	Entire
2.16 Type of veining:	Acrodromous
2.17 Leaf texture:	Glabrous coriaceous
2.18 Leaf hairiness:	No hairs

3. *Reproductive characters*	
3.1 Spike orientation:	Erect
3.2 Spike shape:	Cylindrical
3.3 Spike colour:	Green
3.4 Spike length (cm):	1.83
3.5 Type of hermaphroditism:	Predominantly bisexual
3.6 Peduncle length (cm):	0.4
3.7 Number of spikes per lateral branches:	4.0
3.8 Flower arrangement:	Free
3.9 Spike texture:	Glabrous
3.10 Bract type	Peltate orbicular
3.11 Flower nature:	Sessile
3.12 Fruit shape:	Round
3.13 Fruit taste:	Spicy
3.14 Fruit size:	Very small
3.15 Fruit colour while ripening:	Green to black
Male plant	
3.16 Spike length (cm):	1.83
3.17 Number of stamens:	Two
3.18 Filament length:	Intermediate

Spike

Table 15. 5 Morpho-taxonomic description of *Piper attenuatum* Buch-Ham.

1. *Passport details*

1.1 Name of the species:	***Piper attenuatum***
1.2 Accession number:	**0699**
1.3 IC number:	318274
1.4 Place of collection:	Peruvannamuzhi, Calicut

2. *Morphological descriptors*

2.1 Plant growth habit:	Climbing
2.2 Branching type:	Dimorphic
2.3 Shoot tip colour:	Greenish yellow
2.4 Runner shoot production:	Many
2.5 Holding capacity:	Strong
2.6 Adventitious root production:	Many
2.7 Lateral branch habit:	Horizontal
2.8 Lateral branch length:	58.0
2.9 Number of nodes per lateral branch:	20.0
2.10 Leaf petiole length (cm):	1.7
2.11 Leaf length (cm):	10.6
2.12 Leaf width (cm):	5.2
2.13 Leaf lamina shape:	Ovate-elliptic
2.14 Leaf base shape:	Round
2.15 Leaf margin:	Entire
2.16 Type of veining:	Campylodromous
2.17 Leaf texture:	Glabrous membranous
2.18 Leaf hairiness:	No hairs

3. *Reproductive characters*

3.1 Spike orientation:	Pendant
3.2 Spike shape:	Filiform
3.3 Spike colour:	Green
3.4 Spike length (cm):	21.0
3.5 Type of hermaphroditism:	Pistillate flowers only
3.6 Peduncle length (cm):	1.7
3.7 Number of spikes per lateral branches:	9.0
3.8 Flower arrangement:	Free
3.9 Spike texture:	Glabrous
3.10 Bract type:	Sessile, oblong and adnate to rachis
3.11 Flower nature:	Sessile
3.12 Fruit shape:	Ovate
3.13 Fruit taste:	Bitter
3.14 Fruit size:	Small
3.15 Fruit colour while ripening:	Green to black

Male plant

3.16 Spike length (cm):	18.0
3.17 Number of stamens:	4.0
3.18 Filament length:	Long

♂ spike

♀ spike

Table 15. 6 Morpho-taxonomic description of *Piper argyrophyllum* Miq.

1. *Passport details*

1.1	Name of the species:	***Piper argyrophyllum***
1.2	Accession number:	**0625**
1.3	IC number:	318241
1.4	Place of collection:	Sastanode Thiruvananthapuram

2. *Morphological descriptors*

2.1	Plant growth habit:	Climbing
2.2	Branching type:	Dimorphic
2.3	Shoot tip colour:	Light green
2.4	Runner shoot production:	Many
2.5	Holding capacity:	Strong
2.6	Adventitious root production:	Many
2.7	Lateral branch habit:	Horizontal
2.8	Lateral branch length:	45.0
2.9	Number of nodes per lateral branch:	11
2.10	Leaf petiole length (cm):	1.0
2.11	Leaf length (cm):	9.2
2.12	Leaf width (cm):	3.9
2.13	Leaf lamina shape:	Ovate-elliptic
2.14	Leaf base shape:	Round
2.15	Leaf margin:	Entire
2.16	Type of veining:	Campylodromous
2.17	Leaf texture:	Downy membranous
2.18	Leaf hairiness:	Along with the veins

3. *Reproductive characters*

3.1	Spike orientation:	Pendant
3.2	Spike shape:	Filiform
3.3	Spike colour:	Light green
3.4	Spike length (cm):	11.5
3.5	Type of hermaphroditism:	Pistillate flowers only
3.6	Peduncle length (cm):	1.2
3.7	Number of spikes per lateral branches:	9.0
3.8	Flower arrangement:	Free
3.9	Spike texture:	Glabrous
3.10	Bract type:	Sessile, oblong and adnate to rachis
3.11	Flower nature:	Free
3.12	Fruit shape:	Ovate
3.13	Fruit taste:	Bitter
3.14	Fruit size:	Small
3.15	Fruit colour while ripening:	Green to black

Male plant

3.16	Spike length (cm):	12.4
3.17	Number of stamens:	Three
3.18	Filament length:	Intermediate

♂ spike

♀ spike

Table 15. 7 Morpho-taxonomic description of *Piper hymenophyllum* (Miq) Wight.

1. *Passport details*

1.1 Name of the species:	***Piper hymenophyllum***
1.2 Accession number:	**5345**
1.3 IC number:	285501
1.4 Place of collection:	Thrissur

2. *Morphological descriptors*

2.1 Plant growth habit:	Climbing
2.2 Branching type:	Dimorphic
2.3 Shoot tip colour:	Light green
2.4 Runner shoot production:	Many
2.5 Holding capacity:	Strong
2.6 Adventitious root production:	Many
2.7 Lateral branch habit:	Erect
2.8 Lateral branch length:	48.0
2.9 Number of nodes per lateral branch:	9.0
2.10 Leaf petiole length (cm):	1.8
2.11 Leaf length (cm):	12.0
2.12 Leaf width (cm):	6.2
2.13 Leaf lamina shape:	Ovate- elliptic
2.14 Leaf base shape:	Round
2.15 Leaf margin:	Entire
2.16 Type of veining:	Campylodromous
2.17 Leaf texture:	Glabrous coriaceous
2.18 Leaf hairiness:	All over the leaves

3. *Reproductive characters*

3.1 Spike orientation:	Erect
3.2 Spike shape:	Filiform
3.3 Spike colour:	Green
3.4 Spike length (cm):	12.1
3.5 Type of hermaphroditism:	Pistillate flowers only
3.6 Peduncle length (cm):	2.5
3.7 Number of spikes per lateral branches:	15
3.8 Flower arrangement:	Free
3.9 Spike texture:	Glabrous
3.10 Bract type:	Sessile, oblong and adnate to rachis
3.11 Flower nature:	Sessile
3.12 Fruit shape:	Ovate
3.13 Fruit taste:	Bitter
3.14 Fruit size:	Small
3.15 Fruit colour while ripening:	Green to black

Male plant

3.16 Spike length (cm):	9.5
3.17 Number of stamens:	Two
3.18 Filament length:	Intermediate

♂ spike

♀ spike

Table 15. 8 Morpho-taxonomic description of *Piper bababudani* Rahiman

1. *Passport details*

1.1 Name of the species:	***Piper bababudani***
1.2 Accession number:	**4674**
1.3 IC number:	325144
1.4 Place of collection:	Kodagu, Karnataka

2. *Morphological descriptors*

2.1 Plant growth habit:	Climbing
2.2 Branching type:	Polymorphic
2.3 Shoot tip colour:	Dark purple
2.4 Runner shoot production:	Many
2.5 Holding capacity:	Strong
2.6 Adventitious root production:	Many
2.7 Lateral branch habit:	Erect
2.8 Lateral branch length:	42.0
2.9 Number of nodes per lateral branch:	7.0
2.10 Leaf petiole length (cm):	2.1
2.11 Leaf length (cm):	17.8
2.12 Leaf width (cm):	8.2
2.13 Leaf lamina shape:	Ovate
2.14 Leaf base shape:	Round
2.15 Leaf margin:	Entire
2.16 Type of veining:	Acrodromous
2.17 Leaf texture:	Glabrous coriaceous
2.18 Leaf hairiness:	No hairs

3. *Reproductive characters*

3.1 Spike orientation:	Erect
3.2 Spike shape:	Filiform
3.3 Spike colour:	Light yellow
3.4 Spike length (cm):	10.8
3.5 Type of hermaphroditism:	Pistillate flowers only
3.6 Peduncle length (cm):	2.1
3.7 Number of spikes per lateral branches:	6.0
3.8 Flower arrangement:	Free
3.9 Spike texture:	Glabrous
3.10 Bract type:	Deeply copular with decurrent base
3.11 Flower nature:	Sessile
3.12 Fruit shape:	Round
3.13 Fruit taste:	Initially bitter then pungent
3.14 Fruit size:	Large
3.15 Fruit colour while ripening:	Green to yellow and orange

Male plant

3.16 Spike length (cm):	12.1
3.17 Number of stamens:	Two
3.18 Filament length:	Short

♂ spike

♀ spike

Table 15. 9 Morpho-taxonomic description of *Piper trichostachyon* C.DC.

1. *Passport details*

1.1	Name of the species:	***Piper trichostachyon***
1.2	Accession number:	**3340**
1.3	IC number:	318491
1.4	Place of collection:	Wayanad, Kerala

2. *Morphological descriptors*

2.1	Plant growth habit:	Climbing
2.2	Branching type:	Polymorphic
2.3	Shoot tip colour:	Dark purple
2.4	Runner shoot production:	Few
2.5	Holding capacity:	Strong
2.6	Adventitious root production:	Few
2.7	Lateral branch habit:	Horizontal
2.8	Lateral branch length:	46.0
2.9	Number of nodes per lateral branch:	28.0
2.10	Leaf petiole length (cm):	1.2
2.11	Leaf length (cm):	17.0
2.12	Leaf width (cm):	6.7
2.13	Leaf lamina shape:	Elliptic- lanceolate
2.14	Leaf base shape:	Round
2.15	Leaf margin:	Entire
2.16	Type of veining:	Acrodromous
2.17	Leaf texture:	Glabrous coriaceous
2.18	Leaf hairiness:	No hairs

3. *Reproductive characters*

3.1	Spike orientation:	Erect
3.2	Spike shape:	Filiform
3.3	Spike colour:	Light yellow
3.4	Spike length (cm):	6.1
3.5	Type of hermaphroditism:	Pistillate flowers only
3.6	Peduncle length (cm):	1.1
3.7	Number of spikes per lateral branches:	4.0
3.8	Flower arrangement:	Free
3.9	Spike texture:	Hirtellous
3.10	Bract type::	Fleshy, connate, transformed into a cup
3.11	Flower nature:	Shortly stipitate
3.12	Fruit shape:	Oblong
3.13	Fruit taste:	Bitter
3.14	Fruit size:	Extra bold
3.15	Fruit colour while ripening:	Green to yellow and orange

Male plant

3.16	Spike length (cm):	7.5
3.17	Number of stamens:	Two
3.18	Filament length:	Short

♂ spike

♀ spike

Table 15. 10 Morpho-taxonomic description of *Piper galeatum* C.DC.

1. *Passport details*

1.1 Name of the species:	***Piper galeatum***
1.2 Accession number:	**3339**
1.3 IC number:	318490
1.4 Place of collection:	Wayanad, Kerala

2. *Morphological descriptors*

2.1 Plant growth habit:	Climbing
2.2 Branching type:	Polymorphic
2.3 Shoot tip colour:	Dark purple
2.4 Runner shoot production:	Few
2.5 Holding capacity:	Strong
2.6 Adventitious root production:	Many
2.7 Lateral branch habit:	Horizontal
2.8 Lateral branch length:	46.5
2.9 Number of nodes per lateral branch:	26.0
2.10 Leaf petiole length (cm):	1.9
2.11 Leaf length (cm):	15.8
2.12 Leaf width (cm):	6.6
2.13 Leaf lamina shape:	Elliptic- lanceolate
2.14 Leaf base shape:	Round
2.15 Leaf margin:	Entire
2.16 Type of veining:	Acrodromous
2.17 Leaf texture:	Glabrous coriaceous
2.18 Leaf hairiness:	No hairs

3. *Reproductive characters*

3.1 Spike orientation:	Erect
3.2 Spike shape:	Filiform
3.3 Spike colour:	Greenish yellow
3.4 Spike length (cm):	4.5
3.5 Type of hermaphroditism:	Pistillate flowers only
3.6 Peduncle length (cm):	1.0
3.7 Number of spikes per lateral branches:	5.0
3.8 Flower arrangement:	Free
3.9 Spike texture:	Glabrous
3.10 Bract type:	Fleshy, connate, transformed into a cup
3.11 Flower nature:	Shortly stipitate
3.12 Fruit shape:	Oblong
3.13 Fruit taste:	Bitter
3.14 Fruit size:	Extra bold
3.15 Fruit colour while ripening:	Green to yellow and orange

Male plant

3.16 Spike length (cm):	4.2
3.17 Number of stamens:	Two
3.18 Filament length:	Short

♂ spike

♀ spike

Table 15. 11 Morpho-taxonomic description of *Piper sugandhi* Babu et Naik

1. *Passport Details*

1.1 Name of the species:	***Piper sugandhi***
1.2 Accession number:	**4660**
1.3 IC number:	Not allotted
1.4 Place of collection:	Idukki, Kerala

2. *Morphological descriptors*

2.1 Plant growth habit:	Climbing
2.2 Branching type:	Dimorphic
2.3 Shoot tip colour:	Dark purple
2.4 Runner shoot production:	Many
2.5 Holding capacity:	Strong
2.6 Adventitious root production:	Many
2.7 Lateral branch habit:	Horizontal
2.8 Lateral branch length:	46.0
2.9 Number of nodes per lateral branch:	32.0
2.10 Leaf petiole length (cm):	2.2
2.11 Leaf length (cm):	12.5
2.12 Leaf width (cm):	6.0
2.13 Leaf lamina shape:	Ovate-lanceolate
2.14 Leaf base shape:	Acute
2.15 Leaf margin:	Entire
2.16 Type of veining:	Acrodromous
2.17 Leaf texture:	Glabrous coriaceous
2.18 Leaf hairiness:	No hairs

3. *Reproductive characters*

3.1 Spike orientation:	Pendant
3.2 Spike shape:	Filiform
3.3 Spike colour:	Dark purple
3.4 Spike length (cm):	14.0
3.5 Type of hermaphroditism:	Pistillate flowers only
3.6 Peduncle length (cm):	1.0
3.7 Number of spikes per lateral branches:	8.0
3.8 Flower arrangement:	Free
3.9 Spike texture:	Glabrous
3.10 Bract type:	Cupular with decurrent base
3.11 Flower nature:	Shortly stipitate
3.12 Fruit shape:	Round
3.13 Fruit taste:	Pungent
3.14 Fruit size:	Large
3.15 Fruit colour while ripening:	Green to yellow, and red

Male plant

3.16 Spike length (cm):	7.5
3.17 Number of stamens:	2.0
3.18 Filament length:	2.0

♂ spike

♀ spike

Table 15. 12 Morpho-taxonomic description of *Piper wightii* Miq.

1. *Passport details*

1.1	Name of the species:	*Piper wightii*
1.2	Accession number:	5410
1.3	IC number:	Not allotted
1.4	Place of collection:	Nilgiris, Tamil Nadu

2. *Morphological descriptors*

2.1	Plant growth habit:	Climbing
2.2	Branching type:	Polymorphic
2.3	Shoot tip colour:	Greenish yellow
2.4	Runner shoot production:	Many
2.5	Holding capacity:	Strong
2.6	Adventitious root production:	Few
2.7	Lateral branch habit:	Horizontal
2.8	Lateral branch length:	42.0
2.9	Number of nodes per lateral branch:	36.0
2.10	Leaf petiole length (cm):	1.9
2.11	Leaf length (cm):	11.86
2.12	Leaf width (cm):	7.43
2.13	Leaf lamina shape:	Ovate
2.14	Leaf base shape:	Round
2.15	Leaf margin:	Entire
2.16	Type of veining:	Acrodromous
2.17	Leaf texture:	Glabrous coriaceous
2.18	Leaf hairiness:	No hairs

3. *Reproductive characters*

3.1	Spike orientation:	Pendant
3.2	Spike shape:	Filiform
3.3	Spike colour:	Green
3.4	Spike length (cm):	8.3
3.5	Type of hermaphroditism:	Pistillate flowers only
3.6	Peduncle length (cm):	1.2
3.7	Number of spikes per lateral branches:	6.0
3.8	Flower arrangement:	Free
3.9	Spike texture:	Glabrous
3.10	Bract type:	Peltate-oblong
3.11	Flower nature:	Sessile
3.12	Fruit shape:	Round
3.13	Fruit taste:	Bitter
3.14	Fruit size:	Intermediate
3.15	Fruit colour while ripening:	Green to yellow

Male plant

3.16	Spike length (cm):	12.5
3.17	Number of stamens:	Two
3.18	Filament length:	Intermediate

♂ spike

♀ spike

Table 15. 13 Morpho-taxonomic description of *Piper schmidtii* Hook.f.

1. *Passport details*

1.1	Name of the species:	*Piper schmidtii*
1.2	Accession number:	5403
1.3	IC number:	Not allotted
1.4	Place of collection:	Nilgiris, Tamil Nadu

2. *Morphological descriptors*

2.1	Plant growth habit:	Climbing
2.2	Branching type:	Polymorphic
2.3	Shoot tip colour:	Dark purple
2.4	Runner shoot production:	Few
2.5	Holding capacity:	Strong
2.6	Adventitious root production:	Many
2.7	Lateral branch habit:	Erect
2.8	Lateral branch length:	38.0
2.9	Number of nodes per lateral branch:	28.0
2.10	Leaf petiole length (cm):	1.6
2.11	Leaf length (cm):	8.5
2.12	Leaf width (cm):	4.7
2.13	Leaf lamina shape:	Ovate
2.14	Leaf base shape:	Round
2.15	Leaf margin:	Entire
2.16	Type of veining:	Acrodromous
2.17	Leaf texture:	Glabrous coriaceous
2.18	Leaf hairiness:	No hairs

3. *Reproductive characters*

3.1	Spike orientation:	Pendant
3.2	Spike shape:	Filiform
3.3	Spike colour:	Green
3.4	Spike length (cm):	7.07
3.5	Type of hermaphroditism:	Pistillate flowers only
3.6	Peduncle length (cm):	1.1
3.7	Number of spikes per lateral branches:	8.0
3.8	Flower arrangement:	Free
3.9	Spike texture:	Glabrous
3.10	Bract type:	Peltate orbicular
3.11	Flower nature:	Sessile
3.12	Fruit shape:	Ovate
3.13	Fruit taste:	Bitter
3.14	Fruit size:	Intermediate
3.15	Fruit colour while ripening:	Green to yellow, orange and red

Male plant

3.16	Spike length (cm):	13.5
3.17	Number of stamens:	2
3.18	Filament length:	Intermediate

♂ spike

♀ spike

Table 15. 14 Morpho-taxonomic description of *Piper nigrum* L.

1. *Passport details*

1.1	Name of the species:	***Piper nigrum***
1.2	Accession number:	**0269**
1.3	IC number:	318102
1.4	Place of collection:	Palghat, Kerala

2. *Morphological descriptors*

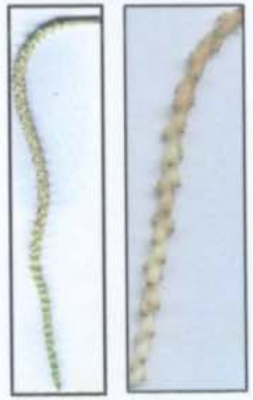
2.1	Plant growth habit:	Climbing
2.2	Branching type:	Dimorphic
2.3	Shoot tip colour:	Light purple
2.4	Runner shoot production:	Many
2.5	Holding capacity:	Strong
2.6	Adventitious root production:	Many
2.7	Lateral branch habit:	Horizontal
2.8	Lateral branch length:	32.0
2.9	Number of nodes per lateral branch:	29.0
2.10	Leaf petiole length (cm):	1.6
2.11	Leaf length (cm):	16.4
2.12	Leaf width (cm):	8.4
2.13	Leaf lamina shape:	Ovate
2.14	Leaf base shape:	Cordate
2.15	Leaf margin:	Entire
2.16	Type of veining:	Acrodromous
2.17	Leaf texture:	Glabrous coriaceous
2.18	Leaf hairiness:	No hairs

3. *Reproductive characters*

3.1	Spike orientation:	Pendant
3.2	Spike shape:	Filiform
3.3	Spike colour:	Light green
3.4	Spike length (cm):	9.2
3.5	Type of hermaphroditism:	Pistillate flowers only
3.6	Peduncle length (cm):	1.2
3.7	Number of spikes per lateral branches:	16.0
3.8	Flower arrangement:	Free
3.9	Spike texture:	Glabrous
3.10	Bract type:	Cupular with decurrent base
3.11	Flower nature:	Sessile
3.12	Fruit shape:	Round
3.13	Fruit taste:	Bitter
3.14	Fruit size:	Intermediate
3.15	Fruit colour while ripening:	Green to yellow, orange and red

Male plant

3.16	Spike length (cm):	7.8
3.17	Number of stamens:	Two
3.18	Filament length:	Short



♂ spike ♀ spike

Table 15. 15. Morpho-taxonomic description of *Piper barberi* Gamble

1. *Passport details*

1.1 Name of the species:	***Piper barberi***
1.2 Accession number:	0614
1.3 IC number:	318232
1.4 Place of collection:	Kanyakumari, Tamil Nadu

2. *Morphological descriptors*

2.1 Plant growth habit:	Climbing
2.2 Branching type:	Polymorphic
2.3 Shoot tip colour:	Light purple
2.4 Runner shoot production:	Many
2.5 Holding capacity:	Weak
2.6 Adventitious root production:	Few
2.7 Lateral branch habit:	Horizontal
2.8 Lateral branch length:	24.5
2.9 Number of nodes per lateral branch:	22
2.10 Leaf petiole length (cm):	2.1
2.11 Leaf length (cm):	14.5
2.12 Leaf width (cm):	5.1
2.13 Leaf lamina shape:	Elliptic- lanceolate
2.14 Leaf base shape:	Oblique
2.15 Leaf margin:	Entire
2.16 Type of veining:	Eucamptodromous
2.17 Leaf texture:	Glabrous sarcous
2.18 Leaf hairiness:	No hairs

3. *Reproductive characters*

3.1 Spike orientation:	Pendant
3.2 Spike shape:	Cylindrical
3.3 Spike colour:	Green
3.4 Spike length (cm):	7.1
3.5 Type of hermaphroditism:	Pistillate flowers only
3.6 Peduncle length (cm):	10.1
3.7 Number of spikes per lateral branches:	4.0
3.8 Flower arrangement:	Free
3.9 Spike texture:	Glabrous
3.10 Bract type:	Peltate orbicular
3.11 Flower nature:	Sessile
3.12 Fruit shape:	Round
3.13 Fruit taste:	Bitter
3.14 Fruit size:	Intermediate
3.15 Fruit colour while ripening:	Green to yellow and red

Male plant

3.16 Spike length (cm):	-
3.17 Number of stamens:	-
3.18 Filament length:	-

Male spike

Table 16. Morphological and reproductive characterization of 15 South Indian *Piper*.

Species	Code	2.1	2.2	2.3	2.4	2.5	2.6	2.7	2.8	2.9	2.10	2.11	2.12	2.13	2.14	2.15	2.16	2.17	2.18
P. longum	1	2	1	1	2	2	2	1	27.50	15.0	0.9	11.80	5.50	4	4	2	2	2	0
P. hapnium	2	1	1	1	1	1	1	1	28.10	15.0	2.2	8.80	4.10	4	4	2	2	5	1
P. mullesua	3	1	1	2	2	2	2	2	32.00	19.0	0.6	8.10	2.80	1	1	1	1	1	0
P. silentvalleyensis	4	1	1	2	1	2	2	2	32.10	18.0	0.6	5.18	2.10	1	1	1	1	1	0
P. attenuatum	5	1	1	1	2	2	2	2	58.00	20.0	1.7	10.60	5.20	2	1	1	2	2	0
P. argyrophyllum	6	1	1	1	2	2	2	2	45.00	11.0	1	9.20	3.90	2	1	1	2	5	1
P. hymenophyllum	7	1	1	1	2	2	2	1	48.00	9.0	1.8	12.00	6.20	2	1	1	2	4	2
P. bababudani	8	1	2	3	2	2	2	1	42.00	7.0	2.1	17.80	8.20	1	1	1	1	1	0
P. wightii	9	1	2	1	2	2	2	2	42.00	36.0	1.9	11.86	7.43	1	1	1	1	2	0
P. schmidtii	10	1	2	3	2	2	2	1	38.00	28.0	1.6	8.50	4.70	1	1	1	1	1	0
P. galeatum	11	1	2	3	1	2	2	2	46.50	26.0	1.9	15.80	6.60	3	1	1	1	1	0
P. trichostachyon	12	1	2	3	1	2	1	2	46.00	28.0	1.2	17.00	6.70	3	1	1	1	1	0
P. sugandhi	13	1	2	3	2	2	2	2	46.00	32.0	2.2	12.50	6.00	3	3	1	1	1	0
P. nigrum	14	1	1	2	2	2	2	1	32.00	29.0	1.6	16.40	8.40	1	2	1	1	1	0
P. barberi	15	1	2	2	1	1	1	2	24.50	22.0	2.1	14.50	5.10	4	4	1	3	3	0

2.1.Plant growth habit, 2.2.Branching type, 2.3. Orthotropic shoot tip colour, 2.4. Runner shoot production, 2.5.Holding capacity, 2.6.Adventitious root production, 2.7. Lateral branch habit,2.8. Lateral branch length, 2.9Number of nodes, 2.10. Leaf petiole length, 2.11.Leaf length, 2.12.Leaf width, 2.13.Leaf lamina shape, 2.14, Leaf base shape, 2.15.Leaf margin, 2.16. Type of veining, 2.17. Leaf texture and 2.18. Leaf hairiness

Table 16. Contd...

Species	Code	3.1	3.2	3.3	3.4	3.5	3.6	3.7	3.8	3.9	3.10	3.11	3.12	3.13	3.14	3.15
P. longum	**1**	1	2	3	2.1	2	1.5	5	2	1	2	1	2	2	1	1
P. hapnium	**2**	1	2	3	5.5	2	2.2	3	2	1	2	1	2	2	1	1
P. mullesua	**3**	1	3	1	1.0	2	2.3	18	1	1	2	1	2	3	1	1
P. silentvalleyensis	**4**	1	2	1	1.8	6	0.4	4	1	1	2	1	2	3	1	1
P. attenuatum	**5**	2	1	1	21.0	2	1.7	9	1	1	1	1	1	1	2	1
P. argyrophyllum	**6**	2	1	1	11.5	2	1.2	9	1	1	1	1	1	1	2	1
P. hymenophyllum	**7**	2	1	1	12.1	2	2.5	15	1	1	1	1	1	1	2	1
P. bababudani	**8**	2	1	3	10.8	2	2.1	6	1	1	5	1	2	2	4	3
P. wightii	**9**	2	1	1	8.3	2	1.2	6	1	1	2	1	2	1	3	3
P. schmidtii	**10**	2	1	1	7.1	2	1.1	8	1	1	2	1	3	1	3	3
P. galeatum	**11**	2	1	2	4.5	2	1	5	1	1	4	2	3	1	4	3
P. trichostachyon	**12**	2	1	2	6.1	2	1.1	4	1	2	4	2	3	1	4	3
P. sugandhi	**13**	2	1	5	14.0	2	1	8	1	1	3	2	2	2	4	2
P. nigrum	**14**	2	1	1	9.2	2	1.2	16	1	1	3	1	2	1	3	2
P. barberi	**15**	2	2	1	7.1	2	10.1	4	1	1	2	1	2	1	2	2

3.1. Spike orientation, 3.2. Spike shape, 3.3. Spike colour, 3.4. Spike length, 3.5. Type of hermaphroditism, 3.6. Peduncle length, 3.7. Number of spikes/lateral branches, 3.8. Flower arrangement, 3.9. Spike texture, 3.10. Bract type, 3.11. Flower nature (insertion), 3.12. Fruit shape, 3.13. Fruit taste, 3.14. Fruit size and 3.15. Fruit colour change while ripening.

Lateral branch length

Lateral branch length ranged from 24.5 cm (*P. barberi*) to 58.0 cm (*P. attenuatum*) with an average of 39.18 cm.

Number of nodes

Number of nodes varied from species to species. It varied from 9 (*P. hymenophyllum*) to 36 in *P. wightii*. The mean value of number of nodes per lateral branches among the species studied was 21 nodes per lateral branch.

Leaf petiole length

Leaf petiole length of the leaves of lateral branches ranged from 0.9 cm (*P. longum*) to 2.2 cm (*P. hapnium*) with a mean of 1.56 cm.

Leaf length

Leaf length varied from 5.18 cm in *P. silentvalleyensis* to 17.80 cm in *P. bababudani* (Mean 12.00 cm).

Leaf width

Leaf width ranged from 2.10 to 8.40 cm. *P. silentvalleyensis* was with narrow leaves and *P. nigrum* was having the widest leaves among the species studied. Mean value of leaf width was 5.53 cm.

Leaf lamina shape

Out of the fifteen species studied, the representative leaves of *P. longum*, *P. hapnium* and *P. barberi* were elliptic-lanceolate in shape. Leaf shape was ovate *in P. mullesua, P. silentvalleyensis, P. bababudani, P. wightii, P. schmidtii* and *P. nigrum*. Three species viz. *P. attenuatum, P. argyrophyllum* and *P. hymenophyllum* were with ovate-elliptic leaves. Leaf lamina shape of *P. galeatum*, *P. trichostachyon* and *P. sugandhi* were ovate-lanceolate.

Leaf base

Leaf base was oblique in *P. longum, P. hapnium* and *P. barberi*. Leaf base of *P. sugandhi* was acute, where as it was cordate in *P. nigrum*. All other species were having round leaf base.

Leaf margin

The leaf margin was wavy in *P. longum* and *P. hapnium* while all other species were having entire leaf margin.

Leaf venation

Campylodromous type of venation was observed in *P. longum, P. hapnium, P. attenuatum, P. argyrophyllum* and *P. hymenophyllum*. Leaf venation was acrodromous in all other species. *P. barberi* is unique with eucamptodromous venation (Fig 20).

Leaf texture

Leaf texture was glabrous membranous in *P. longum, P. attenuatum* and *P. wightii*. It was glabrous coriaceous in species like *P. mullesua, P. silentvalleyensis, P. bababudani, P. schmidtii, P. galeatum, P. trichostachyon* and *P. nigrum*. *P. argyrophyllum* and *P. hapnium* were of downy along the veins where as the leaf texture was downy membranous type in *P. hymenophyllum*. The endangered species *P. hapnium* is having glabrous sarcous type texture.

Leaf hairiness

P. hapnium, P. argyrophyllum and *P. hymenophyllum* were the only three species with hairiness. All other species were having glabrous leaves. In *P. hapnium* and *P. argyrophyllum* minute hairs were present along with the veins on the abaxial side. However, in *P. hymenophyllum* leaf hairiness observed all over the leaf on the abaxial side (Fig 12).

Reproductive characters

Spike orientation

P. longum, P. hapnium, P. mullesua and *P. silentvalleyensis* (Fig 6, 7, 8 and 9) were having erect spike and all other species were having pendant spikes.

Spike shape

The female spikes were cylindrical (Fig. 6, 7, 9 and 20) in *P. longum, P. hapnium, P. barberi* and *P. silentvalleyensis*. *P. mullesua* was the only species with globular spikes (Fig. 8). In all the other species, the spikes were filiform.

Spike colour

Spike colour ranged from green to deep purple. Colour of the young spikes was greenish yellow in *P. longum* and *P. hapnium*. *P. mullesua, P. silentvalleyensis, P. attenuatum, P. argyrophyllum, P. hymenophyllum, P. wightii, P. schmidtii, P. nigrum* and *P. barberi* have green spikes. Spike colour was light yellow in *P. bababudani* and deep purple (Fig. 18) coloured spikes were noticed in *P. sugandhi*. In *P. nigrum* though the predominant colour is green, a few vines with purplish coloured spikes were also observed among populations.

Spike length

Length of spikes varied from species to species from 1.0 cm to 21.0 cm. The shortest spike was that of *P. mullesua* and *P. attenuatum* was having the longest spike with 21.0 cm length. Mean spike length was 8.14 cm.

Type of hermaphroditism

All the species except *P. silentvalleyensis* are dioecious with separate male and female vines. The floral characters of male and female were also found to differ in most of the species. *P. silentvalleyensis* is unique among the South Indian species in that it has both male and female flowers in a single spike (Fig. 9).

Flower nature

Flowers were shortly stipitate (Fig.16, 17 and 18) in *P. galeatum, P. trichostachyon* and *P. sugandhi.* In all other species, flowers were sessile.

Fruit shape

The shape of the fruits varied from ovate, round to oblong. Fruits were round in majority of the species except in *P. attenuatum, P. argyrophyllum* and *P. hymenophyllum* where fruit shape was ovate to conical. Oblong types of fruits were exhibited by *P. schmidtii.* The fruits of *P. galeatum* and *P. trichostachyon* were observed to be oblong to round.

Fruit size

Fruit size ranged from very small to extra bold. Fruits were very small (less than 2.0 mm diameter) in *P. longum, P. hapnium, P. mullesua* and *P. silentvalleyensis.* It was small (between 2.1 and 4.0 mm diameter) in *P. attenuatum, P. argyrophyllum* and *P. hymenophyllum.* Medium type fruits (4.1 to 6.5 mm diameter) were observed in *P. nigrum, P. barberi,P. wightii* and *P. schmidtii.* Fruits were extra bold (more than 6.5 mm diameter) in *P. galeatum, P. trichostachyon, P. bababudani* and *P. sugandhi.*

Fruit taste

The fruits of *P. longum, P. hapnium, P. bababudani* and *P. sugandhi* were pungent. It was spicy in *P. mullesua* and *P. silentvalleyensis* and the fruits were bitter in species like *P. attenuatum, P. argyrophyllum* and *P. hymenophyllum* and *P. nigrum.*

Fruit colour change while ripening

The fruit colour changed directly from green to black during ripening in *P. longum, P. hapnium, P. attenuatum, P. argyrophyllum* and *P. hymenophyllum.* Fruit colour changed to yellow and red during ripening in *P. sugandhi, P. nigrum* and *P. barberi.* In other species like *P. wightii, P. schmidtii, P. silentvalleyensis, P.*

bababudani, P. galeatum and *P. trichostachyon,* they have become orange red when ripe.

The polymorphism observed in the morphological characters of South Indian species of *Piper* are represented in binary form in Table 17.

Morphometric analysis

Morphological and molecular characterizations were carried for fifteen *Piper* species based on 33 discriminative characters and data analyzed as mentioned in materials and methods.

Cluster analysis

Fifteen species of *Piper* were characterized for 25 qualitative and eight quantitative characters. The similarity matrices were given in Table 18.

The relationships among the OTUs were worked out and are represented as a phylogram in Fig. 21. The similarity coefficient between the species ranged from 38% (*P. trichostachyon* and *P. hapnium*) 94 % (*P. galeatum* and *P. trichostachyon*) indicating the good inter species variability.

The phylogram clearly revealed that the fifteen taxa used fall under four major clusters at 68% similarity coefficient level. However, the endangered species *P. barberi* formed a separate cluster.

The four major clusters observed are

Cluster-I	-	*P. longum* and *P. hapnium*
Cluster-II	-	*P. mullesua* and *P. silentvalleyensis, P. attenuatum, P. argyrophyllum* and *P. hymenophyllum*
Cluster-III	-	*P. bababudani, P. wightii, P. schmidtii, P. nigrum* and cv. Karimunda (check), *P. galeatum, P. trichostachyon* and *P. sugandhi*
Cluster-IV	-	*P. barberi*

Table 17. Morpho-taxonomic descriptors of wild *Piper* species

Character		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	Control
2.1- Habit	Prostrate	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Climbing	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
2.2 Branching type	Dimorphic	1	1	1	1	1	1	1	0	0	0	0	0	0	1	0	1
	Polymorphic	0	0	0	0	0	0	0	1	1	1	1	1	1	0	1	0
2.3 Shoot tip colour	Green	1	1	0	0	1	1	1	0	1	0	0	0	0	0	0	0
	Light purple	0	0	1	1	0	0	0	0	0	0	0	0	0	1	1	1
	Dark purple	0	0	0	0	0	0	0	1	0	1	1	1	1	0	0	0
2.4 Runner shoot production	Few	0	1	0	1	0	0	0	0	0	0	1	1	0	0	1	0
	Many	1	0	1	0	1	1	1	1	1	1	0	0	1	1	0	1
2.5 Holding capacity	Weak	1	1	0	0	0	0	0	0	0	0	0	0	0	0	1	0
	Strong	0	0	1	1	1	1	1	1	1	1	1	1	1	1	0	1
2.6 Adventitious root production	Few	1	1	0	0	0	0	0	0	0	0	0	1	0	0	1	0
	Many	0	0	1	1	1	1	1	1	1	1	1	0	1	1	0	1
2.7 Lateral branch habit	Erect	1	1	0	0	0	0	1	1	0	1	0	0	0	0	0	0
	Horizontal	0	0	1	1	1	1	0	0	1	0	1	1	1	1	1	1
2.8 Lateral branch length		0	0	0	0	1	1	1	1	1	0	1	1	1	0	0	0
2.9 No. of nodes/lateral branch		0	0	0	0	0	0	0	0	1	1	1	1	1	1	1	1
2.10 Leaf petiole length		0	0	0	0	1	0	1	1	1	1	1	0	1	1	1	1
2.11 Leaf length		0	0	0	0	0	0	0	1	0	0	1	1	1	1	1	0
2.12 Leaf width		0	0	0	0	0	0	1	1	1	0	1	1	1	1	0	0
2.13 Leaf lamina shape	Ovate	0	0	1	1	0	0	0	1	1	1	0	0	0	1	0	0
	Ovate-elliptic	0	0	0	0	1	1	1	0	0	0	0	0	0	0	0	0
	Ovate-lanceolate	0	0	0	0	0	0	0	0	0	0	1	1	1	0	0	1
	Elliptic-lanceolate	1	1	0	0	0	0	0	0	0	0	0	0	0	0	1	0
2.14 Leaf base shape	Round	0	0	1	1	1	1	1	1	1	1	1	1	0	0	0	1

	Cordate	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0
	Acute	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0
	Oblique	1	1	0	0	0	0	0	0	0	0	0	0	0	0	1	0
2.15 Leaf margin	Even	0	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1
	Wavy	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2.16 Type of veining	Acrodromous	0	0	1	1	0	0	0	1	1	1	1	1	1	1	0	1
	Campylodromous	1	1	0	0	1	1	1	0	0	0	0	0	0	0	0	0
	Eucamptodromous	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0
2.17 Leaf texture	Glabrous coriaceous	0	0	1	1	0	0	0	1	0	1	1	1	1	1	0	1
	Glabrous membranous	1	0	0	0	1	0	0	0	1	0	0	0	0	0	0	0
	Glabrous sarcous	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0
	Downy membranous	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0
	Downy along veins	0	1	0	0	0	1	0	0	0	0	0	0	0	0	0	0
2.18 Leaf hairs	Present	0	1	0	0	0	1	1	0	0	0	0	0	0	0	0	0
	Mainly along the veins	0	1	0	0	0	1	0	0	0	0	0	0	0	0	0	0
	Allover the leaves	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0
3.1 Spike orientation	Erect	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0
	Pendant	0	0	0	0	1	1	1	1	1	1	1	1	1	1	1	1
3.2 Spike shape	Filiform	0	0	0	0	1	1	1	1	1	1	1	1	1	1	0	1
	Cylindrical	1	1	0	1	0	0	0	0	0	0	0	0	0	0	1	0
	Globular	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0
3.3 Spike colour	Green	0	0	1	1	1	1	1	0	1	0	0	0	0	1	1	1
	Greenish yellow	0	0	0	0	0	0	0	0	0	1	1	1	0	0	0	0
	Light purple	1	1	0	0	0	0	0	1	0	0	0	0	0	0	0	0
	Dark purple	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0
3.4 Spike length		0	0	0	0	1	1	1	1	1	1	0	0	1	1	0	0
3.5 Type of hermaphroditism	Pistillate flowers only	1	1	1	0	1	1	1	1	1	1	1	1	1	1	1	0
	Bisexual flower	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1

	Predominantly male	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0
3.6 Peduncle length		0	1	1	0	0	0	1	1	0	0	0	0	0	0	1	0
3.8 Flower arrangement	Free	0	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1
	Fused laterally	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3.9 Spike texture	Hirtellous	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0
3.10 Bract type	Sessile	0	0	0	0	1	1	1	0	0	0	0	0	0	0	0	0
	Peltate	1	1	1	1	0	0	0	0	1	1	0	0	0	0	1	0
	Cupular	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	1
	Fleshy connate, boat shaped	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0
	Deeply copular with decurrent base	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0
3.11Flower nature	Sessile	1	1	1	1	1	1	1	1	1	0	0	0	1	1	1	1
	Shortly stipitate	0	0	0	0	0	0	0	0	0	1	1	1	0	0	0	0
3.12Fruit shape	Ovate	0	0	0	0	1	1	1	0	0	0	0	0	0	0	0	0
	Round	1	1	1	1	0	0	0	1	1	0	0	0	1	1	1	1
	Oblong	0	0	0	0	0	0	0	0	0	1	1	1	0	0	0	0
3.13 Fruit taste	Bitter	0	0	0	0	1	1	1	0	1	1	1	1	0	1	1	0
	Pungent	1	1	0	0	0	0	0	1	0	0	0	0	1	0	0	1
	Spicy	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0
3.14 Fruit size	Very small	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0
	Small	0	0	0	0	1	1	1	0	0	0	0	0	0	0	0	0
	Bold	0	0	0	0	0	0	0	0	1	1	0	0	0	1	1	1
	Extrabold	0	0	0	0	0	0	0	1	0	0	1	1	1	0	0	0
3.15 Fruit colour	Green to black	1	1	1	1	1	1	1	0	0	0	0	0	0	0	0	0
	Green to yellow and red	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1
	Green to yellow and orange red	0	0	0	0	0	0	0	0	1	1	1	1	0	0	0	0

Table 18. Paired affinity indices of wild relatives of black pepper based on morpho-taxonomic descriptors

Species	*P. longum*	*P. hapnium*	*P. mullesua*	*P. silent.*	*P. atten.*	*P. agyro.*	*P. hymeno.*	*P.babubu.*	*P. wightii*	*P. schmid.*	*P. galeat.*	*P. tricho.*	*P. sugand.*	*P. nigrum*	*P. barberi*	**Karimunda (Control)**
P. longum	1.000000															
P. hapnium	0.8311688	1.000000														
P. mullesua	0.6883117	0.6233766	1.000000													
P. silent.	0.6753247	0.6363636	0.9090909	1.000000												
P. atten.m	0.6363636	0.5454545	0.7142957	0.6753247	1.000000											
P. argyro.	0.5974026	0.5844156	0.7012987	0.6623377	0.9350649	1.000000										
P.hymeno.	0.5844156	0.5714286	0.6623377	0.59740226	0.8961039	0.8831169	1.000000									
P. babubu.	0.5974026	0.5584416	0.7012987	0.6363636	0.6753247	0.6363636	0.7012987	1.000000								
P.wightii	0.5844156	0.4935065	0.7402597	0.7012987	0.7922078	0.7272727	0.7142857	0.7792208	1.000000							
P.schmidtii	0.5714266	0.5064935	0.7012987	0.6623377	0.7012987	0.6623377	0.6723247	0.7922070	0.8571429	1.000000						
P. galeatum	0.4285714	0.4155844	0.5844156	0.5974026	0.6623377	0.6233766	0.6103896	0.7532468	0.7662338	0.8051948	1.000000					
P. tricho.	0.4025974	0.3896104	0.5584416	0.5714286	0.6103896	0.5974026	0.5584415	0.7012987	0.7142857	0.7532468	0.9480519	1.000000				
P. sugandhi	0.4935065	0.4545455	0.5974026	0.5844156	0.6233766	0.5844156	0.5714286	0.7922078	0.7272727	0.6883117	0.6311688	0.7792208	1.000000			
P. nigrum	0.5584416	0.4935065	0.7402597	0.7012987	0.7142857	0.6753247	0.6883117	0.7532468	0.8181818	0.7792208	0.6883117	0.6363636	0.7532468	1.000000		
P. barberi	0.5714286	0.6363636	0.6493506	0.6363636	0.5974026	0.5584416	0.5454545	0.5844156	0.7012987	0.6363636	0.5714286	0.5714286	0.5844156	0.7012987	1.000000	
Karimunda	0.5714286	0.5064935	0.7532468	0.7402597	0.7272727	0.6883117	0.6493506	0.7142857	0.7792208	0.7402597	0.6753247	0.6233766	0.7662338	0.8571429	0.6643377	1.000000

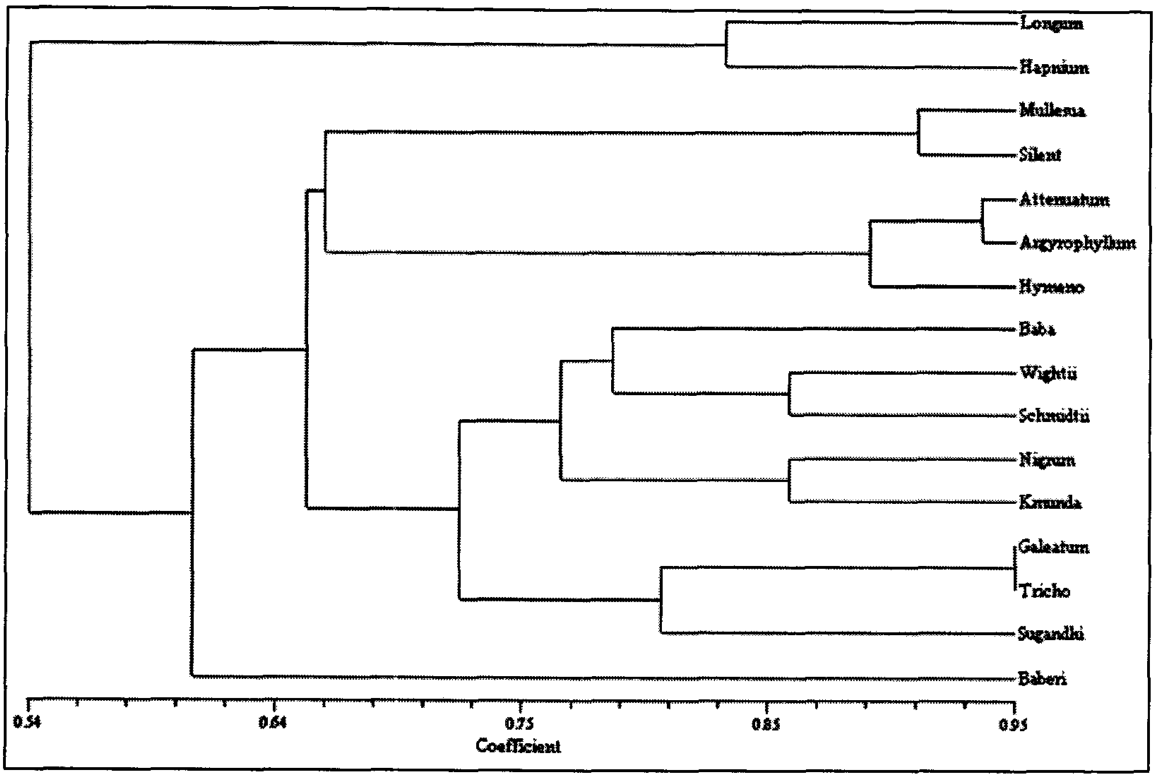


Fig. 21. Phylogram of 15 South Indian species of *Piper* expressed by cluster analysis of morphological characters

The first cluster consisting of *P. longum* and *P. hapnium* exhibited 83 % similarly between them. The second cluster further formed two groups. The first group consisted of *P. mullesua* and *P. silentvalleyensis* with 90% similarity. This group showed 63% similarity with the first cluster and all are having their spike erects. In the second group, there are three members viz. *P. attenuatum*, *P. argyrophyllum* and *P. hymenophyllum.* Ninety three percent similarity was shown between *P. attenuatum* and *P. argyrophyllum* and they shared 88% similarity with *P. hymenophyllum,* the third member in the group. The third cluster consisted of three separate groups. The first group consisted of *P. bababudani, P. wightii and P. schmidtii. P. wightii* and P. *schmidtii* shared 85 % similarity each other and *P. bababudani* out grouped from this with 74 % similarity coefficient. In the second group, the clustering was between *P. nigrum* and the cultivar Karimunda with 85 % similarity. *P. galeatum*, *P. trichostachyon* and *P. sugandhi* formed the third group. 95 % similarity coefficient was observed between *P. galeatum* and *P. trichostachyon* and they clustered together. However, *P. sugandhi* out grouped with 77 % similarity coefficient. *P. barberi* out grouped with the rest of the species and stood independently as the fourth cluster.

Molecular characterization

DNA markers help us to characterize plant species more efficiently and they are not influenced by environment. Hence, the species of *Piper* were profiled using RAPD and ISSR markers.

RAPD and ISSR profiling of Piper species

Molecular profiles were developed for 15 wild species along with popular cultivar Karimunda with 20 RAPD 'Operon' primers *viz.* OPA-03, OPA-08, OPA-13, OPA-18, OPB-05, OPB-07, OPB-14, OPB-20, OPC-02, OPC-09, OPC-13, OPC-18, OPC-20, OPD-07, OPD-10, OPD-13, OPD-15, OPE-02, OPF-10 and OPF-15 (Fig 22 – 25) and 12 ISSR primers *viz.* $(CT)_8GC$, $(CA)_7GT$, $(CA)_7GG$, $(CA)_6CC$, $(CT)_8AC$,$(CT)_8GC$, $(CA)_7AG$, $(GT)_6GG$, $(GT)_6CC$, $(GACA)_3GG$ and $(AGTG)_3TT(TA)_7$ (Fig 26 – 28).

Good polymorphism was observed between species for most of the primers used. RAPD primers OPB-20, OPA-9 and the ISSR primers $(GA)_6CC$ followed by the primer $(CT)_8AC$.

A total number of 475 bands (loci) were scored and the paired affinity indices were calculated based on similarity indices and presented in Table 19. Dendrograms were drawn based on NTSYS Version 2.01 software to study the interrelationships (Fig. 29).

The values of similarity based on Jaccard's coefficient for all fifteen accessions ranged from 0.65 to 0.86 reflecting a broad level of genetic variability within the species.

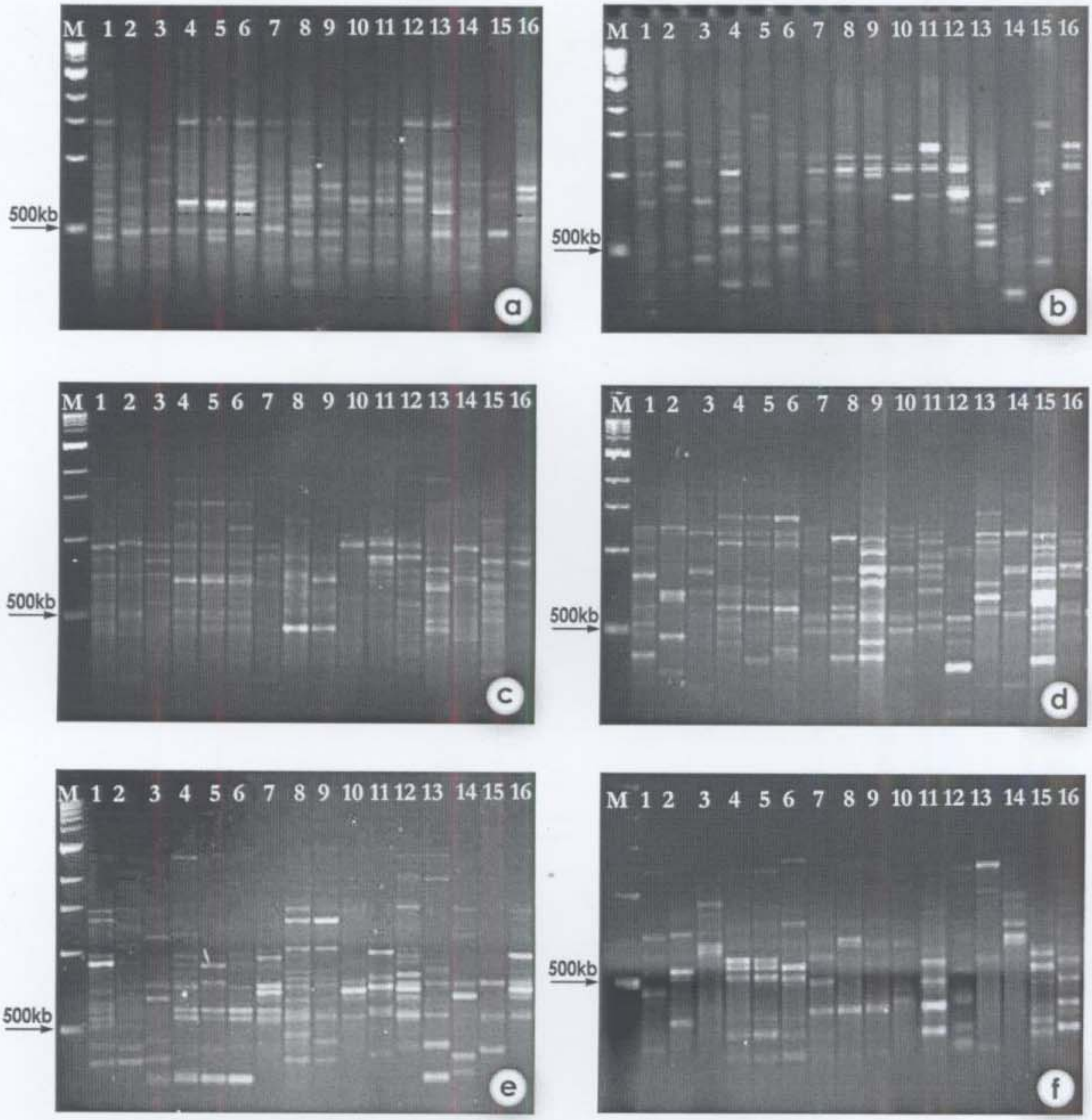


Fig. 22. RAPD profile of 15 *Piper* species

Primers a) OPA-03, b) OPA-09 c) OPA-13, d) OPA-18, e) OPB-05, f) OPB-07

Lane M. 1 kb Marker, 1 *P. longum,* 2 *P. hapnium,* 3 *P. mullesua,* 4 *P. attenuatum*, 5 *P. argyrophyllum*, 6 *P. hymenophyllum,* 7 *P. bababudani*, 8 *P. trichostachyon*, 9 *P. galeatum*, 10 *P. sugandhi*, 11 *P. nigrum,* 12 *P. schmidtii*, 13 *P. wightii,* 14 *P. silentvalleyensis*, 15 P. *barberi* and 16 Karimunda (control)

123-B

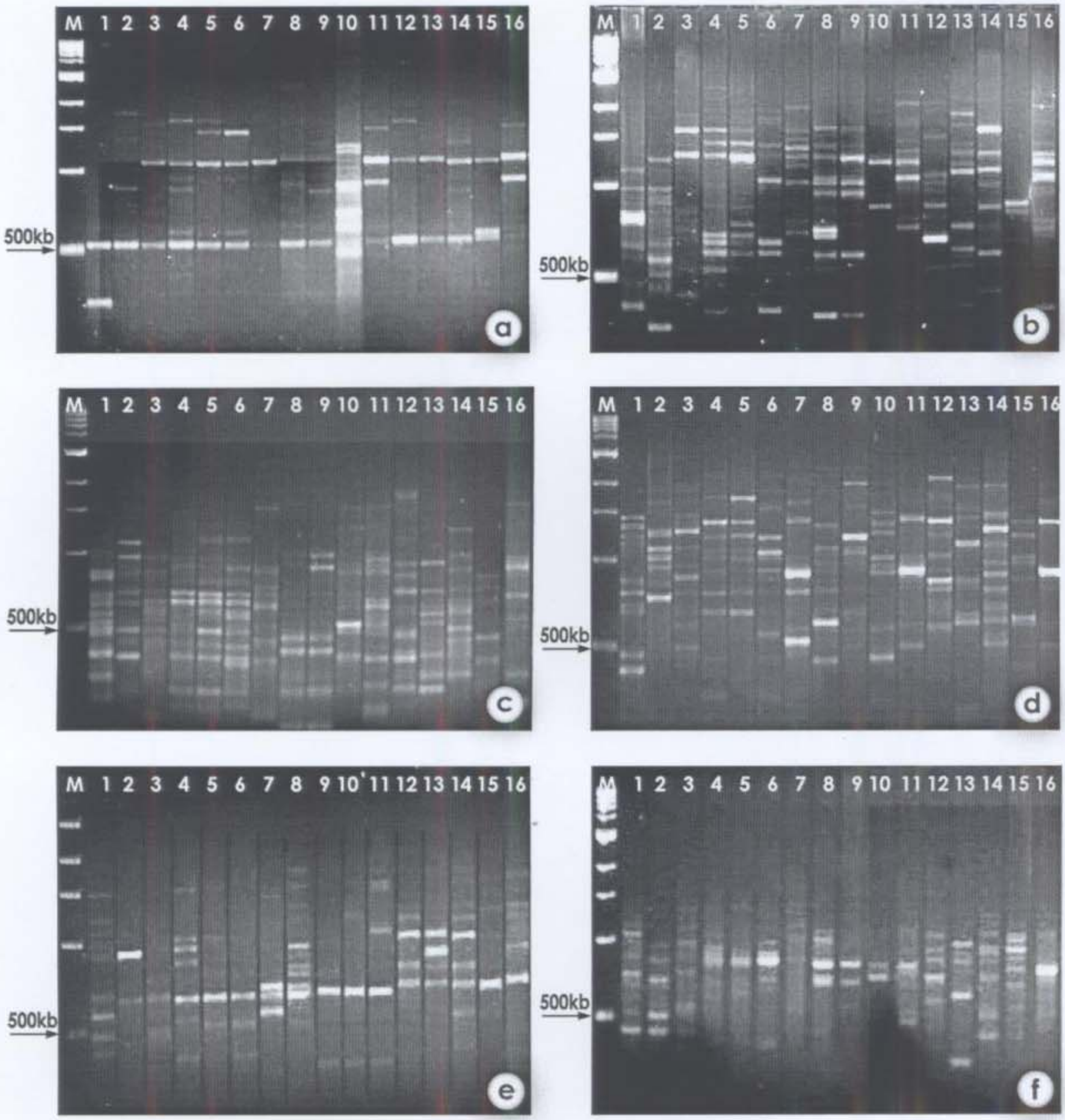


Fig. 23. RAPD profile of 15 *Piper* species

Primers a) OPB-14, b) OPB-20 c) OPC-02, d) OPC-09, e) OPC-13, f) OPC-18

Lane M. 1 kb Marker, 1 *P. longum,* 2 *P. hapnium,* 3 *P. mullesua,* 4 *P. attenuatum,* 5 *P. argyrophyllum,* 6 *P. hymenophyllum,* 7 *P. bababudani*, 8 *P. trichostachyon,* 9 *P. galeatum,*10 *P. sugandhi,* 11 *P. nigrum,* 12 *P. schmidtii,* 13 *P. wightii,* 14 *P. silentvalleyensis,* 15 *P. barberi* and 16 Karimunda (control).

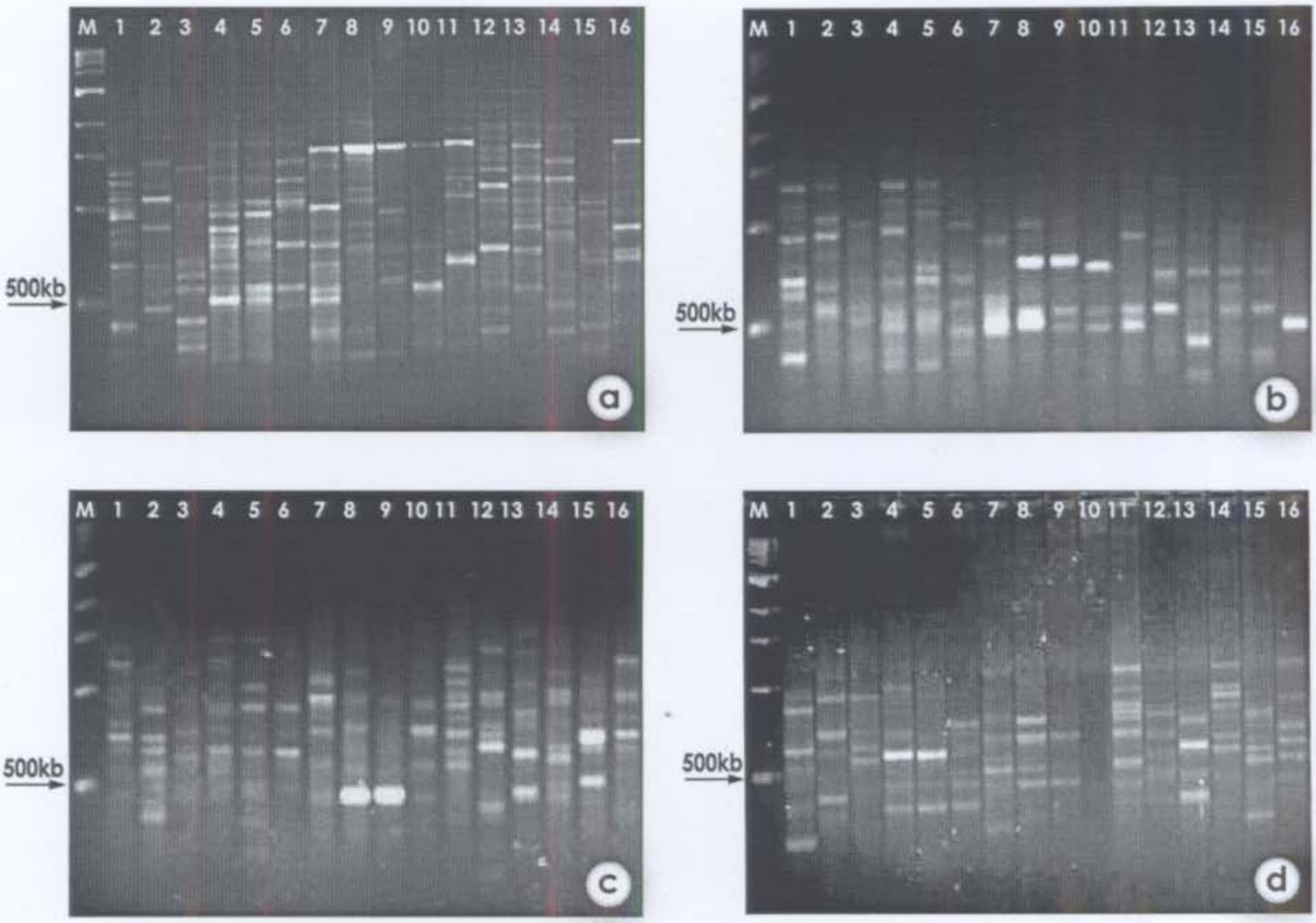


Fig. 24. RAPD profile of 15 *Piper* species
Primers a) OPC-20, b) OPD-07 c) OPD-10, d) OPD-13.

Lane M. 1 kb Marker, 1 *P. longum,* 2 *P. hapnium,* 3 *P. mullesua,* 4 *P. attenuatum*, 5 *P. argyrophyllum*, 6 *P. hymenophyllum,* 7 *P. bababudani*, 8 *P. trichostachyon*, 9 *P. galeatum*, 10 *P. sugandhi*, 11 *P. nigrum,* 12 *P. schmidtii*, 13 *P. wightii,* 14 *P. silentvalleyensis*, 15 P. *barberi* and 16 Karimunda (control)

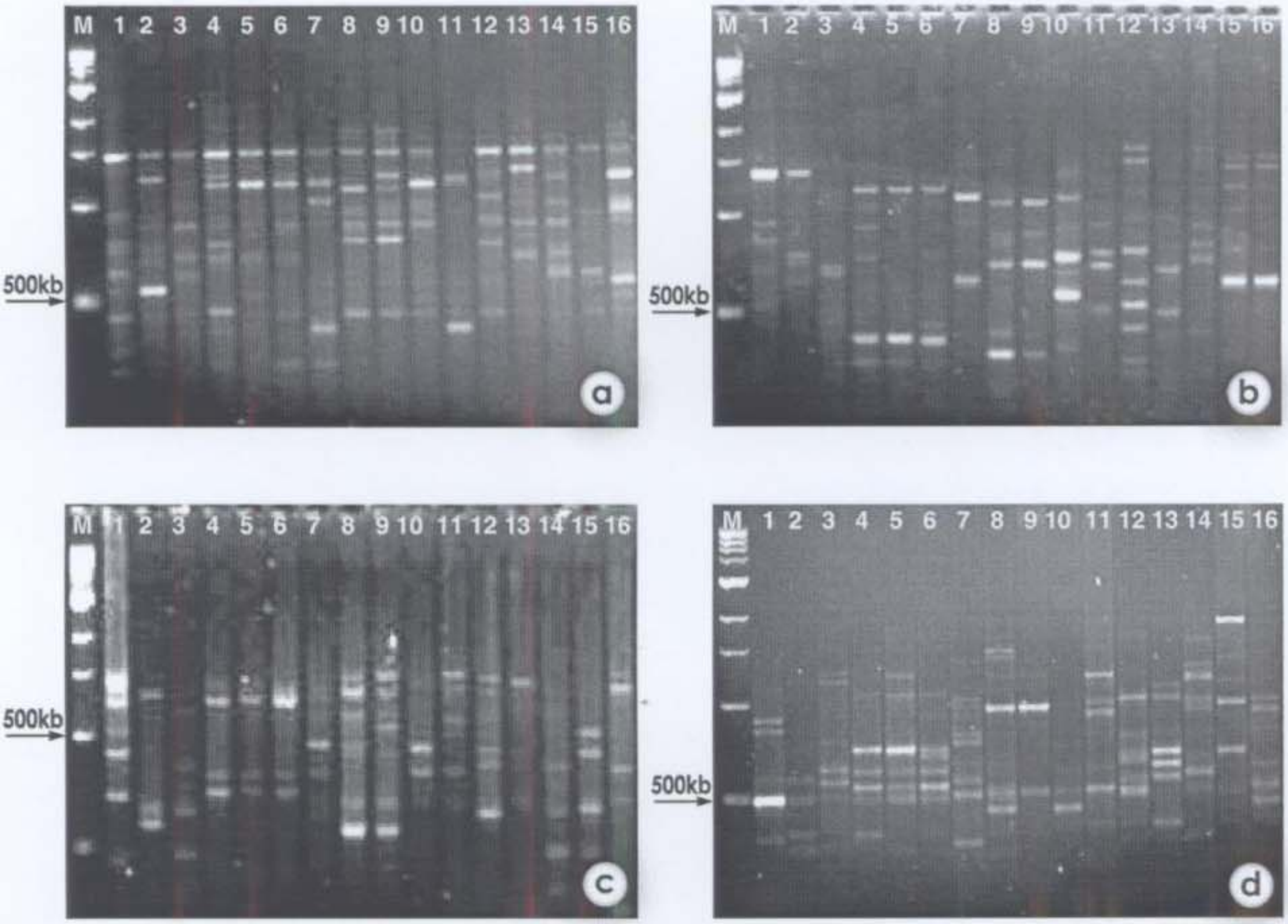


Fig. 25. RAPD profiles of 15 *Piper* species.

Primers a) OPD-15, b) OPE-02 c) OPF-10, d) OPF-15.

Lane M. 1 kb Marker, 1 *P. longum,* 2 *P. hapnium,* 3 *P. mullesua,* 4 *P. attenuatum*, 5 *P. argyrophyllum*, 6 *P. hymenophyllum,* 7 *P. bababudani*, 8 *P. trichostachyon*, 9 *P. galeatum*, 10 *P. sugandhi*, 11 *P. nigrum,* 12 *P. schmidtii*, 13 *P. wightii,* 14 *P. silentvalleyensis*, 15 P. *barberi* and 16 Karimunda (control)

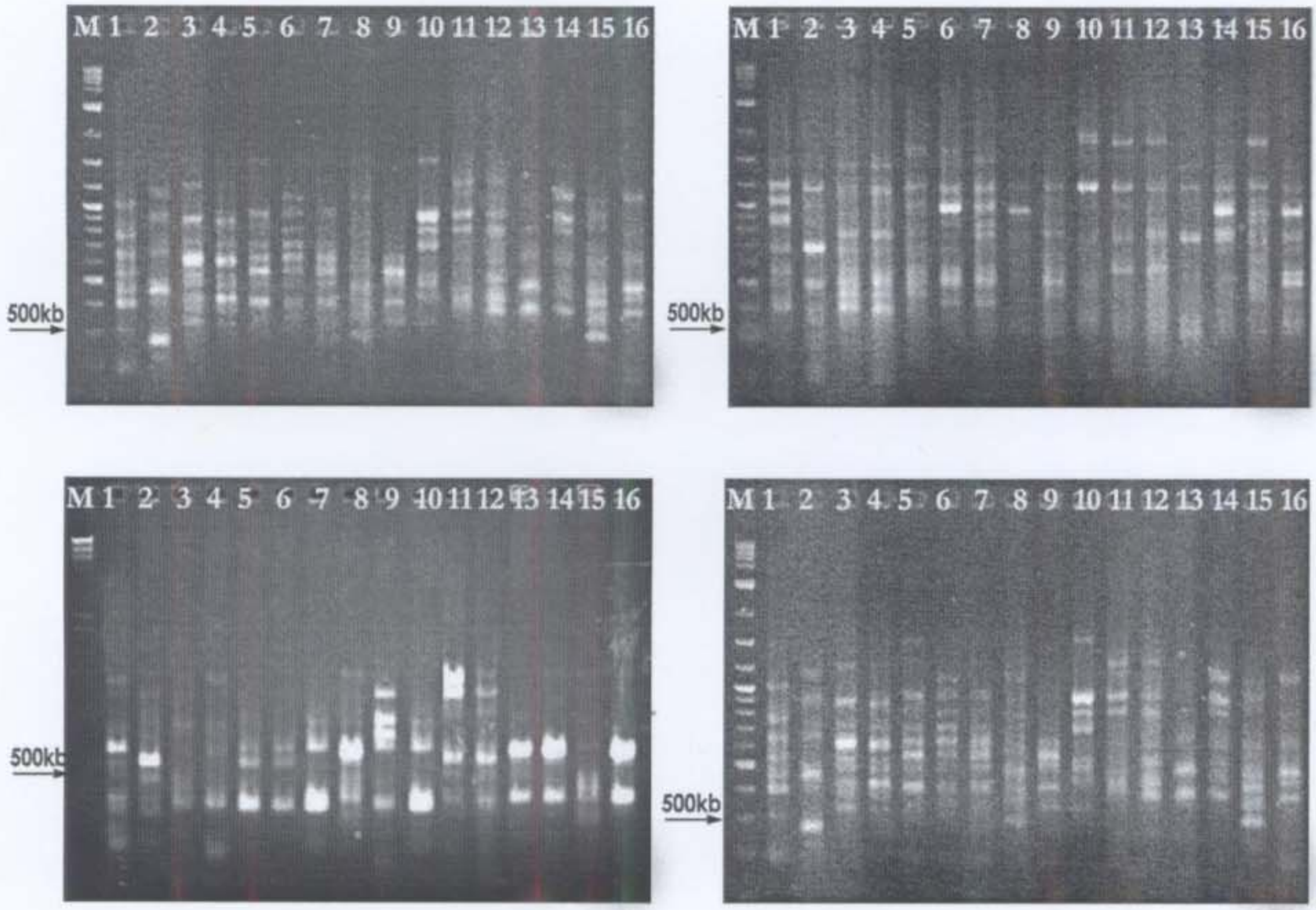


Fig. 26. ISSR profiles of 15 *Piper* species.

Primers a) (CA)7 GG b) (GT)6 GG c) (GT)6 CC and d) (GACA)3 GG.

Lane M- Marker 1 Kb ladder, 1. *P. longum,* 2 *P. hapnium,* 3 *P mullesua,* 4 *P. silentvalleyensis,* 5 *P. attenuatum,* 6 *P. argyrophyllum,* 7 *P. hymenophyllum,* 8 *P. bababudani* , 9 *P.wightii,* 10 *P. schmidtii,* 11 *P. galeatum,* 12 *P. trichostachyon,* 13 *P. sugandhi,* 14 *P. nigrum,* 15 *P. barberi,* and 16 Karimunda (control)

123·F

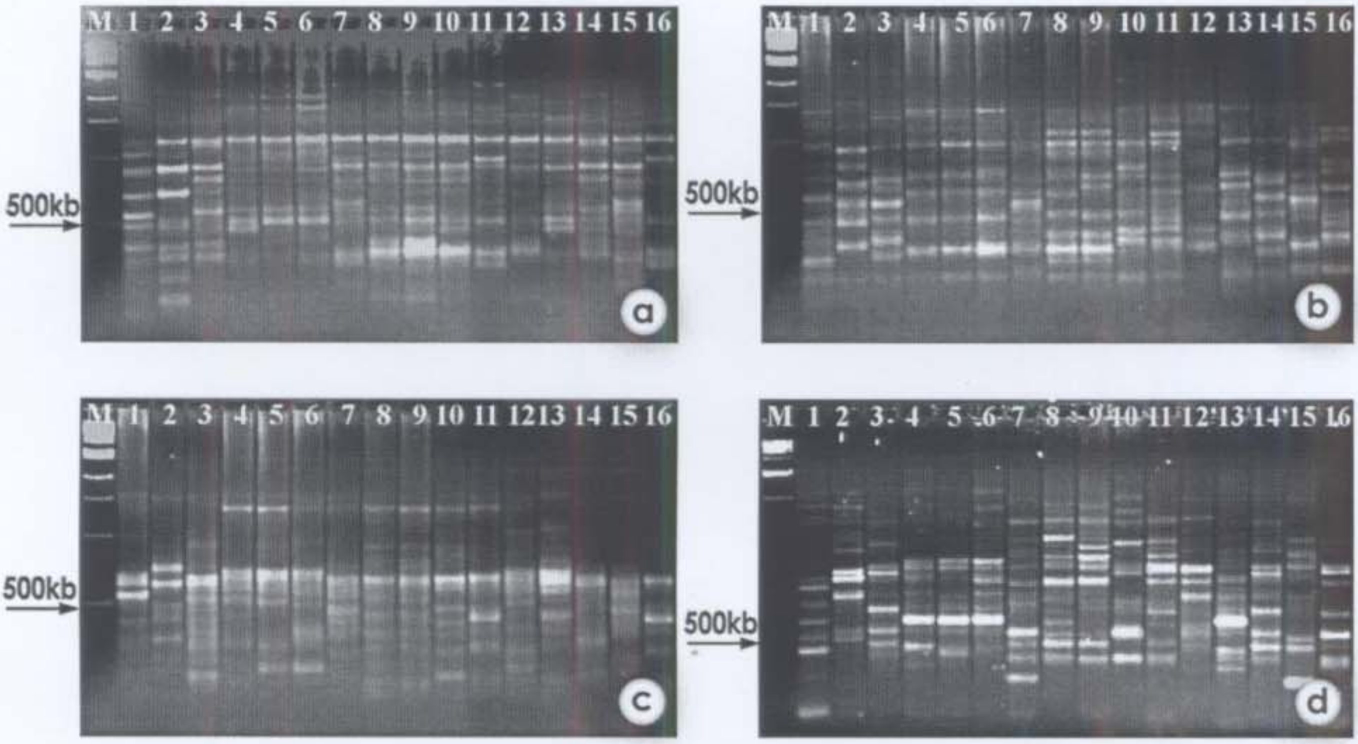


Fig. 27. ISSR profile of 15 *Piper* species.

Primers a) (CT)8GC, b) (CA)7GT, c) (CA)7GG, d)(GA)6CC

Lane M. 1 kb Marker, 1 *P. longum,* 2 *P. hapnium,* 3 *P. mullesua,* 4 *P. attenuatum,* 5 *P. argyrophyllum,* 6 *P. hymenophyllum,* 7 *P. bababudani,* 8 *P. trichostachyon,* 9 *P. galeatum,* 10 *P. sugandhi,* 11 *P. nigrum,* 12 *P. schmidtii,* 13 *P. wightii,* 14 *P. silentvalleyensis,* 15 *P. barberi* and 16 Karimunda (control).

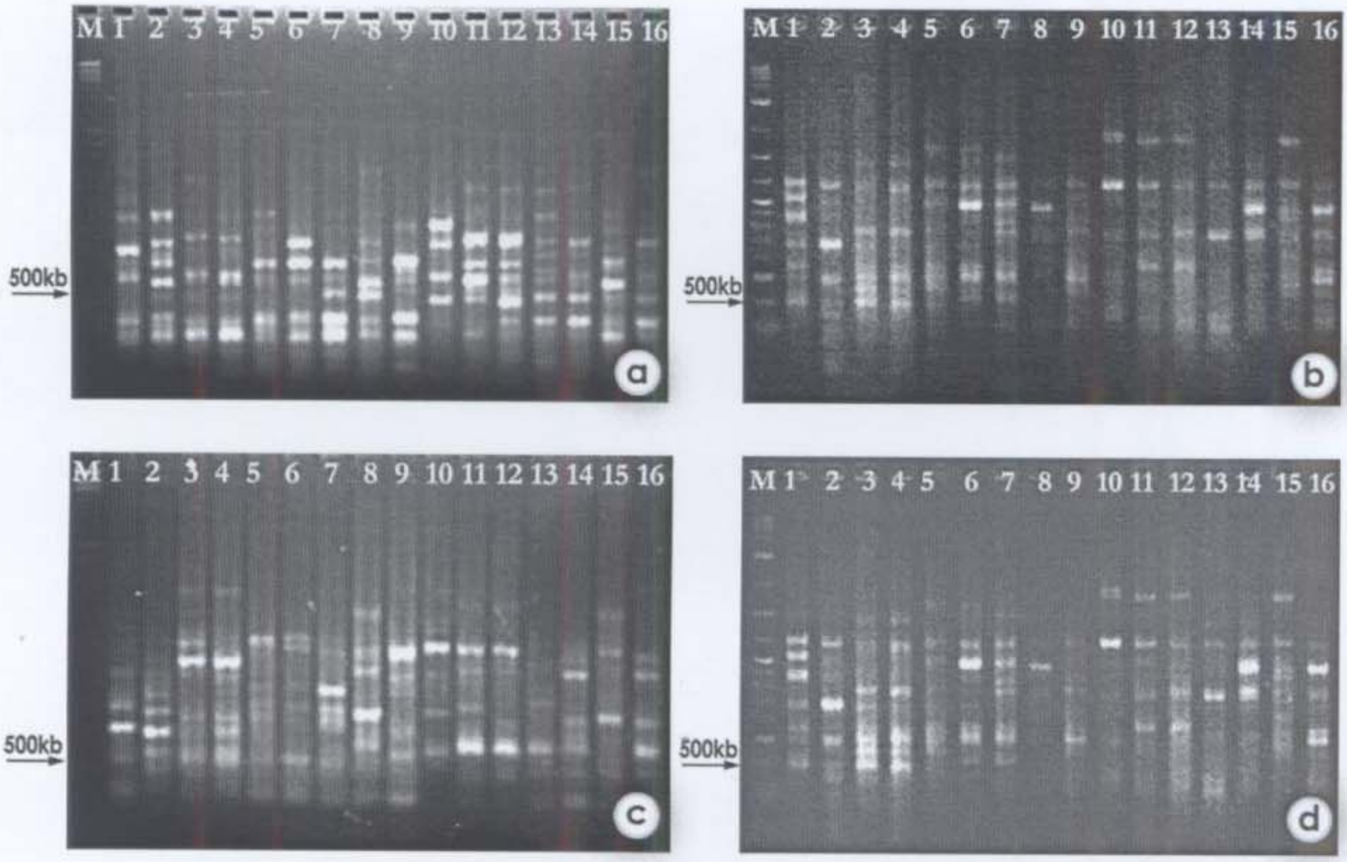


Fig. 28. ISSR profiles of 15 *Piper* species.

Primers a) (CT)8 AC, b) (TA)7 A, c) (AGTG)3 TT and d) (CA)7 AG.

Lane M- Marker 1 Kb ladder, 1. *P. longum,* 2 *P. hapnium,* 3 *P mullesua,* 4 *P. silentvalleyensis,* 5 *P. attenuatum,* 6 *P. argyrophyllum,* 7 *P. hymenophyllum,* 8 *P. bababudani* , 9 *P.wightii,* 10 *P. schmidtii,* 11 *P. galeatum,* 12 *P. trichostachyon,* 13 *P. sugandhi,* 14 *P. nigrum,* 15 *P. barberi,* and 16 Karimunda (control).

Table 19. Paired Affinity Indices of 15 South Indian *Piper* based on RAPD and IISR polymorphism.

Species	*P.longum*	*P.hapnium*	*P.mullesua*	*P.silent.*	*P.atten.*	*P. argyro.*	*P. hymeno.*	*P. babubu.*	*P.wightii*	*P.schmidti*	*P. galeat.*	*P. tricho.*	*P. sugand.*	*P.nigrum*	*P. barberi*	**Karimunda**
P. longum	1.0000000															
P. hapnium	0.7468085	1.0000000														
P. mullesua	0.6851064	0.7382979	1.0000000													
P. silent.	0.6234043	0.6510638	0.7851064	1.0000000												
P. atten.	0.6404255	0.6340426	0.6489362	0.6425532	1.0000000											
P.argyro	0.6382979	0.6404255	0.6723404	0.6574468	0.8659574	1.0000000										
P.hymeno.	0.6425532	0.6489362	0.6680851	0.6574468	0.7765957	0.8255319	1.0000000									
P.baba..	0.6638298	0.6744681	0.6936710	0.6702128	0.6617021	0.6936170	0.6765957	1.0000000								
P. wightii	0.6276596	0.6340426	0.6744681	0.6808511	0.6468085	0.6787234	0.7042553	0.6489362	1.0000000							
P.schmidtii	0.6191489	0.6382979	0.6659574	0.6638298	0.6170213	0.6234043	0.6446809	0.7000000	0.6638298	1.0000000						
P.galeatum	0.6234043	0.6851064	0.7000000	0.6723404	0.6127660	0.6404255	0.6531915	0.6829787	0.6638298	0.7063830	1.0000000					
P.tricho.	0.6191489	0.6468085	0.7000000	0.6382979	0.6042553	0.6361702	0.6531915	0.6914894	0.6510638	0.6936170	0.8680851	1.0000000				
P.sugandhi	0.6638298	0.7127660	0.7063830	0.7000000	0.6276596	0.6765957	0.6936170	0.7489362	0.6914894	72978720.	0.7468085	0.7510638	1.0000000			
P.nigrum	0.6446809	0.6765957	0.6702128	0.6510638	0.6170213	0.6531915	0.6702128	0.7212766	0.6297872	0.6936170	0.7191489	0.7234043	0.7765957	1.0000000		
P.barberi	0.6574468	0.6638298	0.6957447	0.6510638	0.5957447	0.6361702	0.6446809	0.661702	0.6765957	0.6680851	0.6893617	0.6765957	0.7042553	0.6638298	1.0000000	
Karimunda	0.6446809	0.6638298	0.6872340	0.6893617	0.6255319	0.6617021	0.6617021	0.7212766	0.6680851	0.6808511	0.7063830	0.6936170	0.7382979	0.7617021	0.7063830	1.0000000

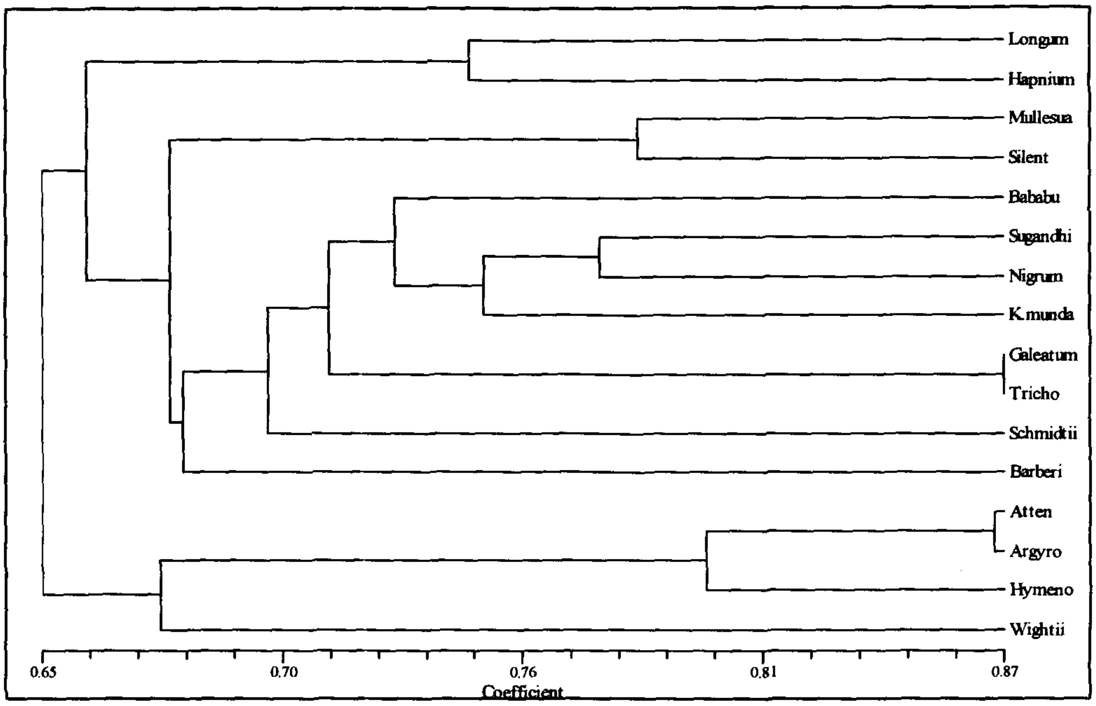


Fig. 29. Dendrogram of divergence in 15 South Indian *Piper* based on RAPD and ISSR polymorphism.

Molecular profiling have resulted the formation of five major clusters at 0.79 similarity coefficient levels. The major clusters formed are

Cluster-I	-	*P. longum* and *P. hapnium*
Cluster-II	-	*P. mullesua* and *P. silentvalleyensis*
Cluster-III	-	*P. bababudani, P. sugandhi, P. nigrum,* Karimunda, *P. galeatum, P. trichostachyon, P. schmidtii and P. barberi*
Cluster-IV	-	*P. attenuatum, P. argyrophyllum* and *P. hymenophyllum*
Cluster-V	-	*P. wightii*

The clustering pattern was similar to the morphological characterization except for cluster III and cluster-V.

The cluster three can be separated in to five groups. *P. bababudani, P. schmidtii* and *P. barberi* formed independent clusters while *P. sugandhi, P. nigrum* and Karimunda with 76% similarity formed one group and *P. trichostachyon* and *P. galeatum* formed other group. This study also failed to distinguish between *P. galeatum* and *P. trichostachyon.*

Molecular characterization, which reflects more of genetic similarities have separated *P. schmidtii* and *P. wightii*, which were grouped together in morphological (phenotype) characterization. *P. schmidtii* is included in the III major cluster along with *P. sugandhi, P. nigrum,* Karimunda, *P. trichostachyon* and *P. galeatum* as mentioned above, while *P. wightii* is unique and is placed in cluster V but distantly grouped with IV major cluster involving *P. attenuatum, P. argyrophyllum* and *P. hymenophyllum.*

Intra species variability

An effort was made to study the morphologic and molecular variation occurring within the species of *Piper*. Two most important and economically useful species viz. *P. nigrum* (wild forms, 15 collections) and *P. longum* (8 collections) were used in the study.

P. nigrum

Fifteen wild forms (♀) of *P. nigrum* collected from various locations viz. Karnataka, Kerala and Tamil Nadu (Table 5) were characterized both morphologically and at molecular level.

Morphological characterization

The *P. nigrum* collections from different regions were characterized for sixteen morphological characters as given in Table.20.

Branching type

Out of the accession studied, 13 of them were having dimorphic type of branching pattern, however collection number 5847 and 5422 were having polymorphic type of branching pattern.

Orthotropic shoot tip colour

Colours of the young orthotropic shoots were light purple in majority of the genotypes studied. Shoot tip colour was dark purple in Acc. 5569 (collected from Kannur), Acc. 5889 (Wayanad), Acc. 370 (Palghat), Acc. 5494 (Pathanamthitta) and Acc. 5492 (Pathanamthitta).

The selected accessions did not show any variability in case of runner shoot production, holding capacity, adventitious root production, type of venation, nature of bracts and leaf texture.

Lateral branch habit

Lateral branch habits ranged from erect to horizontal type. Lateral branches were erect in Acc. 5889, Acc. 5899 (both from Wayanad), Acc. 4520 (from Idukki) and Coll. No. 5492 (Pathanamthitta). Lateral branches were horizontal in all other types.

Lateral branch length

Length of lateral branches varied from 35.6 cm (Acc. 4536) to 42.1 cm (Coll. 5220). The average branch length was 39.6 cm.

Number of nodes

Number of nodes per lateral branches ranged from 23 (Acc. 5492) to 32 (Acc. 370) with a mean of 27.2 nodes/lateral branch.

Leaf petiole length

Petiole length of the leaves ranged form a minimum of 1.0 (Acc. 5899) to the maximum 2.1 (Acc. 5487). The average of petiole length for the genotypes studied was 1.7 cm.

Leaf length

Acc. No. 5899 was having the shortest with a leaf length of 8.7 cm and Acc. 5220 was having the longest leaf size of 14.6 cm. Average leaf length of the samples studied was 11.3 cm.

Leaf width

Width of the leaves ranged from 5.9 cm in Acc. 5847 to 8.6 cm in Acc. 4635. The average of leaf width among the genotypes studied was 7.5 cm.

Leaf lamina shape

Shape of the leaves ranged to ovate, ovate lanceolate and cordate forms. Among the genotypes studied Acc. 5896, 5422, 4536, 5496 and 5311 were having cordate leaf shape. Acc. 5492 was with ovate lanceolate leaves; where as the remaining samples were with ovate leaf shape.

Leaf base shape

Round and cordate types of leaf base shapes were observed in the genotypes studied. Nine samples showed round type of leaf base and the rest of them (Acc. 5569, Acc. 5896, Acc. 370, Acc. 4536, Acc. 5492 and Acc.5311) showed cordate shape of leaf base.

Morphometric analysis

Cluster analysis was carried out based on the above morphological characters and a dendrogram was derived from the paired affinity indices between the genotypes.

Fifteen *Piper nigrum* accessions were selected for numerical analysis following Sokal and Sneath (1963). For numerical evaluation, the morphological characters listed in Table 20 and 21 were recorded. Using the similarity matrix (Table 22) the relationship among the OTUs were worked out which is represented in the form of a dendrogram (Fig. 30).

Peduncle length

In general, no significant variations were observed in the peduncle length of *Piper* spp. except *P. barberi*, which has extra ordinary long peduncle, which is longer the spike itself (Fig. 20). Among the species studied, *P. barberi* had the maximum peduncle length with 10.1 cm. Peduncle length of other species ranged from 0.4 to 2.5 cm. Shortest peduncle length was observed in *P. silentvalleyensis* and it was 2.5 cm in *P. hymenophyllum*.

Number of spikes/lateral branches

The number of spikes per lateral branches ranged from four to eighteen. *P. barberi* produced the minimum number of spikes while maximum numbers of spikes were noticed in *P. attenuatum* and *P. mullesua*.

Flower arrangement

Flowers were fused laterally in *P. longum* and *P. hapnium*. (Fig. 6 and 7). In all the other species flowers were free.

Spike texture

Among the species studied, *P. trichostachyon* was the only species with hirtellous spike (Fig. 17). Rest of the species were of glabrous nature.

Bract type

Type of bract is one of the key identifying features for identification of *Piper* species. Peltate bracts (Fig. 6, 7, 8, 9, 14, 15 and 20) were observed in *P. longum, P. hapnium, P. mullesua, P. silentvalleyensis, P. wightii, P. schmidtii* and *P. barberi*. The bracts were sessile, oblong and adnate to the rachis (Fig. 10, 11 and 12) in *P. attenuatum, P. argyrophyllum* and *P. hymenophyllum*.

Nature of bract in *P. nigrum* and *P. sugandhi* were cupular with decurrent base and it was deeply cupular with decurrent base (Fig. 13) in *P. bababudani*. Bracts were fleshy, connate and transformed them into a cup (boat shaped) in *P. galeatum* and *P. trichostachyon* (Fig. 16 and 17).

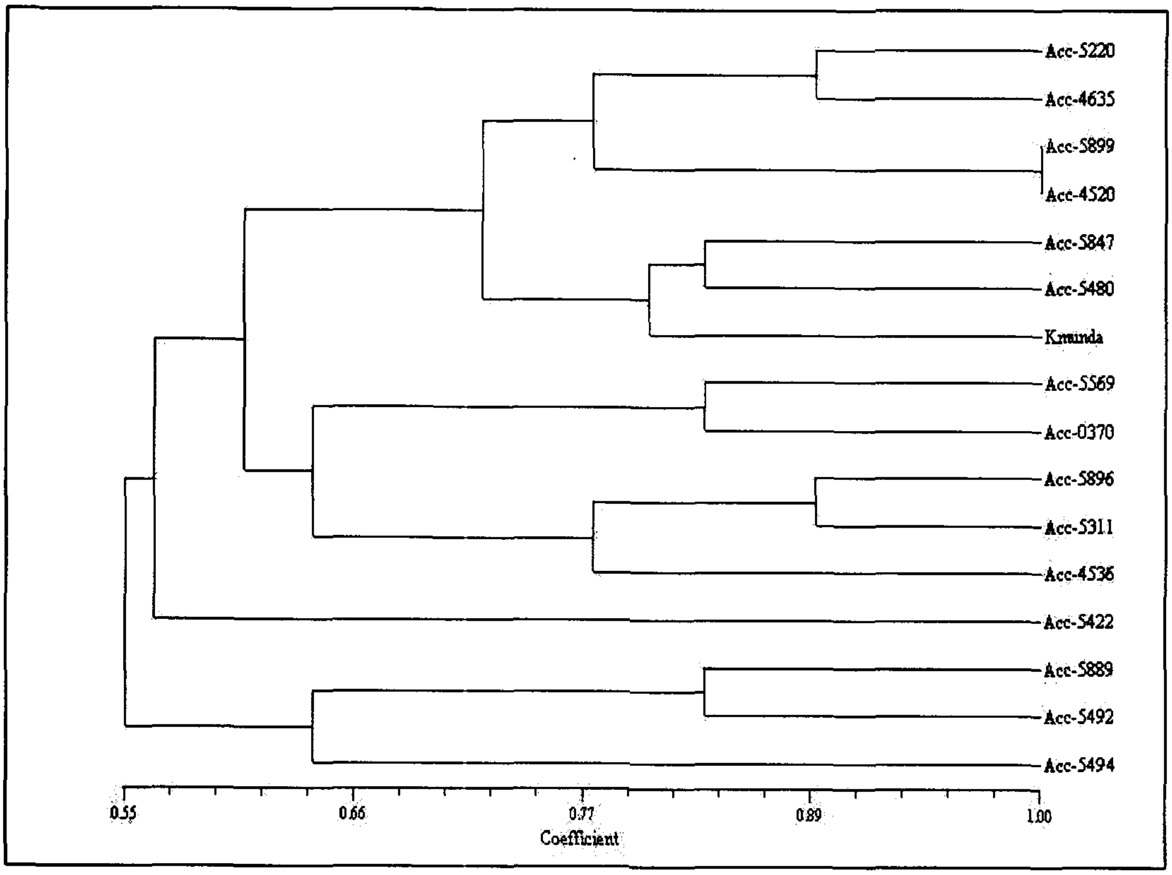


Fig. 30. Dendrogram of divergence of 15 accessions of *Piper nigrum* expressed by morphological characterization

Table 20. Morphological observations of *Piper nigrum* (wild)

Descriptor code	5220	5569	5889	5899	5896	5847	5422	370	4536	4520	4635	5496	5480	5492	5311
2.2 Branching type	1	1	1	1	1	2	2	1	1	1	1	1	1	1	1
2.3 Shoot tip coluor	2	3	3	2	2	2	2	3	2	2	2	3	2	3	2
2.4 Runner shoot	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
2.5 Holding capacity	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
2.6 Advt. root production	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
2.7 Lb. habit	2	2	1	1	2	2	2	2	2	1	2	2	2	1	2
2.8 Lb. length	42.1	38.8	35.9	41.2	40.3	37.8	38	43	35.6	42.3	40	41.5	39.6	38.9	40.1
2.9 No. of nodes	31	26	24	28	29	24	25	32	26	30	28	29	25	23	29
2.10 Leaf petiole length	1.7	1.5	1.2	1	1.8	2.1	1.9	1.7	1.5	1.3	1.4	1.2	1.3	1.2	1.6
2.11 Leaf length	14.6	11.3	11.9	8.7	9.9	10.9	12.2	12	10.5	10.9	12.6	13.2	9.3	10.6	11.3
2.12 Leaf width	7.3	7.3	8.1	6.4	6.8	5.9	9.5	6.8	6.6	6.2	8.6	11.2	6.4	7.9	8.5
2.13 Lamina shape	1	1	1	1	5	1	5	1	5	1	1	5	1	3	5
2.14 Leaf base shape	1	2	1	1	2	1	1	2	2	1	1	1	1	2	2
2.15 Leaf margin	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
2.16 Veining	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
2.17 Leaf hairiness	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1

Table 21. Descriptor code for morphological characters of *Piper nigrum* (wild)

Character		**5220**	**5569**	**5889**	**5899**	**5896**	**5847**	**5422**	**370**	**4536**	**4520**	**4635**	**5496**	**5480**	**5492**	**5311**	**Control**
2.2 Branching type	Dimorphic	1	1	1	1	1	0	0	1	1	1	1	1	1	1	1	1
	Polymorphic	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0
2.3 Shoot tip Colour	Light purple	1	0	0	1	1	1	1	0	1	1	1	0	1	0	1	1
	Dark purple	0	1	1	0	0	0	0	1	0	0	0	1	0	1	0	0
	Erect	0	0	1	1	0	0	0	0	0	1	0	0	0	1	0	0
2.7 Lateral branch habit.	Horizontal	1	1	0	0	1	1	1	1	1	0	1	1	1	0	1	1
2.8 Lateral branch length.		1	0	0	1	1	0	0	1	0	1	1	1	0	0	1	0
2.9 No. of nodes/lateral branch		1	0	0	1	1	0	0	1	0	1	1	1	0	0	1	1
2.10 Leaf petiole length		1	0	0	0	1	1	1	1	0	0	0	0	0	0	1	1
2.11 Leaf length		1	1	1	0	0	0	1	1	0	0	1	1	0	0	1	0
2.12 Leaf width		0	0	1	0	0	0	1	0	0	0	1	1	0	1	1	0
	Ovate	1	1	1	1	0	1	0	1	0	1	1	0	1	0	0	0
2.13Leaf lamina shape	Elliptic-lanceolate	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1
	Cordate	0	0	0	0	1	0	1	0	1	0	0	1	0	0	1	0
	Round	1	0	1	1	0	1	1	0	0	1	1	1	1	0	1	1
2.14 Leaf base shape	Cordate	0	1	0	0	1	0	0	1	1	0	0	0	0	1	0	1

Table 22. Paired Affinity Indices of *Piper nigrum* (wild) based on morphological characterization

	Acc-5220	Acc-5569	Acc-5889	Acc-5899	Acc-5896	Acc-5847	Acc-5422	Acc-0370	Acc-4536	Acc-4520	Acc-4635	Acc-5494	Acc-5480	Acc-5492	Acc-5311	Karimunda
Acc-5220	1.0000000															
Acc-5569	0.6111111	1.0000000														
Acc-5889	0.5555556	0.7222222	1.0000000													
Acc-5899	0.7777778	0.5000000	0.6666667	1.0000000												
Acc-5896	0.7222222	0.5555555	0.2777778	0.6111111	1.0000000											
Acc-5847	0.7222222	0.5555555	0.5000000	0.6111111	0.5555556	1.0000000										
Acc-5422	0.6111111	0.4444444	0.5000000	0.3888889	0.5555556	0.7777778	1.0000000									
Acc-0370	0.7777778	0.8333333	0.5555556	0.5555556	0.7222222	0.5000000	0.3888889	1.0000000								
Acc-4536	0.5555556	0.7222222	0.4444444	0.5555556	0.8333333	0.6111111	0.6111111	0.5555556	1.0000000							
Acc-4520	0.7777778	0.5000000	0.6666667	1.0000000	0.6111111	0.6111111	0.3888889	0.5555556	0.5555556	1.0000000						
Acc-4635	0.8888889	0.6111111	0.6666667	0.7777778	0.6111111	0.6111111	0.6111111	0.6666667	0.5555556	0.7777778	1.0000000					
Acc-5494	0.6666667	0.6111111	0.6666667	0.5555556	0.6111111	0.3888889	0.6111111	0.6666667	0.5555556	0.5555556	0.7777778	1.0000000				
Acc-5480	0.7777778	0.7222222	0.6666667	0.7777778	0.6111111	0.8333333	0.6111111	0.5555556	0.7777778	0.7777778	0.7777778	0.5555555	1.0000000			
Acc-5492	0.3888889	0.5555555	0.8333333	0.6111111	0.3333333	0.4444444	0.4444444	0.3888889	0.5000000	0.6111111	0.5000000	0.6111111	0.6111111	1.0000000		
Acc-5311	0.7222222	0.5555555	0.3888889	0.5000000	0.8888889	0.4444444	0.6666667	0.7222222	0.7222222	0.5000000	0.7222222	0.7222222	0.5000000	0.3333333	1.0000000	
Karimunda	0.8333333	0.5555555	0.5000000	0.7222222	0.7777778	0.7777778	0.6666667	0.6111111	0.7222222	0.7222222	0.7222222	0.6111111	0.8333333	0.5555556	0.6666667	1.0000000

The dendrogram indicated good diversity among collections. The grouping of the collections based on morphological collections did not show any relation with the geographical distribution of the collections.

Molecular characterization

The morphological characterization is supplemented with molecular data obtained through ISSR profiling (Figs. 31 and 32). Molecular profiling of 15 collections were carried out using 10 ISSR primers. The primers used for the study are $(CT)_8AC$, $(CT)_8GC$, $(CA)_7GT$, $(CA)_7AG$, $(CA)_7GG$, $(GT)_6GG$, $(CA)_7AC$, $(GA)_6GG$, $(GA)_6CC$ and $(GT)_6CC$. Seventy markers were scored. Among the primers used the primer $(CA)_7$ GT produced the highest number of fragments followed $(CT)_8$ GC. Out of the 72 markers, produced 49 were polymorphic. The similarity indices were calculated (Table 23), cluster analysis was performed based on the similarity matrix using Jaccard's coefficient and represented in the form of a dendrogram (Fig. 33).

The similarity index values were obtained for each pair wise comparison among the *P. nigrum* accessions. The similarity coefficient based on ISSR markers ranged from 70 to 90 %.

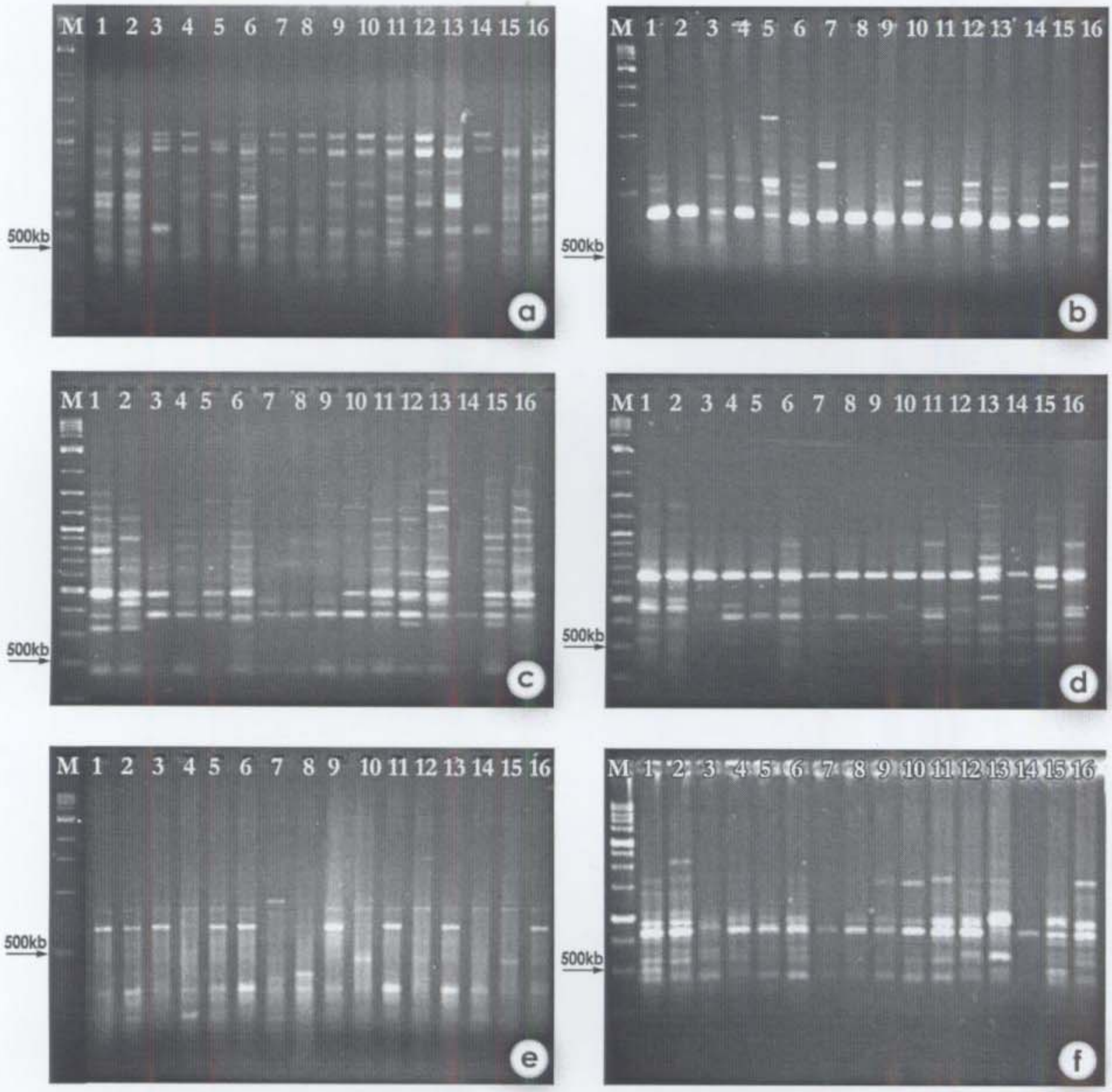


Fig. 31. ISSR profiles of sixteen *Piper nigrum* accessions.
Primers a) (CT)8 AC, b) (CT)8 GC, c) (CA)7 GT, d) (CA)7 AG, e) (CA)7 GG and f) (GT)6 GG.

Lane M- Marker 1 Kb ladder, 1 Acc. 5220 (N. Canara), 2 Acc. 5569 (Kannur), 3 Acc. 5889 (Wyanad), 4 Acc. 5899 (Wyanad), 5 Acc. 5896(Wyanad), 6 Acc. 5847 (Calicut), 7 Acc. 5422 (Palaghat), 8 Acc. 0370 (Palaghat), 9 Acc. 4536 (Idukki), 10 Acc. 4520 (Idukki), 11 Acc. 4635 (Idukki), 12 Acc. 5494 (Pathanamthitta), 13 Acc. 5480 (Pathanamthitta), 14 Acc. 5492 (Pathanamthitta), 15 Acc. 5311 (Courtallum) and
16 Karimunda (Control).

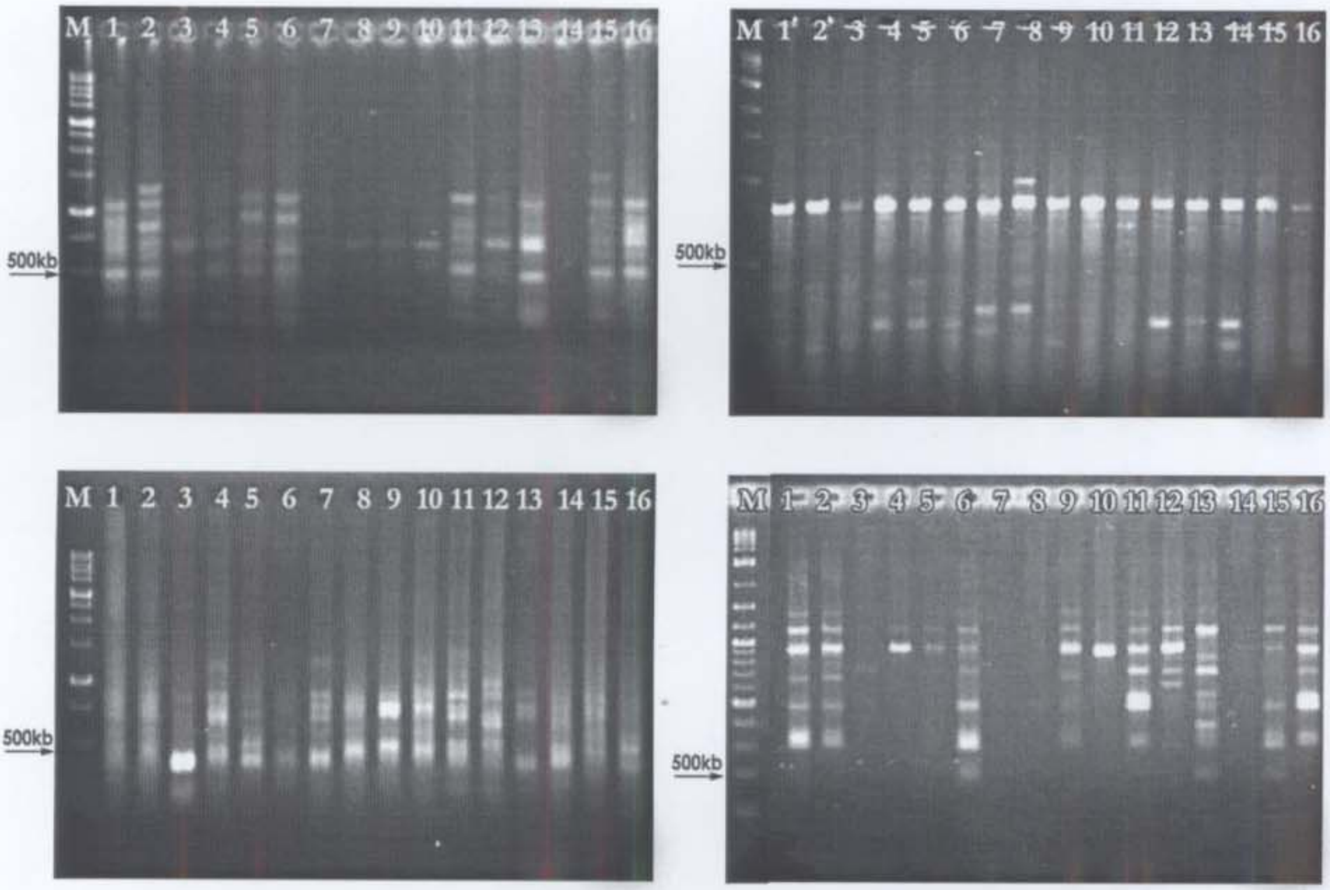


Fig. 32. ISSR profiles of 16 *Piper nigrum* accessions.
Primers a) (CA)7 AC, b) (GA)6 GG, c) (GA)6 CC and d) (GT)6 CC .

Lane M- Marker 1 Kb ladder, 1 Acc. 5220 (N. Canara), 2 Acc. 5569 (Kannur), 3 Acc. 5889 (Wayanad), 4 Acc. 5899 (Wayanad), 5 Acc. 5896 (Wayanad), 6 Acc. 5847 (Calicut), 7 Acc. 5422 (Palaghat), 8 Acc. 0370 (Palaghat), 9 Acc. 4536 (Idukki), 10 Acc. 4520 (Idukki), 11 Acc. 4635 (Idukki), 12 Acc. 5494 (Pathanamthitta), 13 Acc. 5480 (Pathanamthitta), 14 Acc. 5492 (Pathanamthitta), 15 Acc. 5311 (Courtallum) and 16 Karimunda (Control).

Table 23. Paired Affinity Indices of *Piper nigrum* based on molecular characterization

Accessions	5220	5569	5889	5899	5896	5847	5422	370	4536	4520	4635	5494	5480	5492	5311	Karimunda
5220	1.0000000															
5569	0.9166667	1.0000000														
5889	0.9000000	0.8833333	1.0000000													
5899	0.8000000	0.7833333	0.8666667	1.0000000												
5896	0.8000000	0.7500000	0.8333333	0.9000000	1.0000000											
5847	0.7833333	0.7333333	0.7500000	0.8500000	0.8500000	1.0000000										
5422	0.7000000	0.7166667	0.7666667	0.8666667	0.8000000	0.7833333	1.0000000									
370	0.7333333	0.7500000	0.8000000	0.8666667	0.7666667	0.7500000	0.9000000	1.0000000								
4536	0.8166667	0.8000000	0.8166667	0.9166667	0.8500000	0.8666667	0.8500000	0.8500000	1.0000000							
4520	0.8166667	0.7333333	0.8166667	0.8833333	0.8166667	0.8666667	0.8166667	0.8500000	0.9000000	1.0000000						
4635	0.9000000	0.8833333	0.8666667	0.8333333	0.8000000	0.7833333	0.7333333	0.7666667	0.8500000	0.7833333	1.0000000					
5494	0.9000000	0.8166667	0.8666667	0.8000000	0.8000000	0.7833333	0.7333333	0.7333333	0.7833333	0.8500000	0.8333333	1.0000000				
5480	0.7333333	0.7166667	0.6666667	0.7666667	0.7333333	0.8500000	0.7000000	0.6666667	0.8166667	0.7833333	0.7000000	0.7333333	1.0000000			
5492	0.7500000	0.7333333	0.8166667	0.8500000	0.8166667	0.8000000	0.8833333	0.8500000	0.8333333	0.8666667	0.7500000	0.8166667	0.7500000	1.0000000		
5311	0.8000000	0.7833333	0.8000000	0.8000000	0.7666667	0.8166667	0.7666667	0.7666667	0.7833333	0.8166667	0.7666667	0.7666667	0.7000000	0.7500000	1.0000000	
Karimunda	0.8666667	0.8500000	0.8333333	0.7666667	0.7333333	0.7500000	0.7000000	0.7000000	0.7500000	0.7500000	0.8666667	0.8000000	0.7000000	0.7166667	0.833333	1.0000000

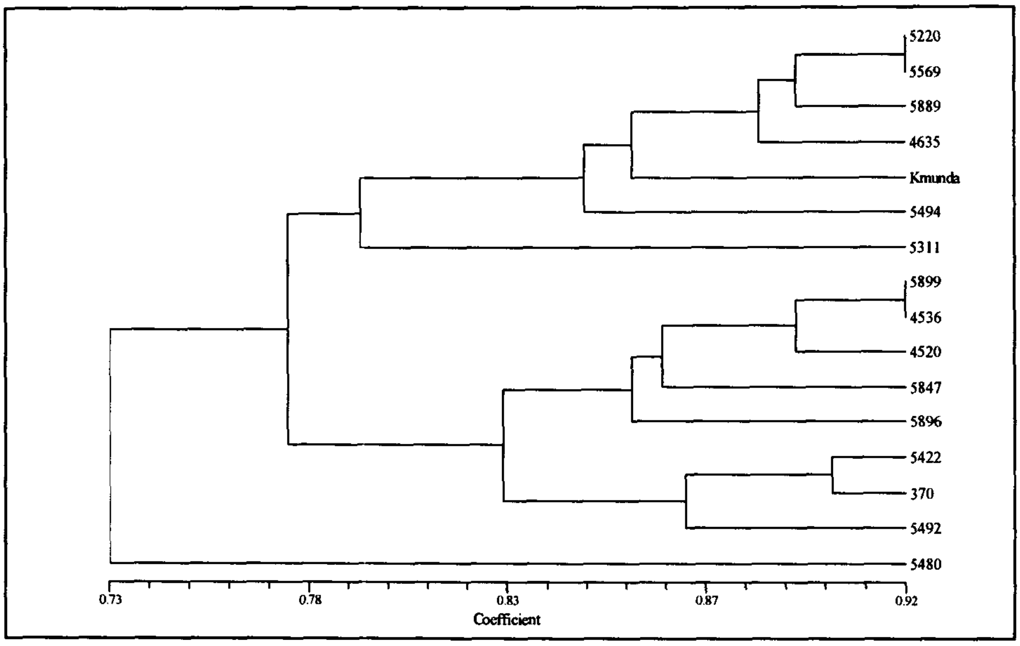


Fig 33. Dendrogram of divergence of 15 *Piper nigrum* (wild) accessions of *Piper* expressed by ISSR markers

Molecular profiles of *P. nigrum* accessions using ISSR markers resulted in three major clusters at 76% similarity coefficient level. The first cluster consisted of Acc. 5220 (N. Kanara), 5569 (Kannur), 5889 (Wayanad), 4635 (Idukki), 9494 (Pathanamthitta), 5311 (Courtallam) and Karimunda (control). The second major cluster was with two sub clusters viz. sub cluster a and b. In the sub cluster 'a' 92% similarity were observed between Acc. 5899 (Wayanad) and Acc. 4536 (Idukki) and this group shared 89% similarity with Acc. 4520 (Idukki). The other members out grouped from this cluster were Acc. 5847 (Calicut) and Acc. 5896 (Wayanad). Sub cluster 'b' consisted of Acc. 5422 (Palghat), Acc. 370 (Palghat) and Acc. 5492 (Pathamthitta). The collection 5480 formed a separate cluster with least similarity index.

Morphological and molecular analysis showed that there is considerable variability among *P. nigrum* accessions collected from different locations, but no patterns were found among the *P. nigrum* collected from similar geographic locations.

This indicates that though there are some phenotypic variability between the accessions from the same locality there is less genotypic variation in them.

P. longum

Eight *wild* forms (♀) of *Piper longum* mainly collected from different parts of Kerala and a collection from Sirsi (Karnataka) (Table 6) were characterized both morphologically and at molecular level.

Morphological characterization

Morphological observations of the *P. longum* collections studied are given in Table 24 and their coded descriptor states are given in Table 25. In general, these collections have similar vegetative and reproductive characters, except in two accessions. The two variants were Acc. No. 4515 (from Nadukani forests of Nilambur District, Kerala) with extra bold spike and Acc. 5476 with light purple colour on the tender spikes.

Table 24. Morphological observations of *Piper longum* accessions

Descriptor code	3184	4515	5383	3270	139	3219	621	5476
2.1	1	1	1	1	1	1	1	1
2.2	1	1	1	1	1	1	1	1
2.3	1	1	1	1	1	1	1	2
2.4	2	2	2	2	2	2	2	1
2.5	2	2	2	2	2	2	2	2
2.6	2	2	2	2	2	2	2	2
2.7	1	1	1	1	1	1	1	1
2.8	28	26	27	25.9	30	43.5	23.9	25.8
2.9	15	13	14	13	18	22	16	13
2.10	1.5	3.2	3.8	4.6	4.4	2.5	1.5	1.8
2.11	10.2	11.2	8.9	9.8	12.4	8.1	9.3	7.8
2.12	6.2	5.8	5.2	4.2	5.3	6.8	7	4.1
2.13	3	3	3	3	3	3	3	3
2.14	4	4	4	4	4	4	4	4
2.15	2	2	2	2	2	2	2	2
2.16	2	2	2	2	2	2	2	2
2.17	2	2	2	2	2	2	2	2
3.3	1	1	1	1	1	1	1	4

Quantitative characters like lateral branch length ranged from 23.9cm in Acc. 621 to 43.5 cm in Acc. 3219 with a mean of 28.7 cm. Number of nodes/lateral branches ranged from 13 (Acc. 4515 and Acc. 5476) to 22 (Acc. 3219) and the average number of nodes were 15.5. Length of the petiole was minimum in Acc. 3184 and Acc. 621 (1.5 cm) and the maximum petiole length was 4.6 cm in Acc. 3270 (mean 2.9 cm). Length of the leaves ranged from 7.8 cm (Acc. 5476) to 12.4 cm (mean 9.7 cm) and leaf width ranged from 4.1 cm (Acc. 5476) to 6.8 cm in Acc. 3219 (mean 5.5 cm).

Table 25. Descriptor code for morphological characters of *P. longum* accessions

Trait		3184	4515	5383	3270	139	3219	621	5476
2.3 Shoot tip colour	Green	1	1	1	1	1	1	1	0
	Light purple	0	0	0	0	0	0	0	1
2.4 Runner shoot production	Few	0	0	0	0	0	0	0	1
	Many	1	1	1	1	1	1	1	0
2.5 Holding capacity	Weak	0	0	0	0	0	0	0	1
	Strong	1	1	1	1	1	1	1	0
2.8 Lateral branch length		0	0	0	0	1	1	0	0
2.9 No. nodes/ lateral branch		0	0	0	0	1	1	1	0
2.10 Leaf petiole length		0	1	1	1	1	0	0	0
2.11 Leaf length		1	1	0	1	1	0	0	0
2.12 Leaf width		1	1	0	0	0	1	1	0
3.3 Spike colour	Light Yellow	1	1	1	1	1	1	1	0
	Light Purple	0	0	0	0	0	0	0	1

Spike colour was light yellow in all the accessions selected except Acc. 5476 where the spikes were light purple in colour.

Paired affinity indices (Table 26) ranged from 0.18 - 0.93 Jaccard's Similarity Index. Cluster analysis (Fig. 34) based on morphological observations were resulted the formation of two major groups at 17% similarity coefficient.

Table 26. Paired Affinity Indices of *Piper longum* accessions based on morphological characterization

Acc. No.	Acc-3184	Acc-4515	Acc-5383	Acc-3270	Acc-0139	Acc-3219	Acc-0621	Acc-5476
3184	1.0000000							
4515	0.8750000	1.0000000						
5383	0.8125000	0.8125000	1.0000000					
3270	0.8750000	0.8750000	0.9375000	1.0000000				
0139	0.7500000	0.7500000	0.8125000	0.8750000	1.0000000			
3219	0.8125000	0.6875000	0.7500000	0.6875000	0.8125000	1.0000000		
0621	0.8750000	0.7500000	0.8125000	0.7500000	0.7500000	0.9375000	1.0000000	
5476	0.1875000	0.1875000	0.2500000	0.1875000	0.0625000	0.1250000	0.1875000	1.0000000

Of the eight collections studied, seven collections formed a major cluster. Ninety three percent similarity coefficient was observed between Acc. 3184 and Acc. 4515, Acc. 5383 and Acc. 3270 and Acc. 3219 and Acc. 0621. Acc. 139 formed a separate sub cluster within the first cluster at 78% similarity coefficient level. Collection 5476 with light purple spike is uniquely placed in a separate group.

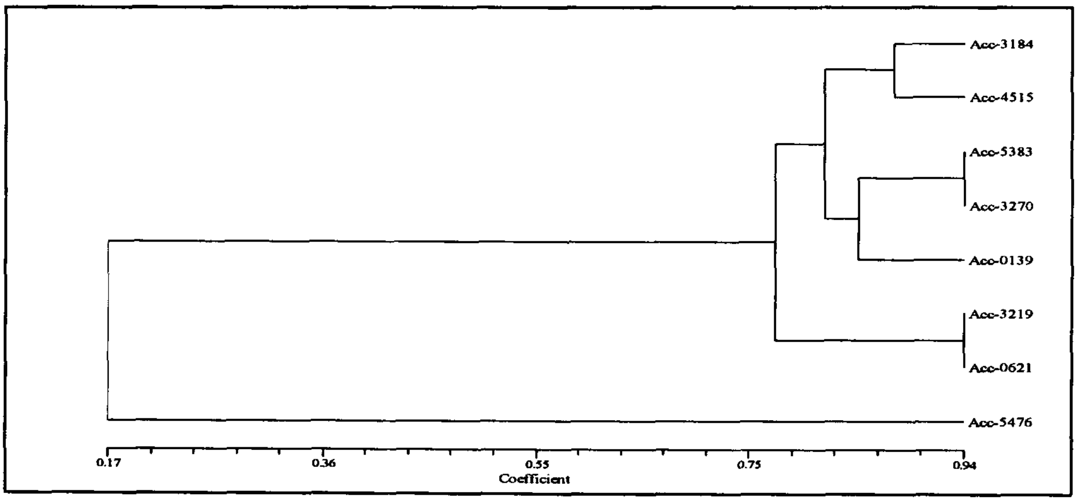


Fig 34. Dendrogram of divergence of eight accessions of *Piper longum* expressed by morphological characterization

Molecular characterization

Molecular profiling of these accessions was carried out using ten ISSR primers viz. $(CAC)_8$ GC, $(CTC)_8$ GC, $(GACA)_3$, $(AGTG)_3$, $(AT)_7$G, $(TA)_7$ A, $(GA)_6$ GG, $(GT)_6$ GG, $(GATA)_3$ CC and $(GT)_6$ CC. Altogether 60 markers were used of which 34 were polymorphic. Maximum polymorphism was observed with the primer $(GATA)_3$ CC (Fig. 35 - 36).

The paired affinity indices (Table 27) ranged from 0.60 JSI to 0.95 JSI indicating the maximum genetic distance was with Acc. 4515 and Acc. 3184 and maximum genetic similarity was between Acc. 5383 and 3270.

Based on the similarity matrix using UPGMA dendrograms were drawn (Fig. 37). The dendrogram showed two major clusters. All the collections of *P. longum*

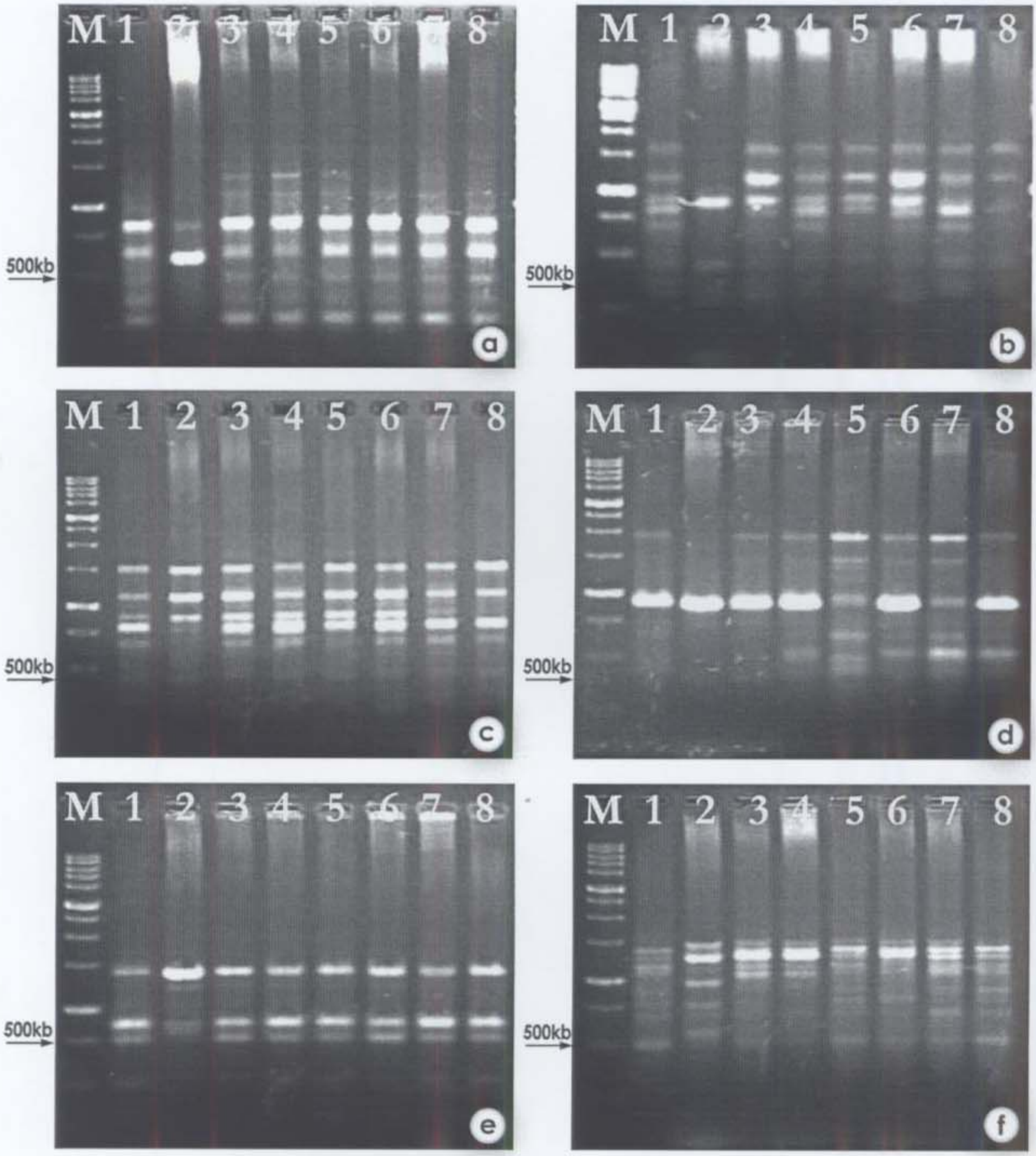


Fig. 35. ISSR profiles of eight *Piper longum* accessions.

Primers a) (CAC)8 GC, b) (CTC)8 GC, c) (GACA)3, d) (AGTG)3, e) (AT)7 G, f) (TA)7 A

Lane M- Marker 1 Kb ladder, 1 Acc. 3184 (Sirsi), 2 Acc. 4515 (Nadukani), 3. Acc. 5383 (Mukkali), 4 Acc. 3270 (Karapara), 5 Acc 139(Idukki), 6 Acc 3219 (Pathanamthitta), 7 Acc. 621 (Kollam) and 8 Acc. 5476 (Thiruvananthapuram)

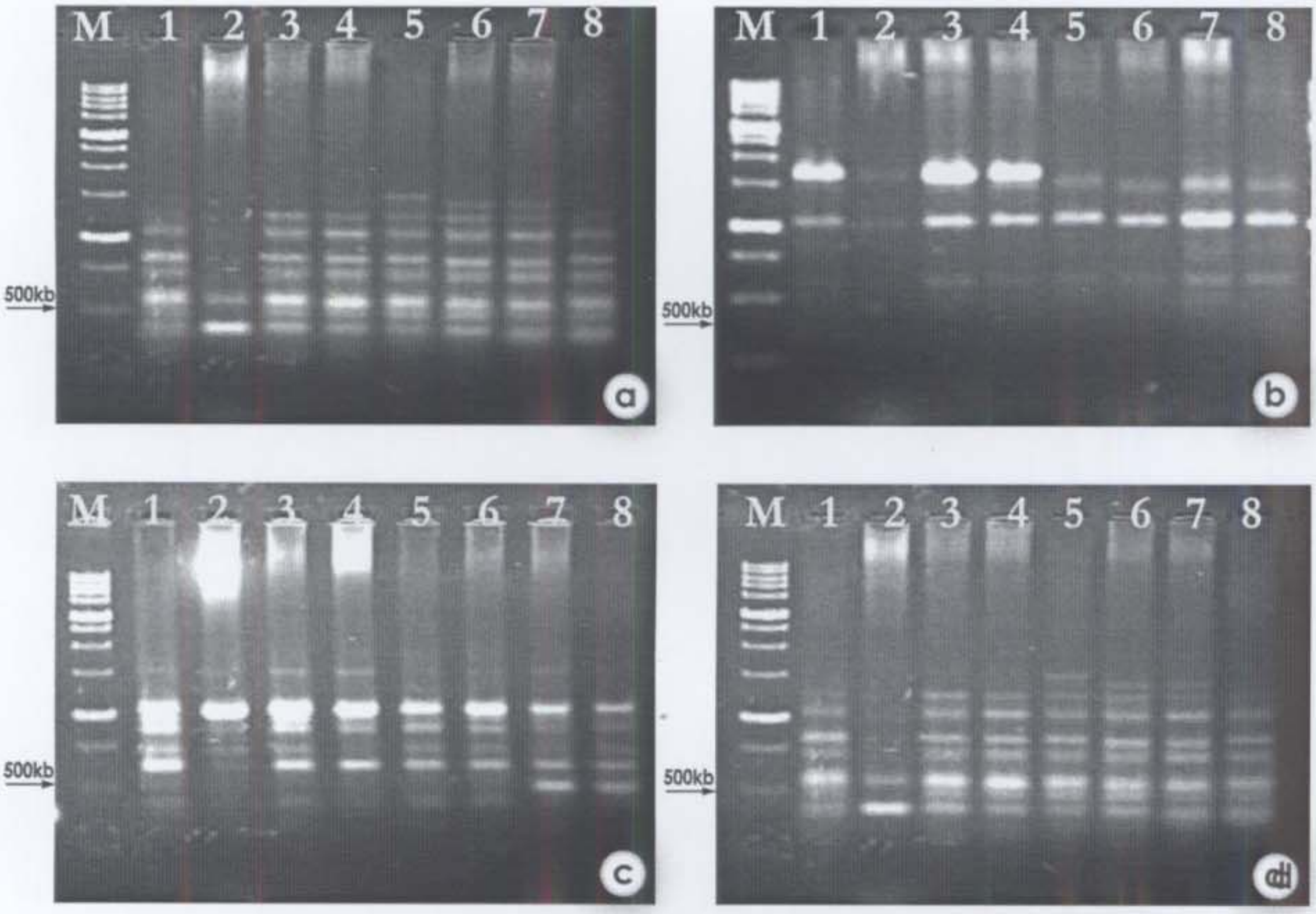


Fig. 36. ISSR profiles of eight *Piper longum* accessions.

Primers a) (GA)6 GG, b) (GT)6 GG, c) (GATA)3 CC and d) (GT)6 CC.

Lane M- Marker 1 Kb ladder, 1 Acc. 3184 (Sirsi), 2 Acc. 4515 (Nadukani), 3. Acc. 5383 (Mukkali), 4 Acc. 3270 (Karapara), 5 Acc 139(Idukki), 6 Acc 3219 (Pathanamthitta), 7 Acc. 621 (Kollam) and 8 Acc. 5476 (Thiruvananthapuram)

Table 27. Paired Affinity Indices of *Piper longum* accessions based on molecular characterization

Acc.	Acc-3184	Acc-4515	Acc-5383	Acc-3270	Acc-0139	Acc-3219	Acc-0621	Acc-5476
3184	1.0000000							
4515	0.6000000	1.0000000						
5383	0.9333333	0.6333333	1.0000000					
3270	0.9166667	0.6500000	0.9833333	1.0000000				
0139	0.9000000	0.5666667	0.9000000	0.9166667	1.0000000			
3219	0.9000000	0.6000000	0.9000000	0.9166667	0.9000000	1.0000000		
0621	0.8833333	0.5833333	0.8833333	0.9000000	0.8833333	0.9500000	1.0000000	
5476	0.8833333	0.5833333	0.8833333	0.9000000	0.9166667	0.9166667	0.9333333	1.0000000

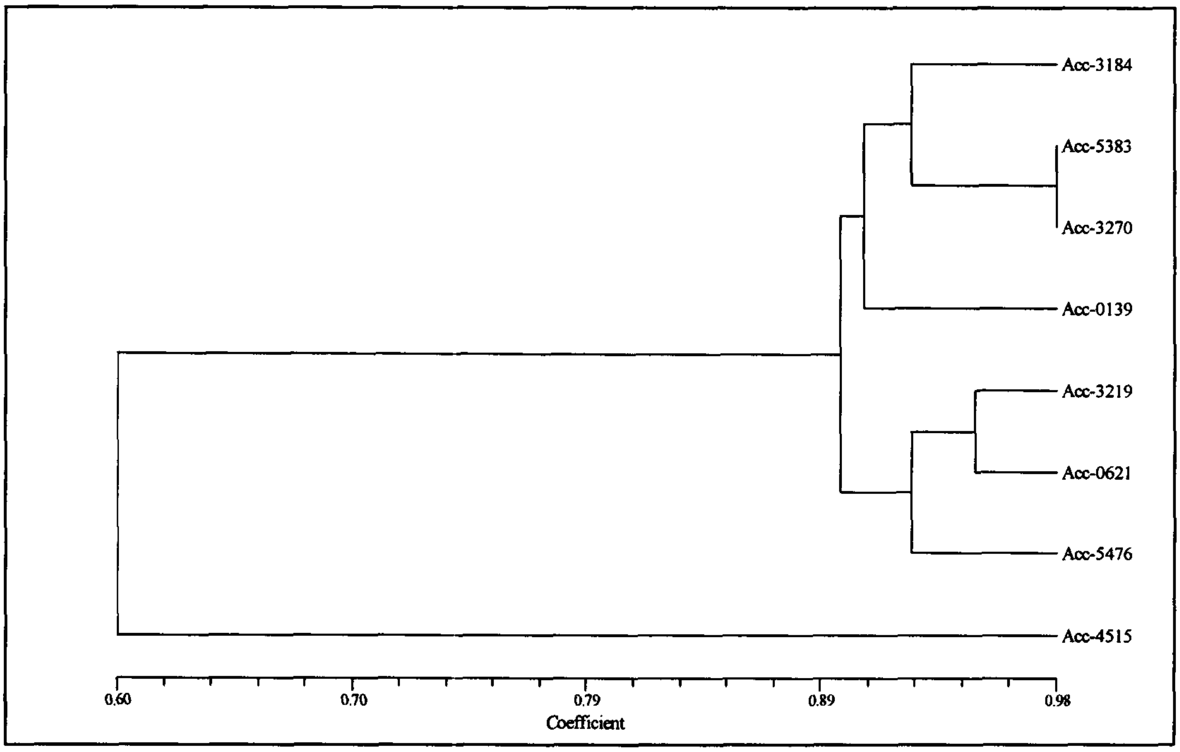


Fig 37. Dendrogram of divergence of 8 *P. longum* accessions expressed by ISSR markers

except Acc. 4515 with extra bold spike are placed in one cluster. Molecular characterization indicated minute differences in genome level between accessions by placing them in different sub groups. Only Acc. 4515 is uniquely placed indicating a major genetic change from the rest of the populations with a bootstrap 'P' value of 100%.

Inter cultivar variability in black pepper

Black pepper has over 100 cultivars are known growing in different regions (Ravindran, 2000). In the present study, 24 popular cultivars and released varieties and 9 less important cultivars were characterized both morphologically (phenotypic) and molecular (genotypic) to understand the extent of diversity and relationship.

Morphological characterization

Thirty-three cultivated black pepper accessions representing the existing diversity of black pepper cultivar germplasm were used for the present study. This includes 14 popular local cultivars, 10 improved varieties and 9 less important cultivars grown only in certain pockets (Table 4). The accessions studied were presented in tabular format (Tables 28.1 to 28.33) with photographs of the plant and a fruiting branch, followed by a morpho-taxonomic description of the plant based on the IPGRI descriptor were characterized based on the IPGRI descriptor. The observations in the coded descriptor states are given in Table 29.1 and 29.2 respectively. The recorded observations in a binary form used for cluster analysis and given in Table 30.1 and 30.2 respectively.

Inter cultivar variation was noticed in many of the cultivars. The salient observations with respect to important discriminating characters on intra cultivar variation are given below.

Branching type

Dimorphic type of branching was observed in 15 members (Karimunda, Kottanadan, Neelamundi, Kalluvally, Cheriyakanniakadan, Panniyur-2, Panniyur-3, Panniyur-4, Sreekara, Subhakara, PLD-2, Nedumchola, TMB-IV, Valiyakaniyakadan and Karimkotta) where as polymorphic type of branching was characterized by the remaining 18 cultivars.

Orthotropic shoot tip colour

The shoot tip colour ranged from green to dark purple, but most of the cultivars studied have light purple shoot tips. Among the cultivars studied, the improved variety Panniyur-1 (Table 28.15) was the only member with light green shoot tip colour, where as shoot tip colour was deep purple in cultivars Kalluvally and Chumalakodi (Table 28.6 and Table 28.27).

Runner shoot production

Runner shoots were few in cultivars *viz.* Balankotta, Kuthiravally, Kalluvally, Arakulammunda, Narayakodi, Perambramunda, Doddagai, Kaniyakadan and Karimkotta. Good number of runner shoots were observed in the remaining cultivars.

Holding capacity

The capacity to hold the plant on its support is one of the key factors of its survival and establishment in the field. If the holding capacity is less, the vines have a tendency to slip down from the support tree and hence cannot support large canopies. Most of the vines were having strong holding capacity on their supports; however, cv. Cheriyakanniakadan and cv. Kaniyakadan were weak in their holding capacity.

Adventitious root production

Adventitious roots were many in 31 cultivars but it was few in cultivars 'Cheriyakanniakadan' and 'Kaniyakadan'.

Table 28. 1 Morpho-taxonomic descriptions of cv. Karimunda

1. Passport details

1.1 Name of the cultivar:	**Karimunda**
1.2 Collection number:	**0815**
1.3 I.C. Number:	316477
1.4 Place of collection:	Kanjikuzhi, Idukki

2. Morphological descriptors

2.1 Vine height (cm):	460.0
2.2 Branching habit:	Dimorphic
2.3 Shoot tip colour:	Light purple
2.4 Runner shoot production:	Many
2.5 Holding capacity:	Strong
2.6 Adventitious root production:	Many
2.7 Lateral branch habit:	Horizontal
2.8 Lateral branch length (cm):	27.3
2.9 Number of nodes per lateral branch:	15.0
2.10 Leaf petiole length (cm):	1.7
2.11 Leaf length (cm):	11.0
2.12 Leaf width (cm):	7.3
2.13 Leaf lamina shape:	Ovate-lanceolate
2.14 Leaf base shape:	Round
2.15 Leaf margin:	Entire
2.16 Type of veining:	Acrodromous
2.17 Leaf texture:	Glabrous coriaceous

3. Reproductive characters

3.1 Spike orientation:	Pendant
3.2 Spike shape:	Filiform
3.3 Spike colour:	Green
3.4 Spike length (cm):	5.0
3.5 Type of hermaphroditism:	Bisexual flowers only
3.6 Peduncle length (cm):	0.8
3.7 Number of spikes/lateral branch :	5.0
3.8 Flower arrangement:	Free
3.9 Number of stamens:	Two
3.10 Spike texture:	Glabrous
3.11 Bract type:	Cupular with decurrent base
3.12 Flower nature:	Sessile
3.13 Fruit setting (%):	60.0
3.14 Number of developed fruits per spike:	55.0
3.15 Number of berries per ten spikes:	556.0
3.16 Fruit shape:	Round

4. Quantitative characters

4.1 100 fruit weight (g):	13.1
4.2 100 fruit volume (ml):	12.8
4.3. Green yield per plant:	2.08
4.4 Dry weight of 100 berries:	4.50

5. Qualitative characters

5.1 Essential oil (%):	3.3
5.2 Oleoresin (%):	11.1
5.3 Piperine (%):	4.9

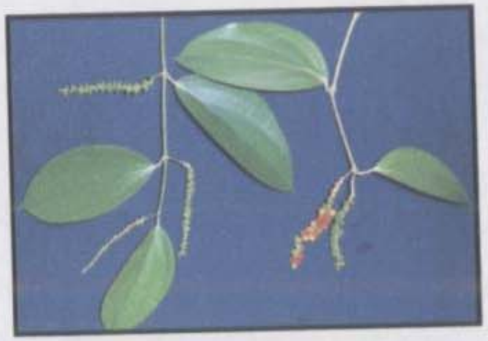


Table 28. 2 Morpho-taxonomic descriptions of cv. Kottanadan

1. *Passport details*

1.1 Name of the cultivar:	**Kottanadan**
1.2 Collection number	**1489**
1.3 I.C. Number:	316890
1.4 Place of collection:	Palode Trivandrum

2. Morphological descriptors

2.1 Vine height (cm):	300.0
2.2 Branching habit:	Dimorphic
2.3 Shoot tip colour:	Light purple
2.4 Runner shoot production:	Many
2.5 Holding capacity:	Strong
2.6 Adventitious root production:	Many
2.7 Lateral branch habit:	Horizontal
2.8 Lateral branch length (cm):	45.5
2.9 Number of nodes per lateral branch:	27.0
2.10 Leaf petiole length (cm):	1.9
2.11 Leaf length (cm):	14.4
2.12 Leaf width (cm):	8.6
2.13 Leaf lamina shape:	Ovate-elliptic
2.14 Leaf base shape:	Round
2.15 Leaf margin:	Entire
2.16 Type of veining:	Acrodromous
2.17 Leaf texture:	Glabrous coriaceous

3. *Reproductive characters*

3.1 Spike orientation:	Pendant
3.2 Spike shape:	Filiform
3.3 Spike colour:	Green
3.4 Spike length (cm):	7.5
3.5 Type of hermaphroditism:	Predominantly bisexual
3.6 Peduncle length (cm):	1.5
3.7 Number of spikes/lateral branch :	8.0
3.8 Flower arrangement:	Free
3.9 Number of stamens:	Two
3.10 Spike texture:	Glabrous
3.11 Bract type:	Cupular with decurrent base
3.12 Flower nature:	Sessile
3.13 Fruit setting (%):	40.0
3.14 Number of developed fruits per spike:	54.0
3.15 Number of berries per ten spikes:	314.0
3.16 Fruit shape:	Round

4. *Quantitative characters*

4.1 100 fruit weight (g):	12.5
4.2 100 fruit volume (ml):	12.0
4.3. Green yield per plant:	0.85
4.4 Dry weight of 100 berries:	3.5

5. *Qualitative characters*

5.1 Essential oil (%):	4.38
5.2 Oleoresin (%):	10.03
5.3 Piperine (%):	1.73

Table 28. 3 Morpho-taxonomic descriptions of cv. Balankotta

1. Passport details	
1.1 Name of the cultivar:	**Balankotta**
1.2 Collection number:	**0971**
1.3 I.C. Number:	316562
1.4 Place of collection:	Ambalavayal ,Wayanad
2. Morphological descriptors	
2.1 Vine height (cm):	250.0
2.2 Branching habit:	Polymorphic
2.3 Shoot tip colour:	Light purple
2.4 Runner shoot production:	Few
2.5 Holding capacity:	Strong
2.6 Adventitious root production:	Many
2.7 Lateral branch habit:	Horizontal
2.8 Lateral branch length (cm):	38.0
2.9 Number of nodes per lateral branch:	17.0
2.10 Leaf petiole length (cm):	2.1
2.11 Leaf length (cm):	14.5
2.12 Leaf width (cm):	9.5
2.13 Leaf lamina shape:	Ovate-lanceolate
2.14 Leaf base shape:	Acute
2.15 Leaf margin:	Entire
2.16 Type of veining:	Acrodromous
2.17 Leaf texture:	Glabrous coriaceous
3. Reproductive characters	
3.1 Spike orientation:	Pendant
3.2 Spike shape:	Filiform
3.3 Spike colour:	Greenish Yellow
3.4 Spike length (cm):	11.0
3.5 Type of hermaphroditism:	Bisexual flowers only
3.6 Peduncle length (cm):	1.2
3.7 Number of spikes/lateral branch :	19.0
3.8 Flower arrangement:	Free
3.9 Number of stamens:	Two
3.10 Spike texture:	Glabrous
3.11 Bract type:	Cupular with decurrent base
3.12 Flower nature:	Sessile
3.13 Fruit setting (%):	55.0
3.14 Number of developed fruits per spike:	56.0
3.15 Number of berries per ten spikes:	563.0
3.16 Fruit shape:	Round
4. Quantitative characters	
4.1 100 fruit weight (g):	13.0
4.2 100 fruit volume (ml):	12.0
4.3. Green yield per plant:	2.84
4.4 Dry weight of 100 berries:	3.5

5. Qualitative characters	
5.1 Essential oil (%):	2.5
5.2 Oleoresin (%):	9.58
5.3 Piperine (%):	2.71

Table 28. 4 Morpho-taxonomic descriptions of cv. Neelamundi

1. *Passport details*	
1.1 Name of the cultivar:	**Neelamundi**
1.2 Collection number:	**0809**
1.3 I.C. Number:	316473
1.4 Place of collection:	Kanjikuzhi, Idukki
2. *Morphological descriptors*	
2.1 Vine height (cm):	320.0
2.2 Branching habit:	Dimorphic
2.3 Shoot tip colour:	Light purple
2.4 Runner shoot production:	Many
2.5 Holding capacity:	Strong
2.6 Adventitious root production:	Many
2.7 Lateral branch habit:	Horizontal
2.8 Lateral branch length (cm):	36.8
2.9 Number of nodes per lateral branch:	18
2.10 Leaf petiole length (cm):	3.8
2.11 Leaf length (cm):	15.3
2.12 Leaf width (cm):	9.6
2.13 Leaf lamina shape:	Ovate-elliptic
2.14 Leaf base shape:	Round
2.15 Leaf margin:	Entire
2.16 Type of veining:	Acrodromous
2.17 Leaf texture:	Glabrous coriaceous

3. *Reproductive characters*	
3.1 Spike orientation:	Pendant
3.2 Spike shape:	Filiform
3.3 Spike colour:	Green
3.4 Spike length (cm):	9.8
3.5 Type of hermaphroditism:	Predominantly bisexual
3.6 Peduncle length (cm):	0.5
3.7 Number of spikes/lateral branch :	9.4
3.8 Flower arrangement:	Free
3.9 Number of stamens:	Two
3.10 Spike texture:	Glabrous
3.11 Bract type:	Cupular with decurrent base
3.12 Flower nature:	Sessile
3.13 Fruit setting (%):	45
3.14 Number of developed fruits per spike:	32
3.15 Number of berries per ten spikes:	322
3.16 Fruit shape:	Round
4. *Quantitative characters*	
4.1 100 fruit weight (g):	17.0
4.2 100 fruit volume (ml):	18.0
4.3. Green yield per plant:	0.64
4.4 Dry weight of 100 berries:	7.0

5. *Qualitative characters*	
5.1 Essential oil (%):	3.3
5.2 Oleoresin (%):	13.9
5.3 Piperine (%):	4.6

Table 28. 5 Morpho-taxonomic descriptions of cv. Kuthiravally

1. *Passport details*

1.1 Name of the cultivar:	**Kuthiravally**
1.2 Collection number:	**0849**
1.3 I.C. Number:	316498
1.4 Place of collection:	Thaliparamba, Kannur

2. Morphological descriptors

2.1 Vine height (cm):	165.0
2.2 Branching habit:	Polymorphic
2.3 Shoot tip colour:	Light purple
2.4 Runner shoot production:	Few
2.5 Holding capacity:	Strong
2.6 Adventitious root production:	Many
2.7 Lateral branch habit:	Horizontal
2.8 Lateral branch length (cm):	29.8
2.9 Number of nodes per lateral branch:	7.0
2.10 Leaf petiole length (cm):	1.5
2.11 Leaf length (cm):	12.5
2.12 Leaf width (cm):	9.0
2.13 Leaf lamina shape:	Ovate-lanceolate
2.14 Leaf base shape:	Round
2.15 Leaf margin:	Entire
2.16 Type of veining:	Acrodromous
2.17 Leaf texture:	Glabrous coriaceous

3. *Reproductive characters*

3.1 Spike orientation:	Pendant
3.2 Spike shape:	Filiform
3.3 Spike colour:	Greenish yellow
3.4 Spike length (cm):	14.2
3.5 Type of hermaphroditism:	Bisexual flowers only
3.6 Peduncle length (cm):	0.9
3.7 Number of spikes/lateral branch :	9.0
3.8 Flower arrangement:	Free
3.9 Number of stamens:	Two
3.10 Spike texture:	Glabrous
3.11 Bract type:	Cupular with decurrent base
3.12 Flower nature:	Sessile
3.13 Fruit setting (%):	80.0
3.14 Number of developed fruits per spike:	68.0
3.15 Number of berries per ten spikes:	428.0
3.16 Fruit shape:	Round

4. *Quantitative characters*

4.1 100 fruit weight (g):	11.5
4.2 100 fruit volume (ml):	10.0
4.3. Green yield per plant:	1.83
4.4 Dry weight of 100 berries:	6.0

5. *Qualitative characters*

5.1 Essential oil (%):	1.58
5.2 Oleoresin (%):	7.15
5.3 Piperine (%):	1.52

Table 28. 6 Morpho-taxonomic descriptions of cv Kalluvally

1. *Passport details*

1.1 Name of the cultivar:	**Kalluvally**
1.2 Collection number:	**1513**
1.3 I.C. Number:	316914
1.4 Place of collection:	Peruvannamuzhi, Calicut

2. *Morphological descriptors*

2.1 Vine height (cm):	600.0
2.2 Branching habit:	Dimorphic
2.3 Shoot tip colour:	Dark purple
2.4 Runner shoot production:	Few
2.5 Holding capacity:	Strong
2.6 Adventitious root production:	Many
2.7 Lateral branch habit:	Hanging
2.8 Lateral branch length (cm):	38.4
2.9 Number of nodes per lateral branch:	36.0
2.10 Leaf petiole length (cm):	1.8
2.11 Leaf length (cm):	16.2
2.12 Leaf width (cm):	8.7
2.13 Leaf lamina shape:	Ovate-elliptic
2.14 Leaf base shape:	Acute
2.15 Leaf margin:	Entire
2.16 Type of veining:	Acrodromous
2.17 Leaf texture:	Glabrous coriaceous

3. *Reproductive characters*

3.1 Spike orientation:	Pendant
3.2 Spike shape:	Filiform
3.3 Spike colour:	Green
3.4 Spike length (cm):	15.8
3.5 Type of hermaphroditism:	Predominantly bisexual
3.6 Peduncle length (cm):	1.1
3.7 Number of spikes/lateral branch :	7.0
3.8 Flower arrangement:	Free
3.9 Number of stamens:	Two
3.10 Spike texture:	Glabrous
3.11 Bract type:	Cupular with decurrent base
3.12 Flower nature:	Sessile
3.13 Fruit setting (%):	60.0
3.14 Number of developed fruits per spike:	81.0
3.15 Number of berries per ten spikes:	592.0
3.16 Fruit shape:	Round

4. *Quantitative characters*

4.1 100 fruit weight (g):	12.0
4.2 100 fruit volume (ml):	12.0
4.3. Green yield per plant:	0.768
4.4 Dry weight of 100 berries:	3.0

5. *Qualitative characters*

5.1 Essential oil (%):	1.40
5.2 Oleoresin (%):	5.94
5.3 Piperine (%):	1.01

Table 28. 7 Morpho-taxonomic descriptions of cv Arakulam munda

1. *Passport details*

1.1 Name of the cultivar:	**Arakulammunda**
1.2 Collection number:	**0894**
1.3 I.C. Number:	316525
1.4 Place of collection:	Wayanad, Kerala

2. Morphological descriptors

2.1 Vine height (cm):	165.00
2.2 Branching habit:	Polymorphic
2.3 Shoot tip colour:	Light purple
2.4 Runner shoot production:	Few
2.5 Holding capacity:	Strong
2.6 Adventitious root production:	Many
2.7 Lateral branch habit:	Horizontal
2.8 Lateral branch length (cm):	40.5
2.9 Number of nodes per lateral branch:	11.0
2.10 Leaf petiole length (cm):	1.5
2.11 Leaf length (cm):	15.0
2.12 Leaf width (cm):	9.2
2.13 Leaf lamina shape:	Ovate-elliptic
2.14 Leaf base shape:	Round
2.15 Leaf margin:	Entire
2.16 Type of veining:	Acrodromous
2.17 Leaf texture:	Glabrous coriaceous

3. *Reproductive characters*

3.1 Spike orientation:	Pendant
3.2 Spike shape:	Filiform
3.3 Spike colour:	Greenish yellow
3.4 Spike length (cm):	13.0
3.5 Type of hermaphroditism:	Bisexual flowers only
3.6 Peduncle length (cm):	1.7
3.7 Number of spikes/lateral branch :	8.0
3.8 Flower arrangement:	Free
3.9 Number of stamens:	Two
3.10 Spike texture:	Glabrous
3.11 Bract type:	Cupular with decurrent base
3.12 Flower nature:	Sessile
3.13 Fruit setting (%):	72.0
3.14 Number of developed fruits per spike:	69.0
3.15 Number of berries per ten spikes:	595.0
3.16 Fruit shape:	Round

4. *Quantitative characters*

4.1 100 fruit weight (g):	12.0
4.2 100 fruit volume (ml):	10.0
4.3. Green yield per plant:	0.797
4.4 Dry weight of 100 berries:	4.0

5. *Qualitative characters*

5.1 Essential oil (%):	1.3
5.2 Oleoresin (%):	5.76
5.3 Piperine (%):	1.8

Table 28. 8 Morpho-taxonomic descriptions of cv Narayakodi

1. *Passport details*

1.1 Name of the cultivar:	**Narayakodi**
1.2 Collection number:	**0965**
1.3 I.C. Number:	316559
1.4 Place of collection:	Poozhithode, Calicut

2. Morphological descriptors

2.1 Vine height (cm):	550.0
2.2 Branching habit:	Polymorphic
2.3 Shoot tip colour:	Light purple
2.4 Runner shoot production:	Few
2.5 Holding capacity:	Strong
2.6 Adventitious root production:	Many
2.7 Lateral branch habit:	Erect
2.8 Lateral branch length (cm):	63.3
2.9 Number of nodes per lateral branch:	13.0
2.10 Leaf petiole length (cm):	1.9
2.11 Leaf length (cm):	12.2
2.12 Leaf width (cm):	7.5
2.13 Leaf lamina shape:	Ovate-lanceolate
2.14 Leaf base shape:	Acute
2.15 Leaf margin:	Entire
2.16 Type of veining:	Acrodromous
2.17 Leaf texture:	Glabrous coriaceous

3. *Reproductive characters*

3.1 Spike orientation:	Pendant
3.2 Spike shape:	Filiform
3.3 Spike colour:	Green
3.4 Spike length (cm):	9.0
3.5 Type of hermaphroditism:	Predominantly female
3.6 Peduncle length (cm):	2.3
3.7 Number of spikes/lateral branch :	7.0
3.8 Flower arrangement:	Free
3.9 Number of stamens:	Two
3.10 Spike texture:	Hirtellous
3.11 Bract type:	Cupular with decurrent base
3.12 Flower nature:	Sessile
3.13 Fruit setting (%):	60.0
3.14 Number of developed fruits per spike:	37.0
3.15 Number of berries per ten spikes:	440.0
3.16 Fruit shape:	Round

4. *Quantitative characters*

4.1 100 fruit weight (g):	14.0
4.2 100 fruit volume (ml):	15.0
4.3. Green yield per plant:	0.844
4.4 Dry weight of 100 berries:	6.0

5. *Qualitative characters*

5.1 Essential oil (%):	3.8
5.2 Oleoresin (%):	7.8
5.3 Piperine (%):	3.4

Table 28. 9 Morpho-taxonomic descriptions of cv Thommankodi

1. *Passport details*

1.1 Name of the cultivar:	**Thommankodi**
1.2 Collection number:	**0966**
1.3 I.C. Number:	316560
1.4 Place of collection:	Chakittapara, Calicut

2. Morphological descriptors

2.1 Vine height (cm):	175.0
2.2 Branching habit:	Polymorphic
2.3 Shoot tip colour:	Light purple
2.4 Runner shoot production:	Many
2.5 Holding capacity:	Strong
2.6 Adventitious root production:	Many
2.7 Lateral branch habit:	Horizontal
2.8 Lateral branch length (cm):	41.0
2.9 Number of nodes per lateral branch:	8.0
2.10 Leaf petiole length (cm):	1.3
2.11 Leaf length (cm):	15.5
2.12 Leaf width (cm):	11.8
2.13 Leaf lamina shape:	Ovate
2.14 Leaf base shape:	Round
2.15 Leaf margin:	Entire
2.16 Type of veining:	Acrodromous
2.17 Leaf texture:	Glabrous coriaceous

3. *Reproductive characters*

3.1 Spike orientation:	Pendant
3.2 Spike shape:	Filiform
3.3 Spike colour:	Greenish yellow
3.4 Spike length (cm):	9.5
3.5 Type of hermaphroditism:	Bisexual flowers only
3.6 Peduncle length (cm):	2.0
3.7 Number of spikes/lateral branch :	12.0
3.8 Flower arrangement:	Free
3.9 Number of stamens:	Two
3.10 Spike texture:	Glabrous
3.11 Bract type:	Cupular with decurrent base
3.12 Flower nature:	Sessile
3.13 Fruit setting (%):	78
3.14 Number of developed fruits per spike:	54.0
3.15 Number of berries per ten spikes:	308.0
3.16 Fruit shape:	Round

4. *Quantitative characters*

4.1 100 fruit weight (g):	11.5
4.2 100 fruit volume (ml):	10.0
4.3. Green yield per plant:	0.637
4.4 Dry weight of 100 berries:	3.5

5. *Qualitative characters*

5.1 Essential oil (%):	3.00
5.2 Oleoresin (%):	9.36
5.3 Piperine (%):	2.04

Table 28. 10 Morpho-taxonomic descriptions of cv Perambramunda

1. *Passport details*

1.1 Name of the cultivar:	**Perambramunda**
1.2 Collection number:	**1240**
1.3 I.C. Number:	316717
1.4 Place of collection:	Pulpally ,Wayanad

2. *Morphological descriptors*

2.1 Vine height (cm):	350.0
2.2 Branching habit:	Polymorphic
2.3 Shoot tip colour:	Light purple
2.4 Runner shoot production:	Few
2.5 Holding capacity:	Strong
2.6 Adventitious root production:	Many
2.7 Lateral branch habit:	Erect
2.8 Lateral branch length (cm):	29.0
2.9 Number of nodes per lateral branch:	9.0
2.10 Leaf petiole length (cm):	1.66
2.11 Leaf length (cm):	11.4
2.12 Leaf width (cm):	5.8
2.13 Leaf lamina shape:	Ovate-elliptic
2.14 Leaf base shape:	Round
2.15 Leaf margin:	Entire
2.16 Type of veining:	Acrodromous
2.17 Leaf texture:	Glabrous coriaceous

3. *Reproductive characters*

3.1 Spike orientation:	Pendant
3.2 Spike shape:	Filiform
3.3 Spike colour:	Green
3.4 Spike length (cm):	9.0
3.5 Type of hermaphroditism:	Predominantly female
3.6 Peduncle length (cm):	0.8
3.7 Number of spikes/lateral branch :	12.85
3.8 Flower arrangement:	Free
3.9 Number of stamens:	2
3.10 Spike texture:	Glabrous
3.11 Bract type:	Cupular with decurrent base
3.12 Flower nature:	Sessile
3.13 Fruit setting (%):	70.0
3.14 Number of developed fruits per spike:	71.0
3.15 Number of berries per ten spikes:	689.0
3.16 Fruit shape:	Round

4. *Quantitative characters*

4.1 100 fruit weight (g):	15.0
4.2 100 fruit volume (ml):	14.0
4.3 Green yield per plant:	0.95
4.4 Dry weight of 100 berries:	5.0

5. *Qualitative characters*

5.1 Essential oil (%):	4.72
5.2 Oleoresin (%):	8.92
5.3 Piperine (%):	2.05

Table 28. 11 Morpho-taxonomic descriptions of cv Poonjaranmunda

1. ***Passport details***

1.1 Name of the cultivar:	**Poonjaranmunda**
1.2 Collection number:	**0845**
1.3 I.C. Number:	316495
1.4 Place of collection:	Taliparamba, Kannur

2. ***Morphological descriptors***

2.1 Vine height (cm):	290.0
2.2 Branching habit:	Polymorphic
2.3 Shoot tip colour:	Light purple
2.4 Runner shoot production:	Few
2.5 Holding capacity:	Strong
2.6 Adventitious root production:	Many
2.7 Lateral branch habit:	Horizontal
2.8 Lateral branch length (cm):	33.5
2.9 Number of nodes per lateral branch:	7.0
2.10 Leaf petiole length (cm):	3.3
2.11 Leaf length (cm):	14.5
2.12 Leaf width (cm):	9.0
2.13 Leaf lamina shape:	Ovate-elliptic
2.14 Leaf base shape:	Round
2.15 Leaf margin:	Entire
2.16 Type of veining:	Acrodromous
2.17 Leaf texture:	Glabrous coriaceous

3. ***Reproductive characters***

3.1 Spike orientation:	Pendant
3.2 Spike shape:	Filiform
3.3 Spike colour:	Greenish yellow
3.4 Spike length (cm):	6.3
3.5 Type of hermaphroditism:	Predominantly female
3.6 Peduncle length (cm):	1.2
3.7 Number of spikes/lateral branch :	11.5
3.8 Flower arrangement:	Free
3.9 Number of stamens:	Two
3.10 Spike texture:	Glabrous
3.11 Bract type:	Cupular with decurrent base
3.12 Flower nature:	Sessile
3.13 Fruit setting (%):	69.0
3.14 Number of developed fruits per spike:	49.0
3.15 Number of berries per ten spikes:	465.0
3.16 Fruit shape:	Round

4. ***Quantitative characters***

4.1 100 fruit weight (g):	14.0
4.2 100 fruit volume (ml):	13.0
4.3. Green yield per plant:	1.44
4.4 Dry weight of 100 berries:	3.5

5. ***Qualitative characters***

5.1 Essential oil (%):	2.75
5.2 Oleoresin (%):	11.32
5.3 Piperine (%):	2.72

Table 28. 12 Morpho-taxonomic descriptions of cv Valiyakaniyakadan

1. *Passport details*

1.1 Name of the cultivar:	**Valiyakaniyakadan**
1.2 Collection number:	**1102**
1.3 I.C. Number:	316645
1.4 Place of collection:	Perikattoor, Wayanad

2. *Morphological descriptors*

2.1 Vine height (cm):	400.0
2.2 Branching habit:	Polymorphic
2.3 Shoot tip colour:	Light purple
2.4 Runner shoot production:	Many
2.5 Holding capacity:	Strong
2.6 Adventitious root production	Many
2.7 Lateral branch habit:	Horizontal
2.8 Lateral branch length (cm):	37.0
2.9 Number of nodes per lateral branch:	22.0
2.10 Leaf petiole length (cm):	1.5
2.11 Leaf length (cm):	12.5
2.12 Leaf width (cm):	9.0
2.13 Leaf lamina shape:	Ovate- elliptic
2.14 Leaf base shape:	Round
2.15 Leaf margin:	Entire
2.16 Type of veining:	Acrodromous
2.17 Leaf texture:	Glabrous coriaceous

3. *Reproductive characters*

3.1 Spike orientation:	Pendant
3.2 Spike shape:	Filiform
3.3 Spike colour:	Greenish yellow
3.4 Spike length (cm):	9.0
3.5 Type of hermaphroditism:	Bisexual flowers only
3.6 Peduncle length (cm):	1.3
3.7 Number of spikes/lateral branch :	11.0
3.8 Flower arrangement:	Free
3.9 Number of stamens:	Two
3.10 Spike texture:	Glabrous
3.11 Bract type:	Cupular with decurrent base
3.12 Flower nature:	Sessile
3.13 Fruit setting (%):	72.0
3.14 Number of developed fruits per spike:	60.0
3.15 Number of berries per ten spikes:	387.0
3.16 Fruit shape:	Round

4. *Quantitative characters*

4.1 100 fruit weight (g):	15.5
4.2 100 fruit volume (ml):	15.0
4.3. Green yield per plant:	0.785
4.4 Dry weight of 100 berries:	4.0

5. *Qualitative characters*

5.1 Essential oil (%):	3.5
5.2 Oleoresin (%):	10.8
5.3 Piperine (%):	2.23

Table 28. 13 Morpho-taxonomic descriptions of cv Cheriyakaniyakadan

1. *Passport details*

1.1 Name of the cultivar:	**Cheriyakaniyakadan**
1.2 Collection number:	**0853**
1.3 I.C. Number:	316499
1.4 Place of collection:	Kannur

2. *Morphological descriptors*

2.1 Vine height (cm):	100.0
2.2 Branching habit:	Dimorphic
2.3 Shoot tip colour:	Light purple
2.4 Runner shoot production:	Few
2.5 Holding capacity:	Weak
2.6 Adventitious root production:	Few
2.7 Lateral branch habit:	Horizontal
2.8 Lateral branch length (cm):	36.5
2.9 Number of nodes per lateral branch:	28.0
2.10 Leaf petiole length (cm):	3.1
2.11 Leaf length (cm):	10.5
2.12 Leaf width (cm):	5.2
2.13 Leaf lamina shape:	Ovate-lanceolate
2.14 Leaf base shape:	Round
2.15 Leaf margin:	Entire
2.16 Type of veining:	Acrodromous
2.17 Leaf texture:	Glabrous coriaceous

3. *Reproductive characters*

3.1 Spike orientation:	Pendant
3.2 Spike shape:	Filiform
3.3 Spike colour:	Greenish yellow
3.4 Spike length (cm):	9.84
3.5 Type of hermaphroditism:	Predominantly female
3.6 Peduncle length (cm):	0.7
3.7 Number of spikes/lateral branch :	18.0
3.8 Flower arrangement:	Free
3.9 Number of stamens:	Two
3.10 Spike texture:	Glabrous
3.11 Bract type:	Cupular with decurrent base
3.12 Flower nature:	Sessile
3.13 Fruit setting (%):	55.0
3.14 Number of developed fruits per spike:	57.0
3.15 Number of berries per ten spikes:	565.0
3.16 Fruit shape:	Round

4. *Quantitative characters*

4.1 100 fruit weight (g):	12.5
4.2 100 fruit volume (ml):	11.8
4.3. Green yield per plant:	0.95
4.4 Dry weight of 100 berries:	4.8

5. *Qualitative characters*

5.1 Essential oil (%):	3.1
5.2 Oleoresin (%):	8.0
5.3 Piperine (%);	2.9

Table 28. 14 Morpho-taxonomic descriptions of cv Uthirankotta

1. ***Passport details***

1.1	Name of the cultivar:	**Uthirankotta**
1.2	Collection number:	**0320**
1.3	I.C. Number:	316721
1.4	Place of collection:	Chettali, Coorg

2. ***Morphological descriptors***

2.1	Vine height (cm):	320.0
2.2	Branching habit:	Polymorphic
2.3	Shoot tip colour:	Dark purple
2.4	Runner shoot production:	Many
2.5	Holding capacity:	Strong
2.6	Adventitious root production:	Many
2.7	Lateral branch habit:	Erect
2.8	Lateral branch length (cm):	25.4
2.9	Number of nodes per lateral branch:	10.4
2.10	Leaf petiole length (cm):	1.6
2.11	Leaf length (cm):	12.6
2.12	Leaf width (cm):	6.5
2.13	Leaf lamina shape:	Ovate-lanceolate
2.14	Leaf base shape:	Round
2.15	Leaf margin:	Entire
2.16	Type of veining:	Acrodromous
2.17	Leaf texture:	Glabrous coriaceous

3. ***Reproductive characters***

3.1	Spike orientation:	Pendant
3.2	Spike shape:	Filiform
3.3	Spike colour:	Green
3.4	Spike length (cm):	8.5
3.5	Type of hermaphroditism:	Predominantly female
3.6	Peduncle length (cm):	1.22
3.7	Number of spikes/lateral branch :	2.8
3.8	Flower arrangement:	Free
3.9	Number of stamens:	Two
3.10	Spike texture:	Glabrous
3.11	Bract type:	Cupular with decurrent base
3.12	Flower nature:	Sessile
3.13	Fruit setting (%):	90.0
3.14	Number of developed fruits per spike:	14.0
3.15	Number of berries per ten spikes:	331.0
3.16	Fruit shape:	Round

4. ***Quantitative characters***

4.1	100 fruit weight (g):	11.0
4.2	100 fruit volume (ml):	10.0
4.3.	Green yield per plant:	0.856
4.4	Dry weight of 100 berries:	5.5

5. ***Qualitative characters***

5.1	Essential oil (%):	3.53
5.2	Oleoresin (%):	8.11
5.3	Piperine (%):	2.17

Table 28. 15 Morpho-taxonomic descriptions of Panniyur-1

1. *Passport details*

1.1 Name of the cultivar:	**Panniyur-1**
1.2 Collection number:	**0874**
1.3 I.C. Number:	316508
1.4 Place of collection:	Panniyur Res. Station Kerala

2. *Morphological descriptors*

2.1 Vine height (cm):	500.0
2.2 Branching habit:	Polymorphic
2.3 Shoot tip colour:	Greenish yellow
2.4 Runner shoot production:	Many
2.5 Holding capacity:	Strong
2.6 Adventitious root production:	Many
2.7 Lateral branch habit:	Erect
2.8 Lateral branch length (cm):	61.2
2.9 Number of nodes per lateral branch:	13.0
2.10 Leaf petiole length (cm):	2.5
2.11 Leaf length (cm):	17.2
2.12 Leaf width (cm):	11.5
2.13 Leaf lamina shape:	Cordate
2.14 Leaf base shape:	Cordate
2.15 Leaf margin:	Entire
2.16 Type of veining:	Acrodromous
2.17 Leaf texture:	Glabrous coriaceous

3. *Reproductive characters*

3.1 Spike orientation:	Pendant
3.2 Spike shape:	Filiform
3.3 Spike colour:	Greenish yellow
3.4 Spike length (cm):	12.2
3.5 Type of hermaphroditism:	Predominantly bisexual
3.6 Peduncle length (cm):	1.7
3.7 Number of spikes/lateral branch :	7.0
3.8 Flower arrangement:	Free
3.9 Number of stamens:	Two
3.10 Spike texture:	Glabrous
3.11 Bract type:	Cupular with decurrent base
3.12 Flower nature:	Sessile
3.13 Fruit setting (%):	95.0
3.14 Number of developed fruits per spike:	86.0
3.15 Number of berries per ten spikes:	885.0
3.16 Fruit shape:	Round

4. *Quantitative characters*

4.1 100 fruit weight (g):	15.5
4.2 100 fruit volume (ml):	14.5
4.3. Green yield per plant:	2.2
4.4 Dry weight of 100 berries:	5.5

5. *Qualitative characters*

5.1 Essential oil (%):	3.5
5.2 Oleoresin (%):	11.8
5.3 Piperine (%):	5.3

Table 28. 16 Morpho-taxonomic descriptions of Panniyur-2

1. *Passport details*

1.1 Name of the cultivar:	**Panniyur-2**
1.2 Collection number:	4127
1.3 I.C. Number:	317082
1.4 Place of collection:	Panniyur Res. Station Kerala

2. *Morphological descriptors*

2.1 Vine height (cm):	475.0
2.2 Branching habit:	Dimorphic
2.3 Shoot tip colour:	Light purple
2.4 Runner shoot production:	Many
2.5 Holding capacity:	Strong
2.6 Adventitious root production:	Many
2.7 Lateral branch habit:	Horizontal
2.8 Lateral branch length (cm):	49.0
2.9 Number of nodes per lateral branch:	29.0
2.10 Leaf petiole length (cm):	1.3
2.11 Leaf length (cm):	12.0
2.12 Leaf width (cm):	8.5
2.13 Leaf lamina shape:	Cordate
2.14 Leaf base shape:	Round
2.15 Leaf margin:	Entire
2.16 Type of veining:	Acrodromous
2.17 Leaf texture:	Glabrous coriaceous

3. *Reproductive characters*

3.1 Spike orientation:	Pendant
3.2 Spike shape:	Filiform
3.3 Spike colour:	Green
3.4 Spike length (cm):	12.4
3.5 Type of hermaphroditism:	Bisexual flowers only
3.6 Peduncle length (cm):	1.1
3.7 Number of spikes/lateral branch :	14.0
3.8 Flower arrangement:	Free
3.9 Number of stamens:	Two
3.10 Spike texture:	Glabrous
3.11 Bract type:	Cupular with decurrent base
3.12 Flower nature:	Sessile
3.13 Fruit setting (%):	Sessile
3.14 Number of developed fruits per spike:	82.0
3.15 Number of berries per ten spikes:	676.0
3.16 Fruit shape:	Round

4. *Quantitative characters*

4.1 100 fruit weight (g):	12.5
4.2 100 fruit volume (ml):	12.0
4.3. Green yield per plant:	4.2
4.4 Dry weight of 100 berries:	4.5

5. *Qualitative characters*

5.1 Essential oil (%):	4.94
5.2 Oleoresin (%):	13.3
5.3 Piperine (%):	3.39

Table 28. 17 Morpho-taxonomic descriptions of Panniyur-3

1. *Passport details*

1.1 Name of the cultivar:	**Panniyur-3**
1.2 Collection number:	**4128**
1.3 I.C. Number:	317083
1.4 Place of collection:	Panniyur Res. Station Kerala

2. Morphological descriptors

2.1 Vine height (cm):	550.0
2.2 Branching habit:	Dimorphic
2.3 Shoot tip colour:	Light purple
2.4 Runner shoot production:	Many
2.5 Holding capacity:	Strong
2.6 Adventitious root production:	Many
2.7 Lateral branch habit:	Horizontal
2.8 Lateral branch length (cm):	51.0
2.9 Number of nodes per lateral branch:	32.0
2.10 Leaf petiole length (cm):	1.3
2.11 Leaf length (cm):	11.5
2.12 Leaf width (cm):	8.3
2.13 Leaf lamina shape:	Ovate-elliptic
2.14 Leaf base shape:	Round
2.15 Leaf margin:	Entire
2.16 Type of veining:	Acrodromous
2.17 Leaf texture:	Glabrous coriaceous

3. *Reproductive characters*

3.1 Spike orientation:	Pendant
3.2 Spike shape:	Filiform
3.3 Spike colour:	Green
3.4 Spike length (cm):	12.5
3.5 Type of hermaphroditism:	Predominantly bisexual
3.6 Peduncle length (cm):	0.98
3.7 Number of spikes/lateral branch :	15.0
3.8 Flower arrangement:	Free
3.9 Number of stamens:	Two
3.10 Spike texture:	Glabrous
3.11 Bract type:	Cupular with decurrent base
3.12 Flower nature:	Sessile
3.13 Fruit setting (%):	85.7
3.14 Number of developed fruits per spike:	68.1
3.15 Number of berries per ten spikes:	682.0
3.16 Fruit shape:	Round

4. *Quantitative characters*

4.1 100 fruit weight (g):	12.7
4.2 100 fruit volume (ml):	12.0
4.3. Green yield per plant:	3.4
4.4 Dry weight of 100 berries:	4.9

5. *Qualitative characters*

5.1 Essential oil (%):	3.1
5.2 Oleoresin (%):	12.7
5.3 Piperine (%):	5.2

Table 28. 18 Morpho-taxonomic descriptions of Panniyur-4

1. *Passport details*

1.1 Name of the cultivar:	**Panniyur-4**
1.2 Collection number:	**4129**
1.3 I.C. Number:	317084
1.4 Place of collection:	Panniyur , Kerala

2. *Morphological descriptors*

2.1 Vine height (cm):	470.0
2.2 Branching habit:	Dimorphic
2.3 Shoot tip colour:	Light purple
2.4 Runner shoot production:	Many
2.5 Holding capacity:	Strong
2.6 Adventitious root production	Many
2.7 Lateral branch habit:	Horizontal
2.8 Lateral branch length (cm):	50.0
2.9 Number of nodes per lateral branch:	25.0
2.10 Leaf petiole length (cm):	2.6
2.11 Leaf length (cm):	17.4
2.12 Leaf width (cm):	12.0
2.13 Leaf lamina shape:	Ovate
2.14 Leaf base shape:	Round
2.15 Leaf margin:	Entire
2.16 Type of veining:	Acrodromous
2.17 Leaf texture:	Glabrous coriaceous

3. *Reproductive characters*

3.1 Spike orientation:	Pendant
3.2 Spike shape:	Filiform
3.3 Spike colour:	Greenish yellow
3.4 Spike length (cm):	9.4
3.5 Type of hermaphroditism:	Predominantly bisexual
3.6 Peduncle length (cm):	1.3
3.7 Number of spikes/lateral branch :	14.0
3.8 Flower arrangement:	Free
3.9 Number of stamens:	Two
3.10 Spike texture:	Glabrous
3.11 Bract type:	Cupular with decurrent base
3.12 Fløwer nature:	Sessile
3.13 Fruit setting (%):	86.0
3.14 Number of developed fruits per spike:	69.8
3.15 Number of berries per ten spikes:	678
3.16 Fruit shape:	Round

4. *Quantitative characters*

4.1 100 fruit weight (g):	11.6
4.2 100 fruit volume (ml):	11.2
4.3. Green yield per plant:	2.2
4.4 Dry weight of 100 berries:	5.1

5. *Qualitative characters*

5.1 Essential oil (%):	2.1
5.2 Oleoresin (%):	9.2
5.3 Piperine (%):	4.4

Table 28. 19 Morpho-taxonomic descriptions of Panniyur-5

1. *Passport details*

1.1 Name of the cultivar:	**Panniyur-5**
1.2 Collection number:	**4130**
1.3 I.C. Number:	317085
1.4 Place of collection:	Panniyur Res. Station Kerala

2. *Morphological descriptors*

2.1 Vine height (cm):	478.0
2.2 Branching habit:	Dimorphic
2.3 Shoot tip colour:	Light purple
2.4 Runner shoot production:	Many
2.5 Holding capacity:	Strong
2.6 Adventitious root production:	Many
2.7 Lateral branch habit:	Hanging
2.8 Lateral branch length (cm):	51.0
2.9 Number of nodes per lateral branch:	29.0
2.10 Leaf petiole length (cm):	1.5
2.11 Leaf length (cm):	11.5
2.12 Leaf width (cm):	9.0
2.13 Leaf lamina shape:	Ovate
2.14 Leaf base shape:	Round
2.15 Leaf margin:	Entire
2.16 Type of veining:	Acrodromous
2.17 Leaf texture:	Glabrous coriaceous

3. *Reproductive characters*

3.1 Spike orientation:	Pendant
3.2 Spike shape:	Filiform
3.3 Spike colour:	Greenish yellow
3.4 Spike length (cm):	13.1
3.5 Type of hermaphroditism:	Predominantly bisexual
3.6 Peduncle length (cm):	2.1
3.7 Number of spikes/lateral branch :	12.0
3.8 Flower arrangement:	Free
3.9 Number of stamens:	Two
3.10 Spike texture:	Glabrous
3.11 Bract type:	Cupular with decurrent base
3.12 Flower nature:	Sessile
3.13 Fruit setting (%):	58.2
3.14 Number of developed fruits per spike:	42.5
3.15 Number of berries per ten spikes:	412
3.16 Fruit shape:	Round

4. *Quantitative characters*

4.1 100 fruit weight (g):	11.8
4.2 100 fruit volume (ml):	10.5
4.3. Green yield per plant:	1.8
4.4 Dry weight of 100 berries:	5.2

5. *Qualitative characters*

5.1 Essential oil (%):	3.8
5.2 Oleoresin (%):	12.33
5.3 Piperine (%):	5.5

Table 28. 20 Morpho-taxonomic descriptions of Sreekara

1. *Passport details*

1.1 Name of the cultivar:	**Sreekara**
1.2 Collection number:	K.S. 14
1.3 Accession number:	2027
1.4 Place of collection:	Calicut

2. *Morphological descriptors*

2.1 Vine height (cm):	175.0
2.2 Branching habit:	Dimorphic
2.3 Shoot tip colour:	Light purple
2.4 Runner shoot production:	Many
2.5 Holding capacity:	Strong
2.6 Adventitious root production:	Many
2.7 Lateral branch habit:	Horizontal
2.8 Lateral branch length (cm):	42.0
2.9 Number of nodes per lateral branch:	12.0
2.10 Leaf petiole length (cm):	1.6
2.11 Leaf length (cm):	11.6
2.12 Leaf width (cm):	6.2
2.13 Leaf lamina shape:	Ovate- lanceolate
2.14 Leaf base shape:	Round
2.15 Leaf margin:	Entire
2.16 Type of veining:	Acrodromous
2.17 Leaf texture:	Glabrous coriaceous

3. *Reproductive characters*

3.1 Spike orientation:	Pendant
3.2 Spike shape:	Filiform
3.3 Spike colour:	Green
3.4 Spike length (cm):	8.6
3.5 Type of hermaphroditism:	Predominantly bisexual
3.6 Peduncle length (cm):	1.4
3.7 Number of spikes/lateral branch :	19.0
3.8 Flower arrangement:	Free
3.9 Number of stamens:	Two
3.10 Spike texture:	Glabrous
3.11 Bract type:	Cupular with decurrent base
3.12 Flower nature:	Sessile
3.13 Fruit setting (%):	63.4
3.14 Number of developed fruits per spike:	61.0
3.15 Number of berries per ten spikes:	612.0
3.16 Fruit shape:	Round

4. *Quantitative characters*

4.1 100 fruit weight (g):	10.8
4.2 100 fruit volume (ml):	10.6
4.3. Green yield per plant:	1.6
4.4 Dry weight of 100 berries:	3.78

5. *Qualitative characters*

5.1 Essential oil (%):	5.1
5.2 Oleoresin (%):	13.0
5.3 Piperine (%):	7.0

Table 28. 21 Morpho-taxonomic descriptions of Subhakara

1. *Passport details*

1.1 Name of the cultivar:	**Subhakara**
1.2 Collection number:	KS-27
1.3 I.C. Number:	2027
1.4 Place of collection:	Palghat

2. *Morphological descriptors*

2.1 Vine height (cm):	185.0
2.2 Branching habit:	Dimorphic
2.3 Shoot tip colour:	Light purple
2.4 Runner shoot production:	Many
2.5 Holding capacity:	Strong
2.6 Adventitious root production:	Many
2.7 Lateral branch habit:	Horizontal
2.8 Lateral branch length (cm):	45.0
2.9 Number of nodes per lateral branch:	14.0
2.10 Leaf petiole length (cm):	1.6
2.11 Leaf length (cm):	12.3
2.12 Leaf width (cm):	6.5
2.13 Leaf lamina shape:	Ovate-lanceolate
2.14 Leaf base shape:	Round
2.15 Leaf margin:	Entire
2.16 Type of veining:	Acrodromous
2.17 Leaf texture:	Glabrous coriaceous

3. *Reproductive characters*

3.1 Spike orientation:	Pendant
3.2 Spike shape:	Filiform
3.3 Spike colour:	Green
3.4 Spike length (cm):	7.7
3.5 Type of hermaphroditism:	Bisexual only
3.6 Peduncle length (cm):	1.5
3.7 Number of spikes/lateral branch :	22.0
3.8 Flower arrangement:	Free
3.9 Number of stamens:	Two
3.10 Spike texture:	Glabrous
3.11 Bract type:	Cupular with decurrent base
3.12 Flower nature:	Sessile
3.13 Fruit setting (%):	67.9
3.14 Number of developed fruits per spike:	68.0
3.15 Number of berries per ten spikes:	684.0
3.16 Fruit shape:	Round

4. *Quantitative characters*

4.1 100 fruit weight (g):	10.3
4.2 100 fruit volume (ml):	10.0
4.3. Green yield per plant:	1.4
4.4 Dry weight of 100 berries:	3.65

5. *Qualitative characters*

5.1 Essential oil (%):	3.4
5.2 Oleoresin (%):	12.4
5.3 Piperine (%):	6.0

Table 28. 22 Morpho-taxonomic descriptions of Panchami

1. *Passport details*

1.1 Name of the cultivar:	**Panchami**
1.2 Collection number:	0856
1.3 I.C. Number:	316500
1.4 Place of collection:	Wayanad

2. *Morphological descriptors*

2.1 Vine height (cm):	180
2.2 Branching habit:	Polymorphic
2.3 Shoot tip colour:	Light purple
2.4 Runner shoot production:	Many
2.5 Holding capacity:	Strong
2.6 Adventitious root production:	Many
2.7 Lateral branch habit:	Horizontal
2.8 Lateral branch length (cm):	54.0
2.9 Number of nodes per lateral branch:	28.0
2.10 Leaf petiole length (cm):	1.5
2.11 Leaf length (cm):	15.5
2.12 Leaf width (cm):	8.4
2.13 Leaf lamina shape:	Ovate-elliptic
2.14 Leaf base shape:	Round
2.15 Leaf margin:	Entire
2.16 Type of veining:	Acrodromous
2.17 Leaf texture:	Glabrous coriaceous

3. *Reproductive characters*

3.1 Spike orientation:	Pendant
3.2 Spike shape:	Filiform
3.3 Spike colour:	Green
3.4 Spike length (cm):	11.3
3.5 Type of hermaphroditism:	Bisexual only
3.6 Peduncle length (cm):	1.4
3.7 Number of spikes/lateral branch :	14.0
3.8 Flower arrangement:	Free
3.9 Number of stamens:	Two
3.10 Spike texture:	Glabrous
3.11 Bract type:	Cupular with decurrent base
3.12 Flower nature:	Sessile
3.13 Fruit setting (%):	82.4
3.14 Number of developed fruits per spike:	84.0
3.15 Number of berries per ten spikes:	838.0
3.16 Fruit shape:	Round

4. *Quantitative characters*

4.1 100 fruit weight (g):	10.7
4.2 100 fruit volume (ml):	10.6
4.3. Green yield per plant:	3.2
4.4 Dry weight of 100 berries:	3.63

5. *Qualitative characters*

5.1 Essential oil (%):	3.4
5.2 Oleoresin (%):	12.5
5.3 Piperine (%):	4.7

Table 28. 23 Morpho-taxonomic descriptions of Pournami

1. *Passport details*

1.1 Name of the cultivar:	**Pournami**
1.2 Collection number:	0812
1.3 I.C. Number:	316475
1.4 Place of collection:	Idukki

2. Morphological descriptors

2.1 Vine height (cm):	185.0
2.2 Branching habit:	Polymorphic
2.3 Shoot tip colour:	Light purple
2.4 Runner shoot production:	Few
2.5 Holding capacity:	Strong
2.6 Adventitious root production:	Many
2.7 Lateral branch habit:	Erect
2.8 Lateral branch length (cm):	36.6
2.9 Number of nodes per lateral branch:	14.3
2.10 Leaf petiole length (cm):	2.1
2.11 Leaf length (cm):	15.6
2.12 Leaf width (cm):	8.5
2.13 Leaf lamina shape:	Ovate-lanceolate
2.14 Leaf base shape:	Round
2.15 Leaf margin:	Entire
2.16 Type of veining:	Acrodromous
2.17 Leaf texture:	Glabrous coriaceous

3. *Reproductive characters*

3.1 Spike orientation:	Pendant
3.2 Spike shape:	Filiform
3.3 Spike colour:	Green
3.4 Spike length (cm):	12.0
3.5 Type of hermaphroditism:	Predominantly bisexual
3.6 Peduncle length (cm):	1.5
3.7 Number of spikes/lateral branch :	13.0
3.8 Flower arrangement:	Free
3.9 Number of stamens:	Two
3.10 Spike texture:	Glabrous
3.11 Bract type:	Cupular with decurrent base
3.12 Flower nature:	Sessile
3.13 Fruit setting (%):	68.0
3.14 Number of developed fruits per spike:	79.0
3.15 Number of berries per ten spikes:	784.0
3.16 Fruit shape:	Round

4. *Quantitative characters*

4.1 100 fruit weight (g):	13.0
4.2 100 fruit volume (ml):	12.8
4.3. Green yield per plant:	1.6
4.4 Dry weight of 100 berries:	4.03

5. *Qualitative characters*

5.1 Essential oil (%):	3.4
5.2 Oleoresin (%):	13.8
5.3 Piperine (%):	4.1

Table 28. 24 Morpho-taxonomic descriptions of PLD-2

1. *Passport details*

1.1 Name of the cultivar:	**PLD-2**
1.2 Collection number:	**5055**
1.3 I.C. Number:	317278
1.4 Place of collection:	Palode, Trivandrum

2. Morphological descriptors

2.1 Vine height (cm):	300.0
2.2 Branching habit:	Dimorphic
2.3 Shoot tip colour:	Light purple
2.4 Runner shoot production:	Few
2.5 Holding capacity:	Strong
2.6 Adventitious root production:	Many
2.7 Lateral branch habit:	Horizontal
2.8 Lateral branch length (cm):	45.5
2.9 Number of nodes per lateral branch:	27.0
2.10 Leaf petiole length (cm):	1.9
2.11 Leaf length (cm):	14.4
2.12 Leaf width (cm):	8.6
2.13 Leaf lamina shape:	Ovate-elliptic
2.14 Leaf base shape:	Round
2.15 Leaf margin:	Entire
2.16 Type of veining:	Acrodromous
2.17 Leaf texture:	Glabrous coriaceous

3. *Reproductive characters*

3.1 Spike orientation:	Pendant
3.2 Spike shape:	Filiform
3.3 Spike colour:	Light green
3.4 Spike length (cm):	8.33
3.5 Type of hermaphroditism:	Predominantly bisexual
3.6 Peduncle length (cm):	1.5
3.7 Number of spikes/lateral branch :	14.0
3.8 Flower arrangement:	Free
3.9 Number of stamens:	Two
3.10 Spike texture:	Glabrous
3.11 Bract type:	Cupular with decurrent base
3.12 Flower nature:	Sessile
3.13 Fruit setting (%):	87.7
3.14 Number of developed fruits per spike:	72.0
3.15 Number of berries per ten spikes:	742.0
3.16 Fruit shape:	Round

4. *Quantitative characters*

4.1 100 fruit weight (g):	12.5
4.2 100 fruit volume (ml):	12.0
4.3. Green yield per plant:	1.62
4.4 Dry weight of 100 berries:	3.5

5. *Qualitative characters*

5.1 Essential oil (%):	4.8
5.2 Oleoresin (%):	15.45
5.3 Piperine (%):	3.0

Table 28. 25 Morpho-taxonomic descriptions of cv Doddagai

1. *Passport details*

1.1	Name of the cultivar:	**Doddagai**
1.2	Collection number:	**0867**
1.3	I.C. Number:	316506
1.4	Place of collection:	Sirsi, Karnataka

2. *Morphological descriptors*

2.1	Vine height (cm):	280.0
2.2	Branching habit:	Polymorphic
2.3	Shoot tip colour:	Light purple
2.4	Runner shoot production:	Few
2.5	Holding capacity:	Strong
2.6	Adventitious root production:	Many
2.7	Lateral branch habit:	Erect
2.8	Lateral branch length (cm):	35.2
2.9	Number of nodes per lateral branch:	14.0
2.10	Leaf petiole length (cm):	1.78
2.11	Leaf length (cm):	13.7
2.12	Leaf width (cm):	9.84
2.13	Leaf lamina shape:	Ovate-lanceolate
2.14	Leaf base shape:	Round
2.15	Leaf margin:	Entire
2.16	Type of veining:	Acrodromous
2.17	Leaf texture:	Glabrous coriaceous

3. *Reproductive characters*

3.1	Spike orientation:	Pendant
3.2	Spike shape:	Filiform
3.3	Spike colour:	Green
3.4	Spike length (cm):	7.0
3.5	Type of hermaphroditism:	Predominantly bisexual
3.6	Peduncle length (cm):	1.2
3.7	Number of spikes/lateral branch :	4.0
3.8	Flower arrangement:	Free
3.9	Number of stamens:	Two
3.10	Spike texture:	Glabrous
3.11	Bract type:	Cupular with decurrent base
3.12	Flower nature:	Two
3.13	Fruit setting (%):	40.0
3.14	Number of developed fruits per spike:	25.0
3.15	Number of berries per ten spikes:	142.0
3.16	Fruit shape:	Round

4. *Quantitative characters*

4.1	100 fruit weight (g):	15.0
4.2	100 fruit volume (ml):	14.0
4.3.	Green yield per plant:	0.75
4.4	Dry weight of 100 berries:	6.5

5. *Qualitative characters*

5.1	Essential oil (%):	-
5.2	Oleoresin (%):	-
5.3	Piperine (%):	-

Table 28. 26 Morpho-taxonomic descriptions of cv Kaniyakadan

1. Passport details

1.1 Name of the cultivar:	**Kaniyakadan**
1.2 Collection number:	**0887**
1.3 I.C. Number:	316519
1.4 Place of collection:	Pathanamthitta

2. Morphological descriptors

2.1 Vine height (cm):	420.0
2.2 Branching habit:	Polymorphic
2.3 Shoot tip colour:	Light purple
2.4 Runner shoot production:	Few
2.5 Holding capacity:	Weak
2.6 Adventitious root production:	Few
2.7 Lateral branch habit:	Erect
2.8 Lateral branch length (cm):	18.6
2.9 Number of nodes per lateral branch:	7.0
2.10 Leaf petiole length (cm):	1.5
2.11 Leaf length (cm):	10.0
2.12 Leaf width (cm):	6.0
2.13 Leaf lamina shape:	Ovate-lanceolate
2.14 Leaf base shape:	Round
2.15 Leaf margin:	Entire
2.16 Type of veining:	Acrodromous
2.17 Leaf texture:	Glabrous coriaceous

3. Reproductive characters

3.1 Spike orientation:	Pendant
3.2 Spike shape:	Filiform
3.3 Spike colour:	Greenish yellow
3.4 Spike length (cm):	7.8
3.5 Type of hermaphroditism:	Predominantly bisexual
3.6 Peduncle length (cm):	1.3
3.7 Number of spikes/lateral branch :	8.0
3.8 Flower arrangement:	Free
3.9 Number of stamens:	Two
3.10 Spike texture:	Glabrous
3.11 Bract type:	Cupular with decurrent base
3.12 Flower nature:	Sessile
3.13 Fruit setting (%):	55
3.14 Number of developed fruits per spike:	48.0
3.15 Number of berries per ten spikes:	398.0
3.16 Fruit shape:	Round

4. Quantitative characters

4.1 100 fruit weight (g):	13.0
4.2 100 fruit volume (ml):	12.0
4.3. Green yield per plant:	0.870
4.4 Dry weight of 100 berries:	4.8

5. Qualitative characters

5.1 Essential oil (%):	-
5.2 Oleoresin (%):	-
5.3 Piperine (%):	-

Table 28. 27 Morpho-taxonomic descriptions of cv Chumalakodi

1. *Passport details*

1.1 Name of the cultivar:	**Chumalakodi**
1.2 Collection number:	**0990**
1.3 I.C. Number:	316573
1.4 Place of collection:	Ernakulam

2. *Morphological descriptors*

2.1 Vine height (cm):	360.0
2.2 Branching habit:	Polymorphic
2.3 Shoot tip colour:	Dark purple
2.4 Runner shoot production:	Many
2.5 Holding capacity:	Strong
2.6 Adventitious root production:	Many
2.7 Lateral branch habit:	Erect
2.8 Lateral branch length (cm):	38.6
2.9 Number of nodes per lateral branch:	26.0
2.10 Leaf petiole length (cm):	2.1
2.11 Leaf length (cm):	12.8
2.12 Leaf width (cm):	7.0
2.13 Leaf lamina shape:	Ovate-elliptic
2.14 Leaf base shape:	Round
2.15 Leaf margin:	Entire
2.16 Type of veining:	Acrodromous
2.17 Leaf texture:	Glabrous coriaceous

3. *Reproductive characters*

3.1 Spike orientation:	Pendant
3.2 Spike shape:	Filiform
3.3 Spike colour:	Green
3.4 Spike length (cm):	7.5
3.5 Type of hermaphroditism:	Predominantly female
3.6 Peduncle length (cm):	1.3
3.7 Number of spikes/lateral branch :	6.0
3.8 Flower arrangement:	Free
3.9 Number of stamens:	Two
3.10 Spike texture:	Glabrous
3.11 Bract type:	Cupular with decurrent base
3.12 Flower nature:	Sessile
3.13 Fruit setting (%):	50.0
3.14 Number of developed fruits per spike:	47.0
3.15 Number of berries per ten spikes:	158.0
3.16 Fruit shape:	Round

4. *Quantitative characters*

4.1 100 fruit weight (g):	14.3
4.2 100 fruit volume (ml):	13.0
4.3. Green yield per plant:	0.95
4.4 Dry weight of 100 berries:	5.2

5. *Qualitative characters*

5.1 Essential oil (%):	-
5.2 Oleoresin (%):	-
5.3 Piperine (%):	-

Table 28. 28 Morpho-taxonomic descriptions of cv Nedumchola

1. *Passport details*

1.1 Name of the cultivar:	**Nedumchola**
1.2 Collection number:	**1085**
1.3 I.C. Number:	316631
1.4 Place of collection:	Kottayam, Kerala

2. *Morphological descriptors*

2.1 Vine height (cm):	190.0
2.2 Branching habit:	Dimorphic
2.3 Shoot tip colour:	Light purple
2.4 Runner shoot production:	Few
2.5 Holding capacity:	Strong
2.6 Adventitious root production:	Many
2.7 Lateral branch habit:	Horizontal
2.8 Lateral branch length (cm):	28.0
2.9 Number of nodes per lateral branch:	11.0
2.10 Leaf petiole length (cm):	2.0
2.11 Leaf length (cm):	8.0
2.12 Leaf width (cm):	6.0
2.13 Leaf lamina shape:	Ovate-lanceolate
2.14 Leaf base shape:	Acute
2.15 Leaf margin:	Entire
2.16 Type of veining:	Acrodromous
2.17 Leaf texture:	Glabrous coriaceous

3. *Reproductive characters*

3.1 Spike orientation:	Pendant
3.2 Spike shape:	Filiform
3.3 Spike colour:	Green
3.4 Spike length (cm):	5.5
3.5 Type of hermaphroditism:	Predominantly bisexual
3.6 Peduncle length (cm):	0.5
3.7 Number of spikes/lateral branch :	12.0
3.8 Flower arrangement:	Free
3.9 Number of stamens:	Two
3.10 Spike texture:	Glabrous
3.11 Bract type:	Cupular with decurrent base
3.12 Flower nature:	Sessile
3.13 Fruit setting (%):	60.0
3.14 Number of developed fruits per spike:	35.0
3.15 Number of berries per ten spikes:	141.0
3.16 Fruit shape:	Round

4. *Quantitative characters*

4.1 100 fruit weight (g):	9.0
4.2 100 fruit volume (ml):	9.0
4.3. Green yield per plant:	0.566
4.4 Dry weight of 100 berries:	3.0

5. *Qualitative characters*

5.1 Essential oil (%):	8.77
5.2 Oleoresin (%):	17. 04
5.3 Piperine (%):	2.95

Table 28. 29 Morpho-taxonomic descriptions of cv Malamundi

1. Passport details

1.1 Name of the cultivar:	**Malamundi**
1.2 Collection number:	1159
1.3 I.C. Number:	316668
1.4 Place of collection:	Kottayam, Kerala

2. Morphological descriptors

2.1 Vine height (cm):	163.0
2.2 Branching habit:	Polymorphic
2.3 Shoot tip colour:	Light purple
2.4 Runner shoot production:	Few
2.5 Holding capacity:	Strong
2.6 Adventitious root production:	Many
2.7 Lateral branch habit:	Horizontal
2.8 Lateral branch length (cm):	31.0
2.9 Number of nodes per lateral branch:	9.0
2.10 Leaf petiole length (cm):	2.1
2.11 Leaf length (cm):	16.5
2.12 Leaf width (cm):	10.0
2.13 Leaf lamina shape:	Ovate-elliptic
2.14 Leaf base shape:	Round
2.15 Leaf margin:	Entire
2.16 Type of veining:	Acrodromous
2.17 Leaf texture:	Glabrous coriaceous

3. Reproductive characters

3.1 Spike orientation:	Pendant
3.2 Spike shape:	Filiform
3.3 Spike colour:	Greenish yellow
3.4 Spike length (cm):	7.5
3.5 Type of hermaphroditism:	Predominantly bisexual
3.6 Peduncle length (cm):	1.1
3.7 Number of spikes/lateral branch :	7.0
3.8 Flower arrangement:	Free
3.9 Number of stamens:	Two
3.10 Spike texture:	Glabrous
3.11 Bract type:	Cupular with decurrent base
3.12 Flower nature:	Sessile
3.13 Fruit setting (%):	48.0
3.14 Number of developed fruits per spike:	49.0
3.15 Number of berries per ten spikes:	158.0
3.16 Fruit shape:	Round

4. Quantitative characters

4.1 100 fruit weight (g):	12.0
4.2 100 fruit volume (ml):	12.0
4.3. Green yield per plant:	0.27
4.4 Dry weight of 100 berries:	6.0

5. Qualitative characters

5.1 Essential oil (%):	-
5.2 Oleoresin (%):	-
5.3 Piperine (%):	-

Table 28. 30 Morpho-taxonomic descriptions of cv Karuthapirimunda

1. *Passport details*

1.1 Name of the cultivar:	**Karuthapirimunda**
1.2 Collection number:	1253
1.3 I.C. Number:	316727
1.4 Place of collection:	Kodagu, Karnataka

2. Morphological descriptors

2.1 Vine height (cm):	110
2.2 Branching habit:	Polymorphic
2.3 Shoot tip colour:	Light purple
2.4 Runner shoot production:	Many
2.5 Holding capacity:	Weak
2.6 Adventitious root production	Few
2.7 Lateral branch habit:	Horizontal
2.8 Lateral branch length (cm):	43.0
2.9 Number of nodes per lateral branch:	37.0
2.10 Leaf petiole length (cm):	1.3
2.11 Leaf length (cm):	14.0
2.12 Leaf width (cm):	8.6
2.13 Leaf lamina shape:	Ovate
2.14 Leaf base shape:	Round
2.15 Leaf margin:	Entire
2.16 Type of veining:	Acrodromous
2.17 Leaf texture:	Glabrous coriaceous

3. *Reproductive characters*

3.1 Spike orientation:	Pendant
3.2 Spike shape:	Filiform
3.3 Spike colour:	Green
3.4 Spike length (cm):	9.4
3.5 Type of hermaphroditism:	Predominantly bisexual
3.6 Peduncle length (cm):	1.2
3.7 Number of spikes/lateral branch :	5.0
3.8 Flower arrangement:	Free
3.9 Number of stamens:	Two
3.10 Spike texture:	Glabrous
3.11 Bract type:	Cupular with decurrent base
3.12 Flower nature:	Sessile
3.13 Fruit setting (%):	68.0
3.14 Number of developed fruits per spike:	78.0
3.15 Number of berries per ten spikes:	768.0
3.16 Fruit shape:	Round

4. *Quantitative characters*

4.1 100 fruit weight (g):	13.1
4.2 100 fruit volume (ml):	12.5
4.3. Green yield per plant:	1.2
4.4 Dry weight of 100 berries:	5.1

5. *Qualitative characters*

5.1 Essential oil (%):	-
5.2 Oleoresin (%):	-
5.3 Piperine (%):	-

Table 28. 31 Morpho-taxonomic descriptions of cv TMB-IV

1. *Passport details*

1.1 Name of the cultivar:	**TMB-IV**
1.2 Collection number:	1262
1.3 I.C. Number:	316733
1.4 Place of collection:	Thaliparamba, Kannur

2. Morphological descriptors

2.1 Vine height (cm):	120.0
2.2 Branching habit:	Dimorphic
2.3 Shoot tip colour:	Light purple
2.4 Runner shoot production:	Few
2.5 Holding capacity:	Strong
2.6 Adventitious root production:	Many
2.7 Lateral branch habit:	Horizontal
2.8 Lateral branch length (cm):	36.0
2.9 Number of nodes per lateral branch:	23.0
2.10 Leaf petiole length (cm):	1.9
2.11 Leaf length (cm):	17.5
2.12 Leaf width (cm):	10.1
2.13 Leaf lamina shape:	Ovate
2.14 Leaf base shape:	Round
2.15 Leaf margin:	Entire
2.16 Type of veining:	Acrodromous
2.17 Leaf texture:	Glabrous coriaceous

3. *Reproductive characters*

3.1 Spike orientation:	Pendant
3.2 Spike shape:	Filiform
3.3 Spike colour:	Greenish yellow
3.4 Spike length (cm):	12.6
3.5 Type of hermaphroditism:	Predominantly bisexual
3.6 Peduncle length (cm):	1.6
3.7 Number of spikes/lateral branch :	18.0
3.8 Flower arrangement:	Free
3.9 Number of stamens:	Two
3.10 Spike texture:	Glabrous
3.11 Bract type:	Cupular with decurrent base
3.12 Flower nature:	Sessile
3.13 Fruit setting (%):	30.0
3.14 Number of developed fruits per spike:	23.0
3.15 Number of berries per ten spikes:	223.0
3.16 Fruit shape:	Round

4. *Quantitative characters*

4.1 100 fruit weight (g):	14.0
4.2 100 fruit volume (ml):	13.0
4.3. Green yield per plant:	0.640
4.4 Dry weight of 100 berries:	4.2

5. *Qualitative characters*

5.1 Essential oil (%):	2.5
5.2 Oleoresin (%):	10.8
5.3 Piperine (%):	5.8

Table 28. 32 Morpho-taxonomic descriptions of cv Valiyakarimunda

1. *Passport details*

1.1 Name of the cultivar:	**Valiyakarimunda**
1.2 Collection number:	**1353**
1.3 I.C. Number:	316781
1.4 Place of collection:	Kodagu, Karnataka

2. *Morphological descriptors*

2.1 Vine height (cm):	190.0
2.2 Branching habit:	Dimorphic
2.3 Shoot tip colour:	Light purple
2.4 Runner shoot production:	Many
2.5 Holding capacity:	Strong
2.6 Adventitious root production:	Many
2.7 Lateral branch habit:	Erect
2.8 Lateral branch length (cm):	37.0
2.9 Number of nodes per lateral branch:	18.0
2.10 Leaf petiole length (cm):	2.2
2.11 Leaf length (cm):	18.5
2.12 Leaf width (cm):	12.3
2.13 Leaf lamina shape:	Ovate-lanceolate
2.14 Leaf base shape:	Round
2.15 Leaf margin:	Entire
2.16 Type of veining:	Acrodromous
2.17 Leaf texture:	Glabrous coriaceous

3. *Reproductive characters*

3.1 Spike orientation:	Pendant
3.2 Spike shape:	Filiform
3.3 Spike colour:	Greenish yellow
3.4 Spike length (cm):	12.1
3.5 Type of hermaphroditism:	Predominantly bisexual
3.6 Peduncle length (cm):	1.2
3.7 Number of spikes/lateral branch :	18.0
3.8 Flower arrangement:	Free
3.9 Number of stamens:	Two
3.10 Spike texture:	Glabrous
3.11 Bract type:	Cupular with decurrent base
3.12 Flower nature:	Sessile
3.13 Fruit setting (%):	68.0
3.14 Number of developed fruits per spike:	72.0
3.15 Number of berries per ten spikes:	698.0
3.16 Fruit shape:	Round

4. *Quantitative characters*

4.1 100 fruit weight (g):	16.0
4.2 100 fruit volume (ml):	16.0
4.3. Green yield per plant:	0.737
4.4 Dry weight of 100 berries:	3.7

5. *Qualitative characters*

5.1 Essential oil (%):	3.16
5.2 Oleoresin (%):	7.09
5.3 Piperine (%):	1.67

Table 28. 33 Morpho-taxonomic descriptions of cv Karimkotta

1. *Passport details*

1.1 Name of the cultivar:	**Karimkotta**
1.2 Collection number:	**1592**
1.3 I.C. Number:	316953
1.4 Place of collection:	Kozhikode, Kerala

2. *Morphological descriptors*

2.1 Vine height (cm):	190.0
2.2 Branching habit:	Dimorphic
2.3 Shoot tip colour:	Light Purple
2.4 Runner shoot production:	Many
2.5 Holding capacity:	Strong
2.6 Adventitious root production	Many
2.7 Lateral branch habit:	Erect
2.8 Lateral branch length (cm):	38.2
2.9 Number of nodes per lateral branch:	16.0
2.10 Leaf petiole length (cm):	1.8
2.11 Leaf length (cm):	13.77
2.12 Leaf width (cm):	7.18
2.13 Leaf lamina shape:	Ovate
2.14 Leaf base shape:	Round
2.15 Leaf margin:	Entire
2.16 Type of veining:	Acrodromous
2.17 Leaf texture:	Glabrous coriaceous

3. *Reproductive characters*

3.1 Spike orientation:	Pendant
3.2 Spike shape:	Filiform
3.3 Spike colour:	Greenish yellow
3.4 Spike length (cm):	8.2
3.5 Type of hermaphroditism:	Predominantly bisexual
3.6 Peduncle length (cm):	1.8
3.7 Number of spikes/lateral branch :	8.0
3.8 Flower arrangement:	Free
3.9 Number of stamens:	Two
3.10 Spike texture:	Glabrous
3.11 Bract type:	Cupular with decurrent base
3.12 Flower nature:	Sessile
3.13 Fruit setting (%):	65.0
3.14 Number of developed fruits per spike:	64.0
3.15 Number of berries per ten spikes:	638.0
3.16 Fruit shape:	Round

4. *Quantitative characters*

4.1 100 fruit weight (g):	10.0
4.2 100 fruit volume (ml):	9.0
4.3. Green yield per plant:	1.61
4.4 Dry weight of 100 berries:	3.0

5. *Qualitative characters*

5.1 Essential oil (%):	3.52
5.2 Oleoresin (%):	8.49
5.3 Piperine (%):	1.58

Lateral branch habit

The lateral branches were either erect, horizontal or hanging types. It was erect in Narayakodi, Perambramunda, Uthirankotta, Panniyur-1, Pournami, Doddagai, Kaniyakadan, Chumalakodi, TMB-IV and Valiyakarimunda. Lateral branches were of hanging nature in cv. Kalluvally and Panniyur-5. The remaining cultivars were having intermediary type of lateral branches.

In black pepper the lateral branch habit in addition to its nature can also be altered by increased length of the lateral branches and heavy fruit set making branches to droop down due to weight.

Lateral branch length

Among the cultivars studied, length of lateral branches ranged from 25.4 cm to 63.3 cm with an average of 39.78 cm. Lateral branch length was minimum in cv. Uthirankotta and minimum length was observed in cv. Narayakodi.

No. of nodes/lateral branch

Number of nodes/lateral branches varied from plant to plant. It ranged from 7-37 with a mean of 18.5. Lowest number of nodes was observed cvs. Kuthiravally, Poonjaranmunda and Kaniyakadan and largest number of nodes occurred in cv. Karuthapirimunda.

Leaf petiole length

Length of petiole varied from cultivar to cultivar. Shortest petiole (1.3 cm) was observed in cv. Karuthapirimunda, cv. Thommankodi, Panniyur-3 where as the longest petiole (3.8 cm) was recorded in cv. Neelamundi and the average petiole length was 1.9 cm.

Leaf length

The shortest leaves were found in cv. Nedumchola (8.0 cm) and the longest leaves were there in cv. TMBIV (18.5 cm). Average leaf lengths among the cultivars studied were 13.6 cm.

Leaf width

Width of the leaves ranged from 5.8 cm (cv. Cheriyakanniakadan) to 12.3 cm (TMB IV).

Leaf lamina shape

Leaf shape was ovate in cultivars Thommankodi, Panniyur-4, Panniyur-5, Panchami, Valiyakarimunda and Karimkotta. Ovate-elliptic types of leaves were recorded from cvs. Kottanadan, Neelamundi, Arakulam munda, Kalluvally, Perambramunda, Poonjaranmunda, Valiyakaniyakadan, Panniyur-3, Pournami, PLD-2 and Malamundi. Leaf shape was ovate lanceolate in cvs. Karimunda, Balankotta, Kuthiravally, Narayakodi, Sreekara, Subhakara, Doddagai, Kaniyakadan, Chumalakodi, Nedumchola and TMB-IV. Cordate leaves were observed in the cv. Panniyur-1 and Panniyur-2.

Leaf base

Among the 33 cultivars, studied, 29 of them were having round leaf base. The improved hybrid variety Panniyur-1 was with cordate type of leaf base and cvs. Balankotta, Kalluvally and Narayakodi were having acute leaf base.

Leaf margin

Leaf margin was even (entire) in all the cultivars studied except the central Travancore variety 'Narayakodi' where the leaf margin was wavy.

Type of veining

Acrodromous type of veining was noticed in all the cultivars used for the study.

Leaf texture

Leaf texture was invariably glabrous coriaceous in all the cultivars.

Spike orientation, spike shape and spike colour

Pendant filiform spikes characterize all the cultivated black pepper varieties. Colour of the tender spikes were green in 18 cultivars and it was greenish yellow in the remaining 15 cultivars. Of these, Panniyur-1 could clearly be distinguished with its predominant yellowish white spike which slowly turns green after fruit set.

Spike length

Among the genotypes studied, the shortest spike was observed in cv. Karimunda (5.0 cm) followed by cv. Nedumchola (5.5 cm) and spike length was maximum in cv. Kalluvally (15.8 cm). The average length of spike was 9.5 cm.

Peduncle length

Wide range of variability observed in the peduncle length of different cultivars. It ranged from 0.5 cm to 2.3 cm. In cvs. Neelamundi and Nedumchola, the petiole length was 0.5 cm where as the maximum petiole length of 2.3 cm was noticed in cv. Narayakodi and the average petiole length of the cultivars studied were 1.2 cm.

Type of hermaphroditism

In the cultivated black pepper, variations do occur with regard to the percent of male, female and bisexual flowers. The flowers on the spikes were predominantly bisexual in 20 cultivars. Only bisexual flowers were produced in cvs. Karimunda, Balankotta, Kuthiravally, Arakulammunda, Thommankodi and Valiyakaniyakadan. However, predominantly female flowers were recorded on the spikes in cvs. Narayakodi, Perambramunda, Cheriyakanniakadan, Uthirankotta and Chumalakodi.

Number of spikes per lateral branches

Maximum number of spikes/lateral branches was observed in the improved varieties Subhakara (22 nos.) followed by Sreekara (19). However, the cv. Doddagai was having the lowest number of spikes (4) in its lateral branches.

Flower arrangement

Flowers were free in all the accessions studied and all were sessile. Stigma and two stamens represent each flower. Spikes were glabrous in all the cultivars studied. All the accessions have cupular bracts with decurrent base.

Fruit setting

Fruit setting percentage of accessions ranged from 30% (Karimkotta) to 95% (Panniyur-1).

No. of developed berries/spike

Development and maturity of fruits are related to the percentage of bisexual: female: male ratio, In some cases especially P-1, due to environmental fluctuations the anthers failed to emerge in excessive shade and in some rare cases the anthers came out much before the emergence of gynoecium resulting in failure of self pollination, thus making self pollination. Number of fruits per spike ranged from 14 nos (cv. Uthirankotta) to 86 (Panniyur-1).

Fruit shape

Shape of fruits was round in all the accessions. In cv. Narayakodi, though the fruit shape was round, the persistent stigma made it appear as pointed at the pistal length, hence the name 'Naraya' kodi.

100 fruit weight

Weight of the berries was evaluated by taking hundred fruits. Weight of hundred fruits ranged from 9 g (Nedumchola) to 17 g (Neelamundi).

Dry weight

Dry weight of 100 berries ranged from 3.0 g to 7.01 g. Dry weight was low in Valiyakarimunda and the highest dry weight value was recorded in cv Neelamundi.

Essential oil, oleoresin and piperine

Percentage of essential oil ranged from 1.3 (Arakulammunda) to 5.1 (Sreekara). Oleoresin percentage ranged from 5.76 to 15.45. Oleoresin content was maximum in the improved variety PLD-2 and it was minimum in cv. Arakulammunda.

Piperine content ranged from 1.61 to 7.0. Lowest percentage of Piperine content recorded in cv. Kalluvally and the highest value recorded in the improved variety Sreekara.

Table 29.1 Morphological observations on major black pepper cultivars

Character	1	2	3	4	5	6	7	8	9	10	11	12
2.2	1	1	2	1	2	1	2	2	2	2	2	2
2.3	2	2	2	2	2	2	2	2	2	2	2	2
2.4	2	2	1	2	1	1	1	1	2	1	1	2
2.5	2	2	2	2	2	2	2	2	2	1	2	2
2.6	2	2	2	2	2	2	2	2	2	2	2	2
2.7	2	2	2	2	2	3	2	1	2	1	2	2
2.8	27.30	45.50	38.00	36.80	29.80	38.40	40.50	63.30	41.00	29.00	33.50	37.00
2.9	15.00	27.00	17.00	18.00	7.00	36.00	11.00	13.00	8.00	9.00	7.00	22.00
2.10	1.70	1.90	2.10	3.80	1.50	1.80	1.50	1.90	1.30	1.66	3.30	1.50
2.11	11.00	14.40	12.00	15.35	12.50	16.20	15.00	12.20	15.40	11.40	14.50	12.50
2.12	7.30	8.60	9.50	9.60	9.00	8.70	9.20	7.50	11.80	5.80	9.00	9.00
2.13	3	2	3	2	3	2	2	3	1	2	2	2
2.14	1	1	3	1	1	3	1	3	1	1	1	1
2.15	1	1	1	1	1	1	1	2	1	1	1	1
2.16	1	1	1	1	1	1	1	1	1	1	1	1
2.17	1	1	1	1	1	1	1	1	1	1	1	1
3.1	2	2	2	2	2	2	2	2	2	2	2	2
3.2	1	1	1	1	1	1	11	1	1	1	·1	1
3.3	1	1	2	1	2	1	2	1	2	1	2	2

2.1. Vine height, 2.2. Branching type, 2.3. Orthotropic Shoot tip colour, 2.4. Runner shoot production, 2.5. Holding capacity, 2.6. Adventitious root production, 2.7. Lateral branch habit, 2.8. Lateral branch length, 2.9. Number of nodes, 2.10. Leaf petiole length, 2.11. Leaf length, 2.12. Leaf width, 2.13. Leaf lamina shape, 2.14. Leaf base shape, 2.15. Leaf margin, 2.16. Type of veining, 2.17. Leaf texture, 3.1. Spike orientation, 3.2. Spike shape, 3.3. Spike colour

Table 29. 1. (Continued from previous page)

3.4	5.00	7.50	11.00	9.80	7.00	15.80	13.00	9.00	9.50	9.00	6.30	9.00
3.5	3	6	3	6	3	6	3	5	3	5	5	3
3.6	0.8	1.5	1.2	0.5	0.9	1.1	1.7	2.3	2	0.8	1.2	1.3
3.7	5.00	8.00	19.00	9.40	9.00	7.00	8.00	7.00	12.00	12.85	11.50	11.00
3.8	1	1	1	1	1	1	1	1	1	1	1	1
3.9	2	2	2	2	2	2	2	2	2	2	2	2
3.10	1	1	1	1	1	1	1	1	1	1	1	1
3.11	3	3	3	3	3	3	3	3	3	3	3	3
3.12	1	1	1	1	1	1	1	1	1	1	1	1
3.13	60.00	40.00	55.00	45.00	80.00	60.00	72.00	60.00	78.00	70.00	69.00	90.00
3.14	55.00	54.00	56.00	32.00	68.00	81.00	69.00	37.00	54.00	71.00	49.00	60.00
3.15	556.00	314.00	563.00	322.00	428.00	592.00	595.00	440.00	308.00	689.00	465.00	387.00
3.16	1	1	1	1	1	1	1	1	1	1	1	1
4.1	13.10	12.50	13.00	17.00	11.50	12.00	12.00	14.00	11.50	15.00	14.00	15.50
4.2	12.80	12.00	12.00	18.00	10.00	12.00	12.00	15.00	12.00	14.00	13.00	15.00
4.3	2.08	0.85	2.84	0.64	1.83	0.77	0.80	0.84	0.64	0.95	1.44	0.79
4.4	4.50	3.50	3.50	7.00	6.00	3.00	4.00	6.00	3.50	5.00	3.50	4.00
5.1	3.30	4.38	2.50	3.30	1.58	1.40	1.30	3.80	3.00	4.72	2.75	3.50
5.2	11.10	10.03	9.58	13.90	7.15	5.94	5.76	7.80	9.36	8.92	11.32	10.80
5.3	4.90	1.73	2.71	4.60	1.52	1.01	1.80	3.40	2.04	2.05	2.72	2.23

3.4. Spike length, 3.5. Type of hermaphroditism, 3.6. Peduncle length, 3.7. Number of spikes/lateral branches, 3.8. Flower arrangement, 3.9. Number of stamen, 3.10. Spike texture, 3.11. Bract type, 3.12. Flower nature (insertion), 3.13. Fruit setting , 3.14. Number of developed fruit /spike, 3.15. Number of berries/10 spike, 3.16. Fruit shape, 4.1. 100 fruit weight, 4.2. 100 fruit volume, 4.3. Yield, 4.4. Dry weight of 100 fruits, 5.1. Essential oil, 5.2. Oleoresin and 5.3. Piperine

Table 29. 1. (Continued from previous page)

Trait	13	14	15	16	17	18	19	20	21	22	23	24
2.2	1	2	2	1	1	1	1	1	1	2	2	1
2.3	2	2	1	2	2	2	2	2	2	2	2	2
2.4	1	2	2	2	2	2	2	2	2	2	1	1
2.5	1	2	2	2	2	2	2	2	2	2	2	2
2.6	1	2	2	2	2	2	2	2	2	2	2	2
2.7	2	1	1	2	2	2	3	3	3	3	1	2
2.8	36.50	25.40	50.10	49.00	51.00	50.00	51.00	42.00	45.00	54.00	36.60	45.50
2.9	28.00	10.00	13.00	29.00	32.00	25.00	29.00	12.00	14.00	28.00	14.30	27.00
2.10	3.10	1.60	2.50	1.30	1.30	2.60	1.50	1.60	1.60	1.50	2.10	1.90
2.11	10.50	12.60	17.20	12.00	11.50	17.40	11.50	11.60	12.30	15.50	15.60	14.40
2.12	5.20	6.50	11.50	8.50	8.30	12.00	9.00	6.20	6.50	8.40	8.50	8.60
2.13	3	2	5	5	2	1	1	3	3	1	2	2
2.14	1	1	2	1	1	1	1	1	1	1	1	1
2.15	1	1	1	1	1	1	1	1	1	1	1	1
2.16	1	1	1	1	1	1	1	1	1	1	1	1
2.17	1	1	1	1	1	1	1	11	1	1	1	1
3.1	2	2	2	2	2	2	2	2	2	2	2	2
3.2	1	1	1	1	1	1	1	1	1	1	1	1
3.3	1	2	1	2	1	1	2	2	1	1	1	1

2.1. Vine height, 2.2. Branching type, 2.3. Orthotropic Shoot tip colour, 2.4. Runner shoot production, 2.5. Holding capacity, 2.6. Adventitious root production, 2.7. Lateral branch habit, 2.8. Lateral branch length, 2.9. Number of nodes, 2.10. Leaf petiole length, 2.11. Leaf length, 2.12. Leaf width, 2.13. Leaf lamina shape, 2.14. Leaf base shape, 2.15. Leaf margin, 2.16. Type of veining, 2.17. Leaf texture, 3.1. Spike orientation, 3.2. Spike shape, 3.3. Spike colour

Table 29. 1. (Continued from previous page)

3.4	9.84	8.50	12.20	12.40	12.50	9.40	13.10	8.60	7.70	11.30	12.00	8.33
3.5	5	5	6	6	6	6	6	6	6	6	6	6
3.6	0.7	1.22	1.7	1.1	0.98	1.3	2.1	1.4	1.5	1.4	1.5	1.5
3.7	18.00	5.80	7.00	14.00	15.00	14.00	12.00	19.00	22.00	14.00	13.00	14.00
3.8	1	1	1	1	1	1	1	1	1	1	1	1
3.9	2	2	2	2	2	2	2	2	2	2	2	2
3.10	1	1	1	1	1	1	1	1	1	1	1	1
3.11	3	3	3	3	3	3	3	3	3	3	3	3
3.12	1	1	1	1	1	1	1	1	1	1	1	1
3.13	55.00	90.00	95.00	74.00	85.00	86.0	58.20	63.40	67.90	82.40	68.00	87.70
3.14	57.00	14.00	86.00	82.00	68.10	69.80	42.50	61.00	68.00	84.00	79.00	72.00
3.15	565.00	331.00	885.00	676.00	652.00	678.00	412.00	612.00	684.00	838.00	784.00	742.00
3.16	1	1	1	1	1	1	1	1	1	1	1	1
4.1	12.50	11.00	15.50	12.50	12.70	11.60	11.80	10.80	10.30	10.70	13.00	12.50
4.2	11.80	10.00	14.50	12.00	12.00	11.20	10.50	10.60	10.00	10.60	12.80	12.00
4.3	0.95	0.86	2.20	4.20	3.40	2.20	1.80	1.60	1.40	3.20	1.60	1.62
4.4	4.80	5.50	5.50	4.50	4.90	5.10	5.20	3.78	3.65	3.63	4.03	3.50
5.1	3.10	3.53	3.50	4.94	3.10	2.10	3.80	5.10	3.40	3.40	3.40	4.80
5.2	8.00	8.11	11.80	13.30	12.70	9.20	12.33	13.00	12.40	12.50	13.80	15.45
5.3	2.90	2.17	5.30	3.39	5.20	4.40	5.50	7.00	6.00	4.70	4.10	3.00

3.4. Spike length, 3.5. Type of hermaphroditism, 3.6. Peduncle length, 3.7. Number of spikes/lateral branches, 3.8. Flower arrangement, 3.9. Number of stamen, 3.10. Spike texture, 3.11. Bract type, 3.12. Flower nature (insertion), 3.13. Fruit setting , 3.14. Number of developed fruit /spike, 3.15. Number of berries/10 spike, 3.16. Fruit shape, 4.1. 100 fruit weight, 4.2. 100 fruit volume, 4.3. Yield, 4.4. Dry weight of 100 fruits, 5.1. Essential oil, 5.2. Oleoresin and 5.3. Piperine

Table 29.2 Morphological observations on less important black pepper cultivars

Descriptor code	1 Doddagai	2 Kaniya kadan	3 Chuma lakodi	4 Nedum chola	5 Mala mundi	6 Karutha pirimunda	7 TMB -IV	8 Valiya kaniakadan	9 Karim kotta
2.2	2	2	2	1	2	2	1	1	1
2.3	2	2	3	2	2	2	2	2	2
2.4	1	1	2	1	1	2	2	2	1
2.5	2	1	2	2	2	2	2	2	2
2.6	2	1	2	2	2	1	2	2	2
2.7	1	1	1	2	2	2	1	1	2
2.8	35.20	18.60	38.60	28.00	31.00	43.00	37.00	38.20	36.00
2.9	14.00	7.00	26.00	11.00	9.00	37.00	18.00	16.00	23.00
2.10	1.78	1.50	2.10	2.00	2.10	1.30	2.20	1.80	1.90
2.11	13.70	10.0	12.80	8.00	16.50	14.00	18.50	13.77	17.50
2.12	9.84	6.00	7.00	6.00	10.50	8.60	12.30	7.18	10.10
2.13	3	3	3	3	2	3	3	1	1
2.14	1	1	1	1	1	1	1	1	1
2.15	1	1	1	1	1	1	1	1	1
2.16	1	1	1	1	1	1	1	1	1
2.17	1	1	1	1	1	1	1	1	1
3.1	2	2	2	2	2	2	2	2	2
3.2	1	1	1	1	1	1	1	1	1
3.3	1	2	1	1	2	1	2	2	2
3.4	7.00	7.80	7.50	5.50	7.50	9.50	12.10	8.20	12.60
3.5	6	6	5	6	6	6	6	6	6
3.6	1.2	1.3	1.3	0.5	1.1	1.2	1.2	1.9	1.6
3.7	4.00	8.00	6.00	12.00	7.00	5.00	18.00	8.00	18.00
3.8	1	1	1	1	1	1	1	1	1
3.9	2	2	2	2	2	2	2	2	2
3.10	1	1	1	1	1	1	1	1	1
3.11	3	3	3	3	3	3	3	3	3
3.12	1	1	1	1	1	1	1	1	1
3.13	40.00	55.00	50.00	60.00	48.00	68.00	68.00	65.00	30.00
3.14	25.00	48.00	47.00	35.00	49.00	78.00	72.00	64.00	23.00
3.15	142.00	398.00	158.00	141.00	158.00	768.00	698.0 0	638.00	223.00
3.16	1	1	1	1	1	1	1	1	1
4.1	15.00	13.00	14.30	9.00	12.00	13.10	16.00	10.00	14.00
4.2	14.00	12.00	13.00	9.00	12.00	1.50	16.00	9.00	13.00
4.3	0.75	0.87	0.93	0.57	0.27	1.20	0.74	1.61	0.64
4.4	6.50	4.80	5.20	3.00	6.00	5.10	3.70	3.00	4.20

2.1. Vine height, 2.2. Branching type, 2.3. Orthotropic Shoot tip colour, 2.4. Runner shoot production, 2.5. Holding capacity, 2.6. Adventitious root production, 2.7. Lateral branch habit, 2.8. Lateral branch length, 2.9. Number of nodes, 2.10. Leaf petiole length, 2.11. Leaf length, 2.12. Leaf width, 2.13. Leaf lamina shape, 2.14. Leaf base shape, 2.15. Leaf margin, 2.16. Type of veining, 2.17. Leaf texture, 3.1. Spike orientation, 3.2. Spike shape, 3.3. Spike colour, 3.4. Spike length, 3.5. Type of hermaphroditism, 3.6. Peduncle length, 3.7. Number of spikes/lateral branches, 3.8. Flower arrangement, 3.9. Number of stamen, 3.10. Spike texture, 3.11. Bract type, 3.12. Flower nature (insertion), 3.13. Fruit setting , 3.14. Number of developed fruit /spike, 3.15. Number of berries/10 spike, 3.16. Fruit shape, 4.1. 100 fruit weight, 4.2. 100 fruit volume, 4.3. Yield and 4.4. Dry weight of 100 fruits.

Cluster analysis

Thirty three black pepper cultivars were characterized and evaluated for 17 vegetative and 16 reproductive characters. Using the similarity matrix (Table 32) the relationship among the OTUs were worked out which is represented in the form of a dendrogram (Fig. 38). The similarity indices ranged from 38 % (Nedumchola and Panniyur-1) to 100 % (Sreekara and Subhakara) indicating wide morphological variation among the cultivars studied.

The dendrogram clearly revealed that the 33 cultivars used for the study fall under 8 major clusters at 69% similarity. The drought tolerant cultivar 'Kalluvally' formed a separate branch. The eight major clusters observed are-

Cluster-1	Karimunda, Sreekara, Subhakara, Valiyakarimunda, Panniyur-2, Panniyur-3.
Cluster-II	Arakulam munda, Thommankodi, Panchami.
Cluster III	Kottanadan, PLD-2, Panniyur-4, Panniyur-5, TMB-IV, Karimkotta
Cluster IV	Balankotta, Nedumchola
Cluster V	Neelamundi, Malamundi, Perambramunda, Doddagai, Kuthiravally, Poonjaranmunda, Valiyakaniyakadan, Narayakodi, Uthirankotta
Cluster VI	Kalluvally
Cluster VII	Panniyur-1, Pournami, Chumalakodi
Cluster VIII	Cheriyakanniakadan, Kaniyakadan, Karuthapirimunda

Table 30.1 Descriptor code for morphological characters on major cultivated black pepper

Descriptor	Descriptor State	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
2.2 Branching type	Dimorphic	1	1	0	1	0	1	0	0	0	0	0	0	1	0	0	1	1	1	1	1	1	0	0	1
	Polymorphic	0	0	1	0	1	0	1	1	1	1	1	1	0	1	1	0	0	0	0	0	0	1	1	0
2.3 Shoot tip colour	Green	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0
	Light purple	1	1	1	1	1	0	1	1	1	1	1	1	1	0	0	1	1	1	1	1	1	1	1	1
	Dark purple	0	0	0	0	0	1	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0
	Few	0	0	1	0	1	1	1	1	0	1	1	0	1	0	0	0	0	0	0	0	0	0	0	1
2.4 Runner shoot production	Many	1	1	0	1	0	0	0	0	1	0	0	1	0	1	1	1	1	1	1	1	1	1	1	0
2.5 Holding capacity	weak	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0
	Strong	1	1	1	1	1	1	1	1	1	1	1	1	0	1	1	1	1	1	1	1	1	1	1	1
	Few	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0
2.6 Adventitious root production	Many	1	1	1	1	1	1	1	1	1	1	1	1	0	1	1	1	1	1	1	1	1	1	1	1
2.7 Lateral branch habit	Erect	0	0	0	0	0	0	0	1	0	1	0	0	0	1	1	0	0	0	0	0	0	0	1	0
	Horizontal	1	1	1	1	1	0	1	0	1	0	1	1	1	0	0	1	1	1	0	1	1	1	0	1
	Hanging	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0
2.8 Lateral branch length.		0	1	0	0	0	0	0	1	0	0	0	0	0	0	1	1	1	1	1	1	1	1	1	1
2.9 No. of nodes/lateral branch		0	1	0	0	0	1	0	0	0	0	0	1	1	0	0	1	1	1	1	0	0	1	0	1
2.10 Leaf petiole length		0	0	1	1	0	0	0	0	0	0	1	0	1	0	1	0	0	1	0	0	0	0	1	1
2.11 Leaf length		0	1	1	1	0	1	1	0	1	0	1	0	0	0	1	0	0	1	0	0	0	1	1	1
2.12 Leaf width		0	1	1	1	1	1	1	0	1	0	1	1	0	0	1	0	0	1	1	0	0	0	0	1
2.13 Leaf lamina shape	Ovate	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0
	Ovate-elliptic	0	1	0	1	0	1	1	0	0	1	1	1	0	0	0	0	1	0	0	0	0	1	0	1
	Ovate-lanceolate	1	0	1	0	1	0	0	1	0	0	0	0	0	1	0	0	0	0	0	1	1	0	1	0
	Elliptic-lanceolate	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0
	Cordate	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0

Table 30.1 (Continued from previous page)

2.14 Leaf base shape	Round	1	1	0	1	1	0	1	0	1	1	1	1	1	1	0	1	1	1	1	1	1	1	1	1
	Cordate	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0
	Acute	0	0	1	0	0	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3.3 Spike colour	Green	1	1	0	1	0	1	0	1	0	1	0	0	0	1	0	1	1	0	0	1	1	1	1	1
	Greenish yellow	0	0	1	0	1	0	1	0	1	0	1	1	1	0	1	0	0	1	1	0	0	0	0	0
3.4 Spike length		0	0	1	0	0	1	1	0	0	0	0	0	0	0	1	1	1	0	1	0	0	1	1	0
	Bisexual flower	1	0	1	0	1	0	1	1	1	0	0	1	0	0	0	1	0	0	0	1	1	1	0	0
	Predominantly female	0	0	0	0	0	0	0	0	0	0	0	1	0	0	1	0	0	0	0	0	0	0	0	0
	Predominantly bisexual	0	1	0	1	0	1	0	0	0	1	0	0	1	0	1	0	1	1	1	0	0	0	1	1
3.6 Peduncle length		0	1	0	0	0	0	1	1	1	0	0	0	0	0	1	0	0	0	1	1	1	1	1	1
3.7 No. of spike/lateral branch		0	0	1	0	0	0	0	0	1	1	0	0	1	0	0	1	1	1	1	1	1	1	1	1
3.15 No. of berries/ten spikes		0	0	1	0	0	1	1	0	0	1	0	0	1	0	1	1	1	1	0	1	1	1	1	1
4.1. 100 fruit weight		1	0	1	1	1	0	0	1	0	1	1	1	0	0	1	0	0	0	0	0	0	0	1	0
4.2 100 fruit volume		1	0	0	1	1	0	0	1	0	1	1	1	0	0	1	0	0	0	0	0	0	0	1	0
4.4 Dry weight of 100 fruits		0	0	0	1	1	0	0	1	0	1	0	0	1	1	1	1	1	1	1	0	0	0	0	0
5.1. Essential oil		1	1	0	1	1	0	0	1	0	1	0	1	0	1	1	1	0	0	1	1	1	1	1	1
5.2 Oleoresin		1	0	0	1	1	0	0	0	0	0	1	1	0	0	1	1	1	0	1	1	1	1	1	1
5.3 Piperine		1	0	0	1	1	0	0	0	0	0	0	0	0	0	1	0	1	1	1	1	1	1	1	0

Table 30.2. Descriptor code for morphological characters of less important black pepper cultivars

Descriptor	Descriptor state	1	2	3	4	5	6	7	8	9	10
2.2Branching type	Dimorphic	0	0	0	1	0	0	1	1	1	1
	Polymorphic	1	1	1	0	1	1	0	0	0	0
2.3 Shoot tip colour	Light purple	1	1	0	1	1	1	1	1	1	1
	Dark purple	0	0	1	0	0	0	0	0	0	0
2.4 Runner shoot production	Few	1	1	0	1	1	1	1	0	0	0
	Many	0	0	1	0	0	0	0	1	1	1
2.5 Holding capacity	weak	0	1	1	0	0	1	0	0	0	0
	Strong	1	0	0	1	1	0	1	1	1	1
2.6 Adventitious root production	Few	0	1	0	0	0	1	0	0	0	0
	Many	1	0	1	1	1	0	1	1	1	1
2.7 Lateral branch habit	Erect	1	1	1	0	0	0	0	1	1	0
	Horizontal	0	0	0	1	1	1	1	0	0	1
2.8 Lateral branch length		1	0	1	0	0	1	1	1	1	0
2.9 No. of nodes/lateral branch		0	0	1	0	0	1	1	0	1	0
2.10 Leaf petiole length		0	0	1	1	1	0	1	0	1	0
2.11 Leaf length		0	0	0	0	1	1	1	0	1	0
2.12 Leaf width		1	0	0	0	1	0	1	0	1	0
2.13Leaflamina shape	ovate	0	0	0	0	0	1	1	0	1	0
	ovate-elliptic	1	1	1	0	1	0	0	0	0	0
	Ovate-lanceolate	0	0	0	1	0	0	0	1	0	1
2.14 Leaf base shape	Round	1	1	1	0	1	1	1	1	1	1
	Acute	0	0	0	1	0	0	0	0	0	0
3.3 Spike colour	Green	1	0	1	1	1	1	0	0	0	1
	Greenish yellow	0	1	0	0	0	0	1	1	1	0
3.4 Spike length (cm)		0	0	0	0	0	1	1	0	1	0
	Bisexual flower	0	0	0	0	0	0	0	0	0	1
3.5 Type of hermaphroditism	Predominantly female	0	0	1	0	0	0	0	0	0	0
	Predominantly bisexual	1	1	0	1	1	1	1	1	1	0
3.6 Peduncle length		0	1	1	0	0	0	0	1	1	0
3.7 No. of spike/lateral branch		0	0	0	1	0	0	1	0	1	0
3.15 No. of berries/10 spike		0	1	0	0	0	1	1	1	0	0
4.1. fruit weight		1	1	1	0	0	1	1	0	1	1
4.2 100 fruit volume		1	1	1	0	1	0	1	0	1	1
4.4 dry weight of 100 berries		1	1	1	0	1	1	0	0	0	0

Table 31. Paired Affinity Indices of 33 black pepper cultivars

	Kmunda	Kotdan	Balankotta	Neelamundi	Kuthavally	Kalluvally	Arakulm	Naryakdi	Thmmnkdi	Prmbramd	Ponjranmd	Vkaniykdn	Cherikadn	Uthkotta	P-1	P-2
Kmunda	1.0000000															
Kotdan	0.7179487	1.0000000														
Balankotta	0.6153846	0.4871795	1.0000000													
Neelamundi	0.7948718	0.8205128	0.5641026	1.0000000												
Kuthavally	0.7948718	0.5641026	0.7692308	0.6923077	1.0000000											
Kalluvall	0.5384615	0.7179487	0.5641026	0.6410256	0.4358974	1.0000000										
Arakulm	0.6410256	0.7179487	0.7692308	0.6410256	0.7435897	0.6410256	1.0000000									
Naryakdi	0.7435897	0.5641026	0.6153846	0.5897436	0.7435897	0.4871795	0.5897436	1.0000000								
Thmmnkdi	0.6923077	0.7179487	0.7179487	0.6410256	0.7435897	0.4871795	0.8461538	0.5897436	1.0000000							
Prmbramda	0.6666667	0.5897436	0.5897436	0.7179487	0.7179487	0.5641026	0.6153846	0.7179487	0.5641026	1.0000000						
Ponjranmd	0.6923077	0.6666667	0.7692308	0.7948718	0.8461538	0.5384615	0.7948718	0.5897436	0.7435897	0.7179487	1.0000000					
Vkaniykdn	0.7692308	0.6923077	0.6410256	0.7179487	0.8205128	0.5128205	0.7692308	0.6153846	0.7692308	0.6410256	0.8205128	1.0000000				
Cherikadn	0.5128205	0.5384615	0.5384615	0.5641026	0.5641026	0.4615385	0.5128205	0.3589744	0.5128205	0.5897436	0.5641026	0.4871795	1.0000000			
Uthkotta	0.7948718	0.6666667	0.5641026	0.6923077	0.7435897	0.5384615	0.6410256	0.7948718	0.6923077	0.7692308	0.6410256	0.6666667	0.5128205	1.0000000		
P-1	0.4358974	0.5128205	0.5641026	0.5897436	0.5384615	0.4358974	0.5897436	0.5897436	0.5384615	0.5641026	0.5897436	0.5641026	0.3589744	0.5384615	1.0000000	
P-2	0.6923077	0.6666667	0.5641026	0.5897436	0.5384615	0.5897436	0.5897436	0.5897436	0.5897436	0.5641026	0.4358974	0.5641026	0.5641026	0.6410256	0.5384615	1.0000000
P-3	0.6923077	0.8205128	0.5128205	0.7435897	0.5384615	0.6923077	0.6410256	0.5384615	0.5897436	0.7179487	0.5384615	0.6153846	0.6666667	0.6923077	0.4871795	0.8461538
P-4	0.5641026	0.7948718	0.5897436	0.7692308	0.5641026	0.6153846	0.6666667	0.4102564	0.7179487	0.5897436	0.6666667	0.6410256	0.6923077	0.5641026	0.5641026	0.6666667
P-5	0.5384615	0.7692308	0.4615385	0.6410256	0.5384615	0.6410256	0.6410256	0.4871795	0.6923077	0.5641026	0.5384615	0.6153846	0.5641026	0.5897436	0.5384615	0.6410256
Sreekara	0.8461538	0.7692308	0.6153846	0.6410256	0.6410256	0.5384615	0.6923077	0.6923077	0.7435897	0.6153846	0.5384615	0.6153846	0.5641026	0.7435897	0.4358974	0.7948718
Subhakara	0.8461538	0.7692308	0.6153846	0.6410256	0.6410256	0.5384615	0.6923077	0.6923077	0.7435897	0.6153846	0.5384615	0.6153846	0.5641026	0.7435897	0.4358974	0.7948718
Panchami	0.6666667	0.7948718	0.6410256	0.6153846	0.5641026	0.6153846	0.8205128	0.6153846	0.7692308	0.6410256	0.6153846	0.6923077	0.4871795	0.6666667	0.5128205	0.7692308
Pournami	0.6666667	0.6410256	0.6410256	0.6666667	0.5641026	0.5641026	0.6153846	0.7179487	0.6153846	0.7435897	0.6153846	0.5384615	0.4358974	0.7179487	0.7179487	0.5641026
PLD-2	0.5897436	0.8717949	0.6153846	0.7435897	0.5384615	0.6923077	0.6923077	0.4871795	0.6410256	0.6666667	0.6923077	0.5641026	0.6666667	0.5384615	0.4871795	0.6410256
Doddagai	0.6666667	0.6923077	0.5384615	0.7692308	0.7692308	0.5641026	0.6153846	0.7692308	0.5641026	0.8974359	0.7692308	0.6923077	0.4871795	0.7692308	0.6153846	0.5128205
Kanikadan	0.5128205	0.4871795	0.4871795	0.5641026	0.6666667	0.4102564	0.6153846	0.6153846	0.5128205	0.7948718	0.6666667	0.5897436	0.6923077	0.6153846	0.5641026	0.3589744
Chumala	0.5641026	0.5897436	0.3333333	0.6153846	0.5128205	0.4615385	0.4615385	0.6666667	0.4615385	0.6410256	0.5641026	0.6410256	0.4358974	0.6666667	0.5641026	0.4615385
Nedumchol	0.7435897	0.6666667	0.7179487	0.6923077	0.6410256	0.6410256	0.5384615	0.6410256	0.5897436	0.6666667	0.6410256	0.5128205	0.6666667	0.6923077	0.3846154	0.6410256
Malamundi	0.6666667	0.7435897	0.6410256	0.8717949	0.7692308	0.6153846	0.7179487	0.6153846	0.6666667	0.7948718	0.8717949	0.6923077	0.5897436	0.7179487	0.5641026	0.5128205
Kpirimund	0.4871795	0.5641026	0.5641026	0.5384615	0.5384615	0.5384615	0.5384615	0.5384615	0.4871795	0.6153846	0.5384615	0.4615385	0.6666667	0.5384615	0.4871795	0.5897436
TMB-IV	0.5897436	0.6666667	0.7179487	0.6923077	0.6410256	0.5897436	0.6410256	0.4358974	0.6410256	0.6153846	0.7435897	0.6153846	0.6666667	0.4358974	0.5897436	0.5897436
Vkmunda	0.7179487	0.7435897	0.5384615	0.6153846	0.6153846	0.5641026	0.6666667	0.6666667	0.6666667	0.6410256	0.5641026	0.5897436	0.5897436	0.7692308	0.6153846	0.6153846
Karimkota	0.5897436	0.7179487	0.5641026	0.6923077	0.5384615	0.5384615	0.5897436	0.5384615	0.6923077	0.5641026	0.6410256	0.6153846	0.5128205	0.5384615	0.6923077	0.5384615

Table 31. (Continued from previous page)

	P-3	P-4	P-5	Sreekara	Subhakara	Panchami	Pournami	PLD-2	Doddagai	Kanikadan	Chumala	Nedmchla	Malmundi	Kpirimund	TMB-IV	Vkmunda	Karimkota
P-3	1.0000000																
P-4	0.8205128	1.0000000															
P-5	0.7948718	0.8205128	1.0000000														
Sreekara	0.7948718	0.6666667	0.6410256	1.0000000													
Subhakara	0.7948718	0.6666667	0.6410256	1.0000000	1.0000000												
Panchami	0.8205128	0.6923077	0.6666667	0.8205128	0.8205128	1.0000000											
Pournami	0.6666667	0.5897436	0.5641026	0.7179487	0.7179487	0.7435897	1.0000000										
PLD-2	0.7948718	0.8205128	0.6923077	0.7435897	0.7435897	0.7692308	0.6666667	1.0000000									
Doddagai	0.6666667	0.5897436	0.6153846	0.5641026	0.5641026	0.5897436	0.6923077	0.6666667	1.0000000								
Kanikadan	0.5128205	0.4871795	0.5128205	0.4615385	0.4615385	0.4871795	0.5897436	0.5128205	0.7435897	1.0000000							
Chumala	0.5641026	0.4871795	0.5128205	0.5128205	0.5128205	0.5897436	0.6410256	0.5128205	0.6923077	0.6410256	1.0000000						
Nedumchol	0.6923077	0.6153846	0.5384615	0.7435897	0.7435897	0.5641026	0.6153846	0.7435897	0.6153846	0.4615385	0.4102564	1.0000000					
Malamundi	0.6666667	0.6923077	0.5641026	0.5641026	0.5641026	0.6410256	0.6410256	0.7692308	0.8461538	0.6410256	0.5897436	0.7179487	1.0000000				
Kpirimund	0.6410256	0.5641026	0.4871795	0.4871795	0.4871795	0.6153846	0.5641026	0.5897436	0.6153846	0.6666667	0.5128205	0.5384615	0.6153846	1.0000000			
TMB-IV	0.6923077	0.8205128	0.6923077	0.5897436	0.5897436	0.6153846	0.6666667	0.7948718	0.6153846	0.5128205	0.4102564	0.6410256	0.6666667	0.6410256	1.0000000		
Vkmunda	0.7179487	0.6923077	0.7179487	0.8205128	0.8205128	0.6410256	0.7435897	0.6666667	0.6410256	0.6410256	0.5384615	0.6666667	0.5384615	0.4615385	0.6153846	1.0000000	
Karimkota	0.6410256	0.7692308	0.7948718	0.5897436	0.5897436	0.6153846	0.7692308	0.6923077	0.6153846	0.5128205	0.5641026	0.5384615	0.5641026	0.4871795	0.8461538	0.7179487	1.0000000

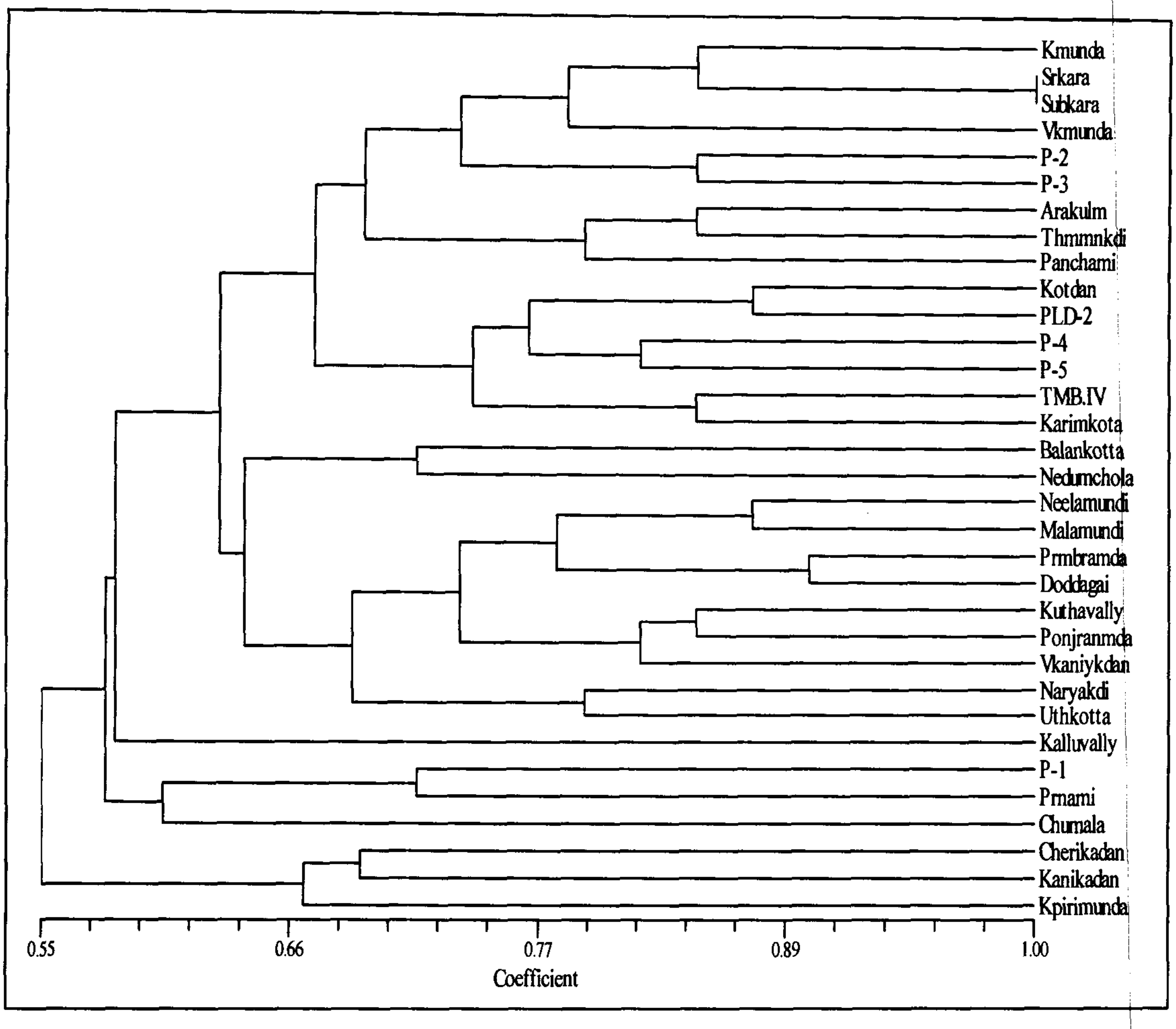


Fig. 38. Dendrogram of local cultivars of black pepper by cluster analysis of morphological characters

In the first major cluster, the popular cultivar Karimunda grouped with the improved varieties Sreekara and Subhakara with 84% similarity coefficient. 100 % similarity was shown between Sreekara and Subhakara. The less popular cultivar Valiyakarimunda showed 64% similarity with this group. The improved varieties Panniyur-2 and Panniyur-3 also grouped with this cluster with 54 % similarity. In the second cluster, cultivars Arakulam munda and Thommankodi formed a sub group with 84 % similarity, while their genetic similarity with the improved variety Panchami was only 76%. In the third cluster, there were three sub clusters. Cultivar

Kottanadan and the improved variety of Kottanadan selection PLD-2 shared 87% genetic similarity and formed the first sub cluster. The improved varieties Panniyur-4 and Panniyur-5 formed the second sub cluster with 82 % similarity. The less important cultivars TMB-4 and Karimkotta were the members in the third sub cluster with 84 % similarity. However, the genetic similarities between these groups were only 71%. The fourth cluster consisted of cv. Balankotta and Nedumchola with 71 % similarity. However, these two cultivars are morphologically very distinct in leaf size and spike length, their clustering together may be because of the other similar characters. Maximum members were in the fifth cluster with four sub clusters. Cultivar Neelamundi and Malamundi shared 87 % similarity and formed the first sub cluster. In the second sub cluster, the members were Perambramunda and Doddagai grouped with 89 % similarity. Three cultivars grouped in the third sub cluster. The first two members viz. Kuthiravally and Poonjaranmunda showed 84 % similarity, while the third member Valiyakaniyakadan joined these members with 82 % similarity. The fourth sub cluster consisted of Narayakodi and Uthirankotta with 79 % similarity. The cultivar Kalluvally alone formed the sixth cluster and its similarity index ranged from 43 to 71 % with other members. There were three members in the seventh clusters. The improved varieties Panniyur-1 and Pournami clustered together with 71 % similarity and they shared 56 % with the third member Chumalakodi. In the eighth cluster also there were three members. The first two members viz. Cheriyakanniakadan and Kaniyakadan expressed 69 % similarity, while they showed only 66 % similarity with the third member Karuthapirimunda.

Molecular characterization

Molecular characterization was done to supplement the morphometric data of 33 cultivars molecular data obtained from 13 RAPD and 7 ISSR profiles were used. However, for the less important cultivars only 10 RAPD markers were used, hence they were analyzed separately.

Important cultivars and varieties

The 24 important cultivars (Table 4) were characterized using thirteen RAPD (Fig.39 - 40) and seven ISSR (Fig. 41) primers. The operon primers used for RAPD analysis are OPA-09, OPA-15, OPB-20, OPC-07, OPC-09, OPC-13, OPD-03, OPD-15, OPE-02, OPE-11, OPF-09, OPF-10 and OPF-15, where as primers $(CT)_8$ AC, $(CT)_8$ GC, $(CA)_7$ GT, $(CA)_7$ AG, $(CA)_7$ GG, $(GA)_6$ GG and $(CAC)_3$ GC were used for ISSR profiling. A total number of 171 markers were formed out of which 73 were polymorphic. Similarity indices were calculated using Jaccard's coefficients (Table 32) using this molecular data and dendrograms (Fig. 42) were drawn using NTSYs software

The paired affinity indices ranged from 76% to 96% between cultivars. The resultant dendrogram grouped into two major clusters. Cultivars Kottanadan, Kuthiravally, Valiyakaniyakadan, Narayakodi, Poonjaranmunda and Panniyur- 3 were grouped in one cluster where as all the remaining 16 were grouped in another major cluster.

The first major cluster has further resulted 5 sub clusters. The second major cluster sub divided into two sub clusters. The clustering pattern was as follows.

	Sub cluster-1	: Karimunda, Vellamunda and Balankotta
	Sub cluster-2	: Balankotta, Thommankodi
Cluster -I	Sub cluster-3	: Kalluvally, Sreekara, Panniyur-2, Subhakara
	Sub cluster-4	: Panniyur-4, Panchami, Pournami, PLD-2
	Sub cluster-5	: Arakulammunda, Cheriyakanniakadan

Cluster -II	Sub cluster-1	: Kottanadan, Kuthiravally, Valiyakaniyakadan, Poonjaranmunda
	Sub cluster- 2	: Panniyur-3

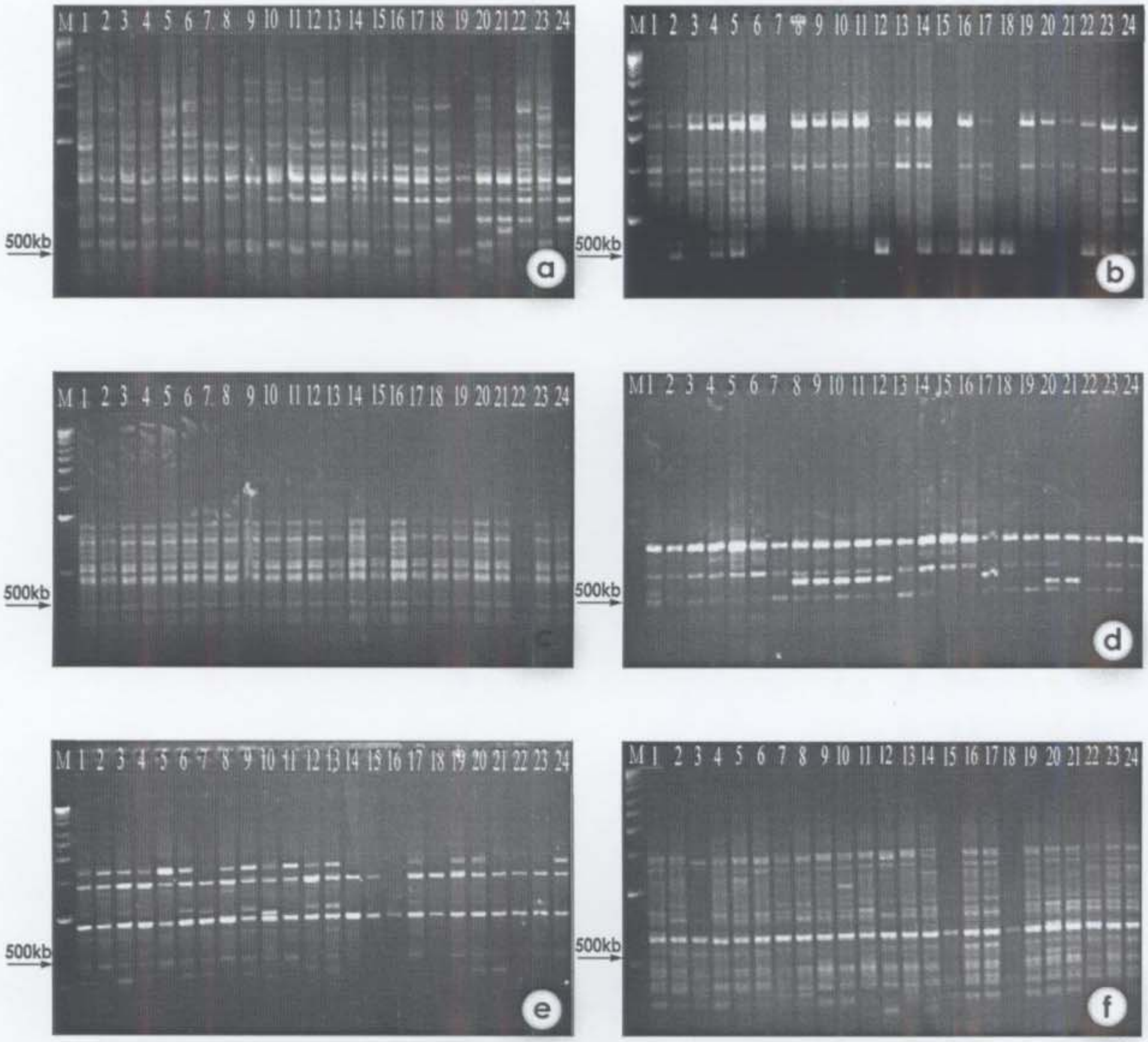


Fig. 39. RAPD profiles of 24 cultivars of black pepper

Primers a) OPA-09 b) OPA-15 c) OPB-20 d) OPC-07 e) OPC-09 f) OPC-13.

Lane M. 1Kb ladder, 1 Karimunda, 2 Kottanadan, 3 Balankotta, 4 Neelamundi, 5 Kuthiravaly, 6 Kalluvally, 7 Arakkulam munda, 8 Narayakodi, 9 Thommankodi, 10 Perambramundi, 11 Poonjaranmunda, 12 Valiyakaniakadan, 13 Cheriyakaniyakadan, 14 Uthirankotta, 15 Panniyur-1, 16 Panniyur-2, 17 Panniyur-3, 18 Panniyur-4, 19 Panniyur-5, 20 Sreekara, 21 Subhakara, 22. Panchami, 23 Pournami and 24 Palode-2.

203.B

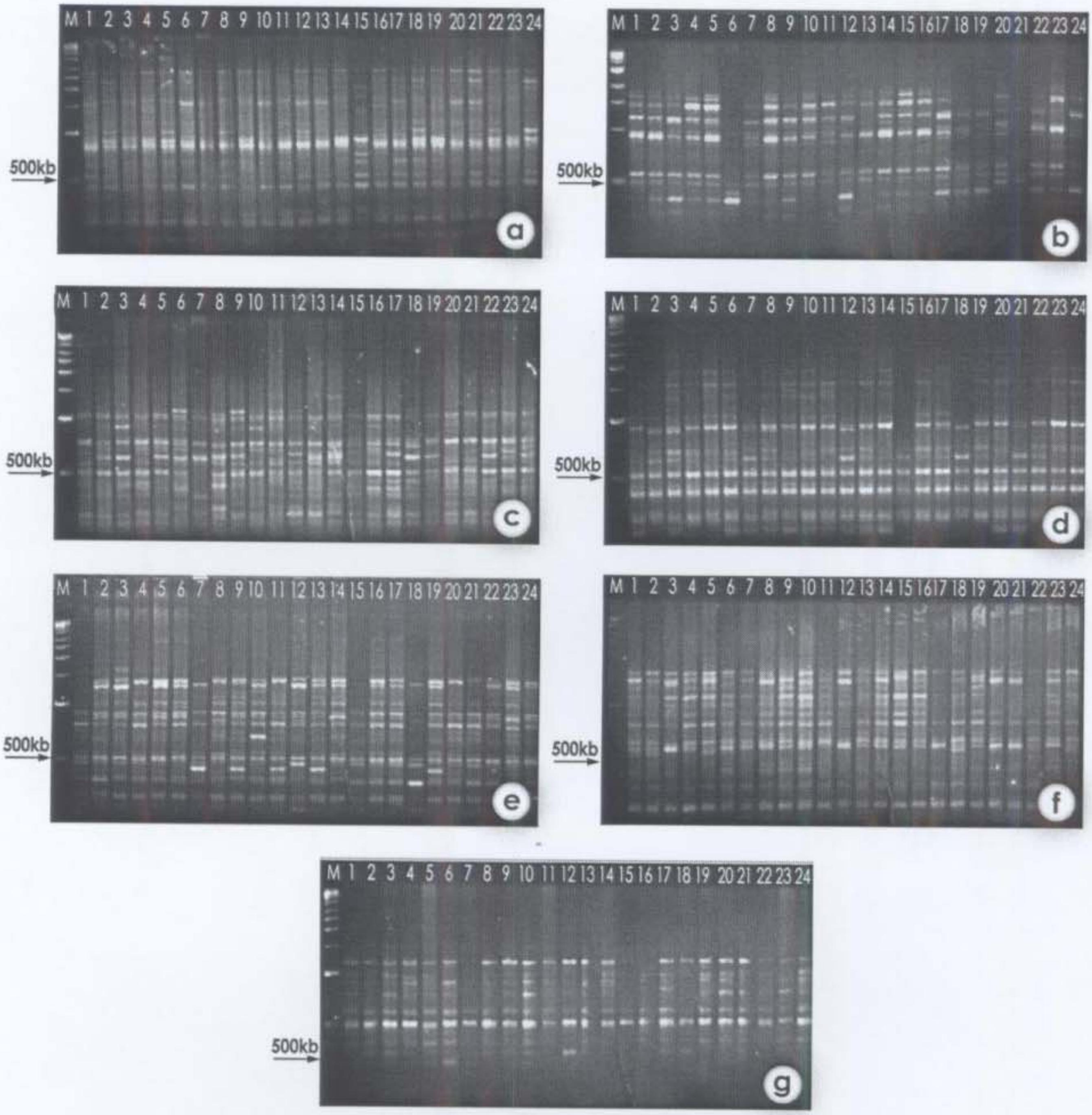


Fig. 40. RAPD profiles of 24 cultivars of black pepper

Primers a) OPD-03, b) OPD-15 c) OPE-02 d) OPE-11 e) OPF-09 f) OPF-10 g) OPF-15

Lane M. 1Kb ladder, 1 Karimunda, 2 Kottanadan, 3 Balankotta, 4 Neelamundi, 5 Kuthiravaly, 6 Kalluvally, 7 Arakkulam munda, 8 Narayakodi, 9 Thommankodi, 10 Perambramundi, 11 Poonjaranmunda, 12 Valiyakaniakadan, 13 Cheriyakaniyakadan, 14 Uthirankotta, 15 Panniyur-1, 16 Panniyur-2, 17 Panniyur-3, 18 Panniyur-4, 19 Panniyur-5, 20 Sreekara, 21 Subhakara, 22. Panchami, 23 Pournami and 24 Palode-2.

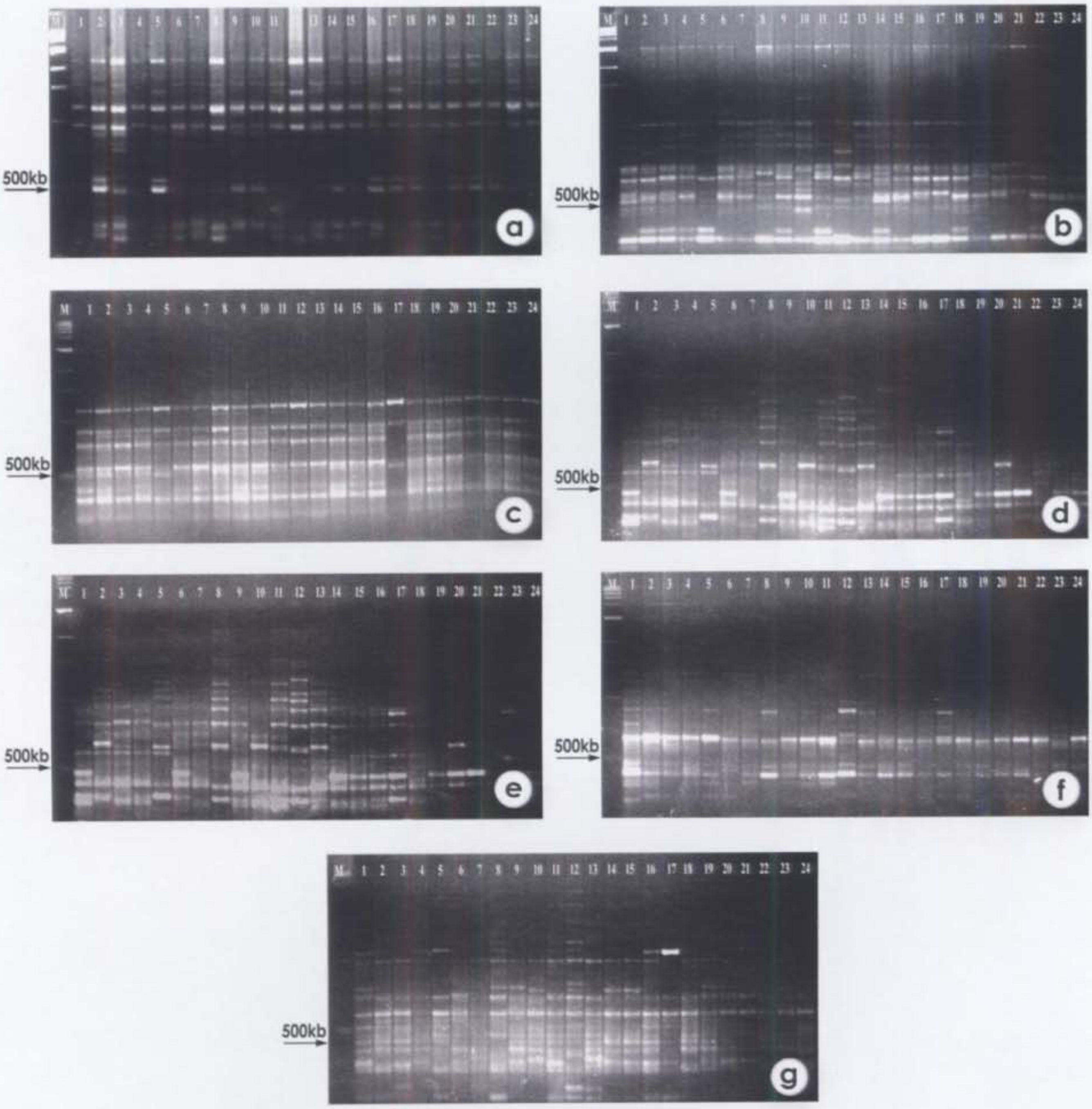


Fig. 41. ISSR profiles of 24 cultivars of black pepper.

Primers (a) (CT)8 AC (b) (CT)8GC (c) (CA)7GT (d) (CA)7AG (e) (CA)7GG (f) (GA)6GG (g)(CAC)3GC.

Lane. M. 1Kb ladder, 1 Karimunda, 2 Kottanadan, 3 Balankotta, 4 Neelamundi, 5 Kuthiravaly,.6 Kalluvally, 7 Arakkulam munda, 8 Narayakodi, 9 Thommankodi, 10 Perambramundi, 11 Poonjaranmunda, 12 Valiyakaniakadan, 13 Cheriyakaniyakadan, 14 Uthirankotta, 15. Panniyur-1, 16 Panniyur-2, 17 Panniyur-3, 13 Panniyur-4, 19 Panniyur-5, 20 Sreekara, 21 Subhakara 22 Panchami, 23 Pournami and 24 Palode-2.

Table 32. Paired Affinity Indices of 24 important cultivars based on molecular characterization

Cultivar	Kmunda	Kotndn	Balkta	Nlmdi	Kthvly	Kalvly	Akmunda	Narkdi	Thmkdi	Pmbmda	Poonjmda	Vlkdn
Kmunda	1.0000000											
Kotndn	0.8333333	1.0000000										
Balkta	0.8850575	0.8908046	1.0000000									
Nlmdi	0.9080460	0.8103448	0.8965517	1.0000000								
Kthvly	0.8218391	0.9310345	0.8333333	0.8218391	1.0000000							
Kalvly	0.8850575	0.8333333	0.8735632	0.8505747	0.8448276	1.0000000						
Akmunda	0.8390805	0.7988506	0.8505747	0.8505747	0.8103448	0.8850575	1.0000000					
Narkdi	0.8218391	0.8505747	0.8103448	0.8103448	0.8505747	0.7873563	0.8103448	1.0000000				
Thmkdi	0.8505747	0.8218391	0.8620690	0.8390805	0.7988506	0.8735632	0.8505747	0.8103448	1.0000000			
Pmbmda	0.8620690	0.7988506	0.8505747	0.8505747	0.7988506	0.8620690	0.8390805	0.8448276	0.8850575	1.0000000		
Poonjmda	0.7931034	0.8448276	0.8275862	0.8160920	0.8333333	0.8045977	0.8390805	0.8908046	0.8275862	0.8505747	1.0000000	
Vlkdn	0.7988506	0.8850575	0.7873563	0.7528736	0.8735632	0.7988506	0.7643678	0.8735632	0.7643678	0.7873563	0.8333333	1.0000000
Chkdn	0.8160920	0.8448276	0.8620690	0.8275862	0.8103448	0.8275862	0.9195402	0.8333333	0.8390805	0.8275862	0.8620690	0.7988506
Uthkta	0.8505747	0.7988506	0.8275862	0.8275862	0.8218391	0.8735632	0.8850575	0.8103448	0.8505747	0.8505747	0.8275862	0.7873563
P-1	0.9022989	0.7931034	0.8448276	0.8678161	0.8160920	0.8678161	0.8563218	0.7816092	0.8333333	0.8333333	0.7758621	0.7586207
P-2	0.8678161	0.7931034	0.8793103	0.8563218	0.8045977	0.8678161	0.8333333	0.7701149	0.8218391	0.8563218	0.7988506	0.7816092
P-3	0.8505747	0.8448276	0.8160920	0.8275862	0.8218391	0.8160920	0.7816092	0.8333333	0.7931034	0.7816092	0.8045977	0.8448276
P-4	0.8333333	0.8505747	0.8448276	0.8218391	0.8620690	0.8793103	0.8563218	0.8045977	0.8333333	0.8218391	0.7873563	0.7701149
P-5	0.8275862	0.7758621	0.8390805	0.8275862	0.7873563	0.8735632	0.8850575	0.8103448	0.8850575	0.8275862	0.7931034	0.7413793
Sreekara	0.8448276	0.7701149	0.8333333	0.8103448	0.7816092	0.9022989	0.8563218	0.7931034	0.8563218	0.8448276	0.7988506	0.7471264
Subhakara	0.8678161	0.7816092	0.8563218	0.8563218	0.7701149	0.8563218	0.8333333	0.7816092	0.8333333	0.8103448	0.7758621	0.7356322
Panchami	0.8390805	0.8793103	0.8850575	0.8275862	0.8563218	0.8850575	0.8505747	0.8103448	0.8505747	0.8735632	0.8045977	0.7873563
Pournami	0.8793103	0.8160920	0.8563218	0.8103448	0.7931034	0.8563218	0.8563218	0.8390801	0.8333331	0.7873563	0.827862	0.8563216
PLD-2	0.8793103	0.8160920	0.8908046	0.8448276	0.7816092	0.8563218	0.8333333	0.8160920	0.8448276	0.8448276	0.7758621	0.7586207

Table 32. Contd. from previous page

Cultivars	Chkdn	Uthkta	P-1	P-2	P-3	P-4	P-5	Sreekara	Subhakara	Panchami	Pournami	PLD-2
Chkdn	1.0000000											
Uthkta	0.8505747	1.0000000										
P-1	0.8333333	0.9137931	1.0000000									
P-2	0.8333333	0.8793103	0.9080460	1.0000000								
P-3	0.7931034	0.8045977	0.8103448	0.8448276	1.0000000							
P-4	0.8103448	0.8678161	0.8735632	0.8390805	0.7988506	1.0000000						
P-5	0.8735632	0.8620690	0.8793103	0.8333333	0.7701149	0.8563218	1.0000000					
Sreekara	0.8103448	0.8678161	0.8390805	0.8390805	0.7758621	0.8275862	0.8793103	1.0000000				
Subhakara	0.8103448	0.8448276	0.8735632	0.8850575	0.8103448	0.8505747	0.9022989	0.8965517	1.0000000			
Panchami	0.8505747	0.8735632	0.8563218	0.8678161	0.8160920	0.9367816	0.8620690	0.8448276	0.8333333	1.0000000		
Pournami	0.8793103	0.8793103	0.8735632	0.8620690	0.8678161	0.8505747	0.8678161	0.8620690	0.8275862	0.8908046	1.0000000	
PLD-2	0.8448276	0.8448276	0.8390805	0.8620690	0.8333333	0.8505747	0.8793103	0.8505747	0.8620690	0.9022989	0.9195402	1.0000000

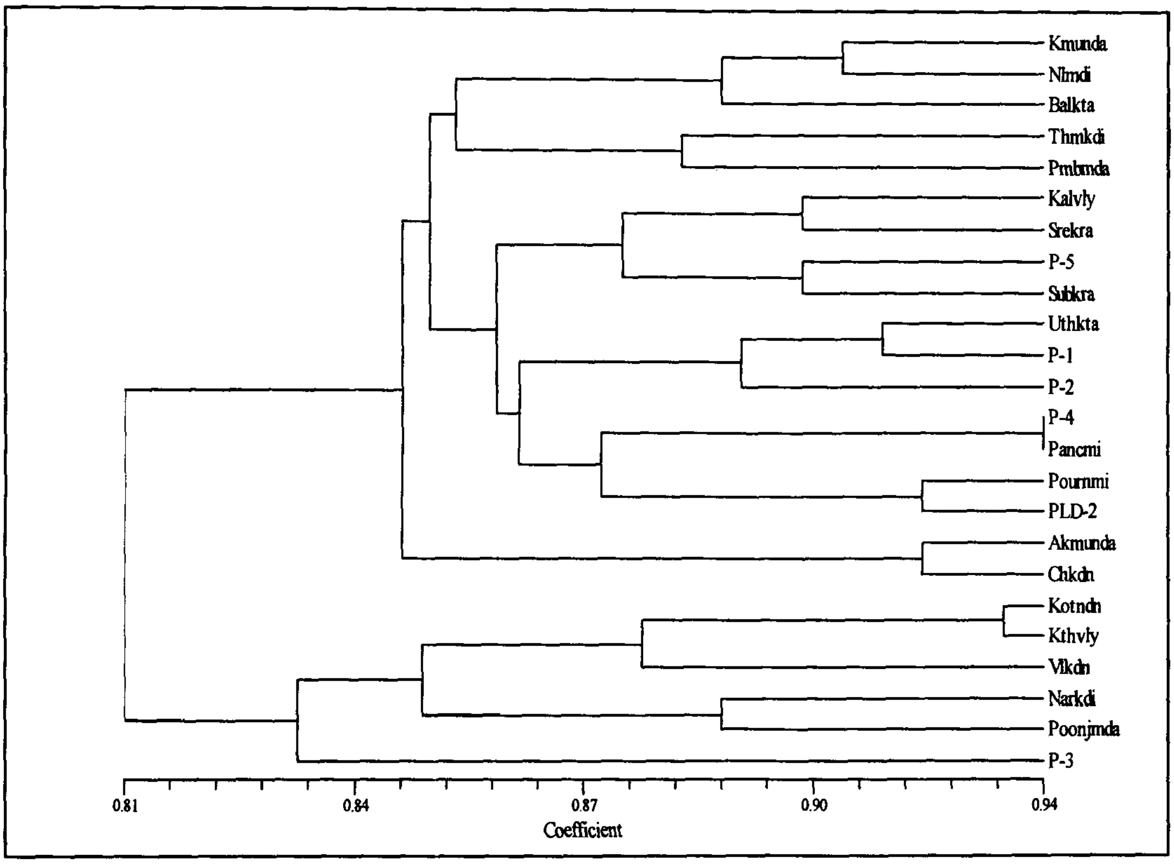


Fig. 42. Dendrogram showing the genetic relationships among 24 accessions important local cultivars and improved varieties based on RAPD and ISSR markers derived from Jaccard coefficient of similarity

```
                        +---Karimunda
                    +52.0
                +27.0   +---Neelamundi
                |   |
            +-4.0  +--------Balankotta
            |   |
            |   |       +---Thommankodi
        +-1.0  +-----61.0
        |   |           +---Perambramunda
        |   |
        |   |           +---Arakulam munda
        |   +----------83.0
        |               +---Cheriyakanniakadan
    +-2.0
    |   |               +---Kalluvally
    |   |           +42.0
    |   |           |   +---Sreekara
    |   |       +13.0
    |   |      |    |   +---Subhakara
    |   |      |    +26.0
    |   +-------4.0     +---P-5
    |          |
+36.0          |   +--------P-2
|   |           +36.0
|   |              |   +---P-1
|   |               +56.0
|   |                  +---Uthirankotta
|   |
|   |                   +---Panchami
|   |               +87.0
|   |               |   +---P-4
|   +---------------10.0
|                   |   +---PLD-2
|                   +74.0
|                       +---Pournami
|
|                       +---Kottanadan
|                   +84.0
|               +53.0  +---Kuthiravally
|              |   |
|           +45.0  +--------Valiyakaniyakadan
|           |  |
|           |  |       +---Narayakodi
+----------34.0+-----69.0
            |           +---Poonjaranmunda
            |
            +-----------------P-3
```

Fig. 43. Dendrogram showing the genetic relationships among 24 accessions important local cultivars and improved varieties based on RAPD and ISSR markers derived from Jaccard coefficient of similarity. Bootstrap *P* values are given at the corresponding node for each cluster.

In cluster-I, the members of the first sub cluster, 90% similarity coefficient was shown between cvs. Karimunda and Neelamundi. They have shared 85% similarity with Balankotta. The members in the second sub cluster showed 83% similarity. In the third sub cluster the Kalluvally, Sreekara, P-5 and Subhakara showed 92% similarity each other. However, the common similarities between these two groups were 87%. The improved variety Panniyur-1 expressed 94% similarity with one of its parents Uthirankotta and this group shared 87% similarity with Panniyur-2. Members in the 4th sub cluster *viz.* P4 and Panchami showed 95% similarity where as Pournami and PLD-2 had 91% similarity coefficient.

The fifth sub cluster Arakulam munda and Cheriyakanniakadan showed 93% similarity each other, however this sub cluster have out-grouped from the other sub clusters of the first major cluster.

The members in the second major cluster formed two sub clusters. The members of the first sub cluster in this group *viz.* Kottanadan and Kuthiravally had a close similarity coefficient of 93% and they shared 88% similarity with Valiyakaniyakadan. Narayakodi and Poonjaranmunda showed 88.5% similarity and the common affinity in the sub groups in the sub clusters were 87%. The improved variety P-3 out-grouped in the second major cluster.

Bootstrap analysis of the molecular data divided 24 cultivars (Fig. 43) into four major clusters. Among the clusters there were four sub clusters with significant P value above 70% *viz.* Arakulam munda and Cheriyakanniakadan; Panchami and Panniyur-4, PLD-2 and Pournami and Kottanadan and Kuthiravally.

Less important cultivars

Molecular characterization

Molecular characterization was done to supplement the morphometric data with 10 RAPD primers, (Fig 44 and 45) The similarity indices were calculated using Jaccard's coefficients (Table 33) based on the molecular data and dendrograms (Fig 46) were drawn using NTSYs software. A total number of 91 markers were formed out of which 58 were polymorphic.

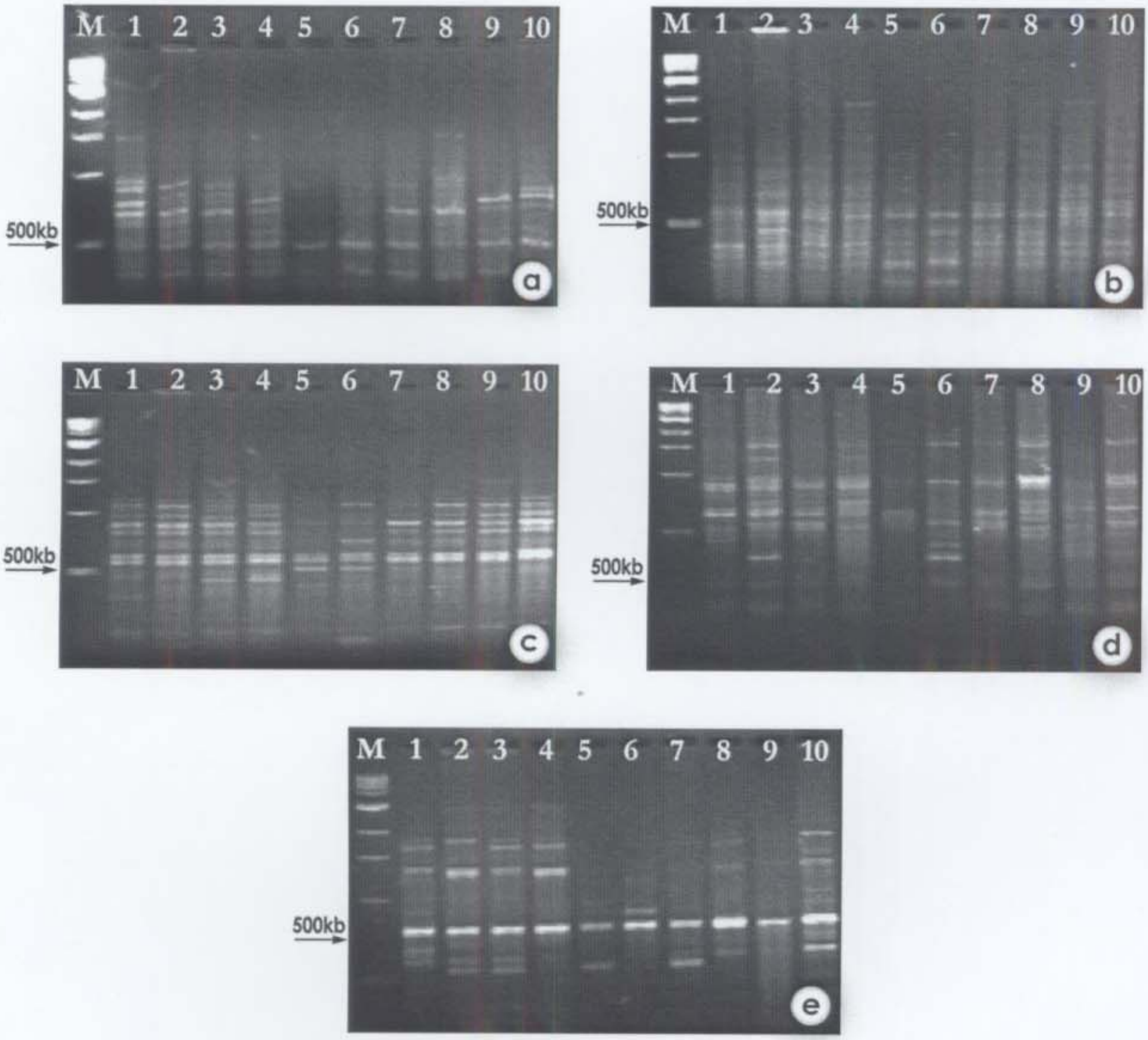


Fig. 44. RAPD profiles of 9 cultivars of black pepper (less important)
Primers a) OPA-03, b) OPA-13, c) OPA-18, d) OPC-02, e) OPC-07

Lane M. 1Kb marker, 1 Doddigai, 2 Kaniakadan, 3 Chumalakodi, 4 Nedumchola, 5 Malamundi, 6 Karuthapirimunda, 7 TMB IV, 8 Valiyakarimunda, 9 Karimkotta and 10 Karimunda (control).

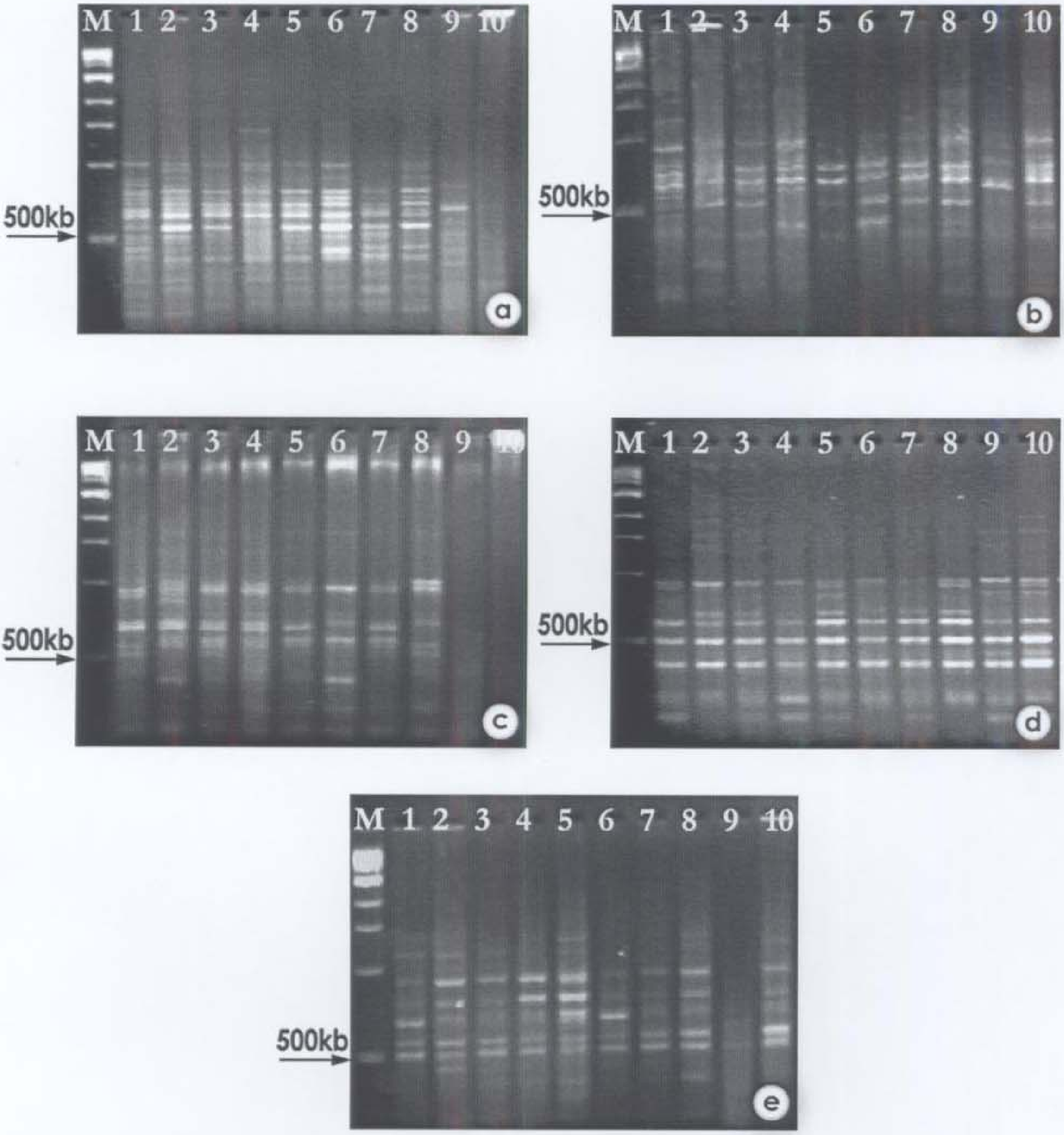


Fig. 45. RAPD profiles of 9 cultivars (less popular)
Primers a) OPD-02, b) OPD-03, c) OPE-02, d) OPE-11, e) OPE-14

Lane M. 1Kb marker, 1 Doddigai, 2 Kaniakadan, 3 Chumalakodi, 4 Nedumchola, 5 Malamundi, 6 Karuthapirimunda, 7 TMB IV, 8 Valiyakarimunda, 9 Karimkotta and 10 Karimunda (control).

Table 33 Paired Affinity Indices of 9 less important cultivars based on molecular characterization.

Cultivar	Doddagai	Kaniakada	Chumala	Nedumchol	Malamundi	Karutha	TMB-IV	Vaiyakari	Karimkott	Karimunda
Doddagai	1.0000000									
Kaniakada	0.7555555	1.0000000								
Chumala	0.8111111	0.8777778	1.0000000							
Nedumchol	0.7000000	0.8333333	0.8222222	1.0000000						
Malamundi	0.7222222	0.7444444	0.8000000	0.7333333	1.0000000					
Karutha	0.7555555	0.7555556	0.7222222	0.6777778	0.8111111	1.0000000				
TMB-IV	0.8000000	0.8222222	0.8555556	0.8111111	0.8111111	0.8000000	1.0000000			
Vaiyakari	0.7888889	0.7888889	0.8222222	0.8222222	0.7111111	0.7222222	0.8333333	1.0000000		
Karimkott	0.7333333	0.6888889	0.7444444	0.7666667	0.7444444	0.7333333	0.8222222	0.7444444	1.0000000	
Karimunda	0.7777778	0.7333333	0.7666667	0.7666667	0.7666667	0.7555555	0.8000000	0.7888889	0.8666667	1.0000000

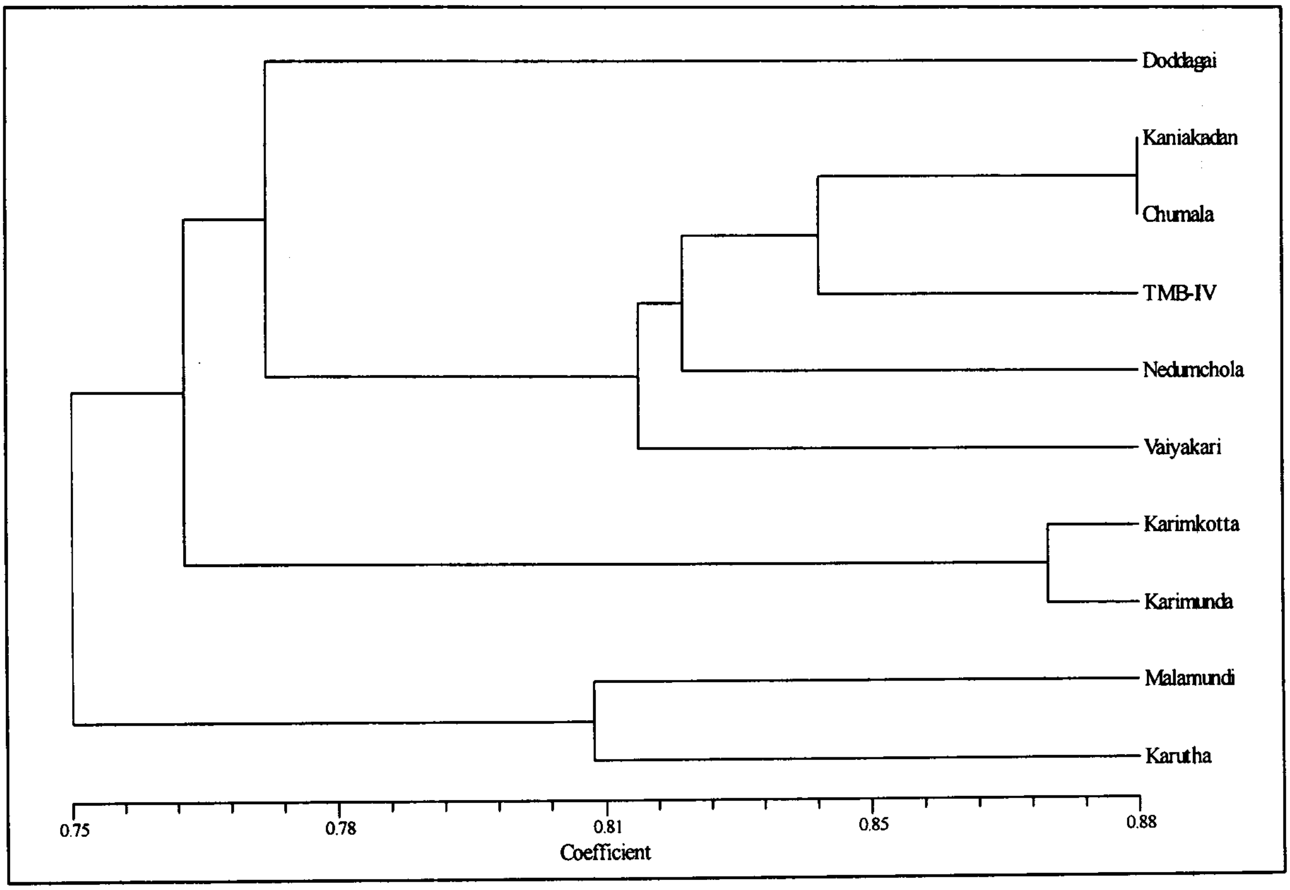


Fig. 46. Dendrogram of divergence of 9 local cultivars (less important) and Karimunda expressed by RAPD markers

Cluster-I - Doddagai

Cluster-II - Kaniyakadan, Chumalakodi, TMB IV, Nedumchola and Valiyakaniyakadan

Cluster-III - Karimkotta and Karimunda

Cluster-IV - Malamundi and Karuthapirimunda

The first cluster consisted only one member Doddagai. In the second cluster, there were five members. Maximum similarity was with Kaniyakadan and Chumalakodi that showed 88% similarity and they shared 85% similarity with TMB IV. Other OTUs in the group Nedumchola and Valiyakarimunda out grouped from the major cluster with 83 and 81% similarity coefficient respectively. The third major cluster consisted of two member Karimkotta and Karimunda (control) and they shared 87% similarity each other.

Intra cultivar variability in Karimunda and Kottanadan accessions

Efforts were made to study the morphologic and molecular variation occurring within the populations two morphologically distinct popular cultivars *viz.* Karimunda characterized by short ovate elliptic leaves and Kottanadan characterized by broad ovate leaves were selected. The Karimunda population consisted of 6 accessions (Table 7) including the improved variety Subhakara (KS-27). Kottanadan accession comprised of seven collections including the improved variety PLD-2 (Acc. 5055).

Morphological characterization

The accessions were characterized for the following morphological characters. The observations in the coded descriptor states are given in Table 34 and the recorded observations in a binary form used for cluster analysis and given in Table 35.

Branching type

Polymorphic type of branching was observed in all Karimunda collections. Dimorhpic type of branching was observed in Kottanadan collections.

Colour of the shoot tip

Shoot tip colour of the orthotropic branch were light purple in all the accessions studied.

Runner shoot production

Among the Karimunda populations, good number of runner shoots was observed in accessions KS-2, KS-50 and KS-14 where as less number of runner shoots were observed in KS-113, KS-120 and KS-161.

In the Kottanadan population, many runner shoots were produced in Acc. 893, 1484 and 5055. Few runner shoots were produced by the remaining collections *viz.* Acc. 1485, 1488, 1489 and 1494.

Holding capacity

Holding capacity was either weak or strong. In Karimunda accession, holding capacity was weak in four accessions *viz.* KS-50, KS-113, KS-120 and KS-161 and strong holding capacity was noticed in accessions KS-2 and KS-14.

Acc. 1485 was the only a member in Kottanadan collections having weak holding nature where as the other six members were having strong holding nature to its support.

Adventitious root production

In Karimunda populations, production of adventitious roots was high in KS-2 and KS-14, but was less in the remaining four members. All the members in Kottanadan collections except Acc. 893 were with good production of adventitious roots.

Lateral branch habit

Lateral branches were erect KS-2, KS-50, KS-113, KS-120, KS-161 and Acc. 1485. Horizontal type of lateral branches observed in KS-14, Acc. 893, 1488, 1489, 1494 and 5055. Hanging nature of lateral branches observed in Acc. 1485.

Lateral branch length

In the Karimunda population, length of lateral branches ranged from 15.5 cm (KS-113) to 45 cm (KS-14) and in Kottanadan collections lateral branch length varied from 38.0 cm (Coll. 893) to 54.0 cm (Acc. 1484).

Number of nodes per lateral branches

Number of nodes per lateral branches ranged from a minimum of 9.8 (KS-113) to 34 (Acc.1484).

Leaf petiole length

Petiole length of the leaves ranged from 1.2 cm to 2.83 cm. The shortest petiole was noticed in Acc. 1485 where as KS-120 had the longest petiole. Average petiole length of the leaves was 1.92 cm.

Leaf length

Shorter leaves characterize Karimunda populations and in Kottanadan cultivars, the leaves are longer and broader. Among the Karimunda collections, the leaf length ranged from 8.3 cm (KS-50) to 13 cm (KS-161). In Kottanadan samples length of leaves ranged from 9.75 cm (Acc. 1485) to 16.3 cm (Acc. 1484). The average leaf length was 12.42 cm.

Leaf width

The range of leaf width in Karimunda collections were from 4.5 cm (KS-50) to 7.16 cm (KS-2) and in Kottanadan collections the leaf width ranged from 5.4 cm (Acc. 1485) to 10.1 cm (Acc. 1484).

Leaf lamina shape

Ovate-lanceolate type of leaf shape was observed in all Karimunda populations and the Karimunda collections were characterized by ovate-elliptic type of leaves.

Leaf base

All the Karimunda and Kottanadan accessions studied were having round leaf base.

Leaf margin, type of veining and leaf texture

All were having entire leaf margin, acrodromous type of veining and glabrous coriaceous textured leaves.

Spike length

Length of spikes ranged from 3.5 cm (KS-50) to 11.9 cm (Acc. 14.84) with an average of 7.74 cm.

Type of hermaphroditism

In Karimunda population, the flowers were bisexual but in Kottanadan the spike composition was predominantly bisexual.

Peduncle length

Length of peduncle ranged from 0.66 cm to 1.6 cm with an average of 1.33. Shortest peduncle was noticed in KS-113 where as the longest peduncle was by Acc. 1488.

Number of spikes/lateral branch

Good variability was observed in spike numbers. Spike numbers per lateral branches ranged from a minimum of 5.0 in KS-113 to a maximum of 22 in Subhakara.

The flowers were free, number of stamens two, the spikes were glabrous in texture were having cupular bracts with decurrent base in all the collections.

Fruit setting

Percentage of fruit setting on the spikes ranged from 40% (KS-50) and Acc. 1489) to 95% (Acc. 1485) with a mean 69.1% fruits per spike.

Number of berries per ten spikes

The total number of developed berries (fruits) on ten spikes was counted and it ranged from 100 (KS-50) to 698 numbers (Acc. 1488) with an average of 404.92 fruits in ten spikes.

Morphometric analysis

Morphological characterizations were carried for six Karimunda and seven Kottanadan accessions based on 27 discriminative characters and the data were analyzed as mentioned in materials and methods. Cluster analysis based on morphological observations was carried out. The paired affinity indices showed minimum of 14% similarity between Acc. 5055 to KS-113, KS-120 and KS-161 and the maximum similarity index was between KS-113 and KS-50 and KS-120 and KS-50. The similarity indices were calculated using Jaccard's coefficients (Table 36) derived from the morphologic data. The dendrograms (Fig. 47) were drawn using NTSYs software.

Table 34. Morphological observations on Karimunda and Kottanadan accessions

Descriptor	KS-2	KS-50	KS-113	KS-120	KS-161	KS-14	893	1484	1485	1488	1489	1494	5055
2.2 Branching type	2	2	2	2	2	2	1	1	1	1	1	1	1
2.3 Shoot tip colour	2	2	2	2	2	2	2	2	2	2	2	2	2
2.4 Runner shoot production	2	2	1	1	1	2	2	2	1	1	1	1	2
2.5 Holding capacity	2	1	1	1	1	2	1	2	1	2	2	2	2
2.6 Adventitious root production	2	1	1	1	1	2	2	2	1	2	2	2	2
2.7 Lateral branch habit	1	1	1	1	1	2	2	3	1	2	2	2	2
2.8 Lateral branch length (cm)	28.6	21.7	15.5	37.5	29.6	45	38	54.4	46.6	52.2	44.5	26.0	45.5
2.9 No. of nodes/lateral branch	16	14	9.8	14	14.6	14	28	34	31.2	22	26	16.0	27
2.10 Leaf petiole length (cm)	2	1.6	2.25	2.83	2.5	1.6	1.8	1.6	1.2	2.4	1.9	1.4	1.9
2.11 Leaf length (cm)	9	8.3	10.87	9.37	13	12.3	13.5	16.3	9.75	16.1	14.5	14.0	14.5
2.12 Leaf width (cm)	7.16	4.5	7.25	5.87	6.8	6.5	9.4	10.1	5.4	9.8	8	9.5	9.6
2.13 Leaf lamina shape	3	3	3	3	3	3	2	2	2	2	2	2	2
2.14 Leaf base shape	1	1	1	1	1	1	1	1	1	1	1	1	1
2.15 Leaf margin	1	1	1	1	1	1	1	1	1	1	1	1	1
2.16 Type of veining	1	1	1	1	1	1	1	1	1	1	1	1	1
2.17 Leaf texture	1	1	1	1	1	1	1	1	1	1	1	1	1
3.4 Spike length (cm)	5.8	3.5	6.3	5.62	6.9	7.7	7.5	11.9	9.1	10.3	7.5	7.8	8.3
3.5 Type of hermaphroditism	3	3	3	3	3	3	3	6	6	6	6	6	6
3.6 Peduncle length (cm)	1.3	1.12	0.66	1.37	1.2	1.5	1.3	1.2	1.2	1.6	1.5	1.5	1.5
3.7 No. of spikes/lateral branch	9.6	5.5	5	7	7	22	5.6	10	11	7	8	14	14
3.8 Flower arrangement	1	1	1	1	1	1	1	1	1	1	1	1	1
3.9 No. of stamen	2	2	2	2	2	2	2	2	2	2	2	2	2
3.10 Spike texture	1	1	1	1	1	1	1	1	1	1	1	1	1
3.11Bract type	3	3	3	3	3	3	3	3	3	3	3	3	3
3.12 Flower nature	1	1	1	1	1	1	1	1	1	1	1	1	1
3.13 Fruit setting	60	40	60	70	70	67.9	50	60	95	80	40	65	87
3.15 No. of berries/ten spikes	232	100	327	294	287	684	235	351	405	698	314	595	742

Table 35. Descriptor code for morphological characters of Karimunda and Kottanadan accessions

Descriptor	Descriptor state	KS-2	KS-50	KS-113	KS-120	KS-161	KS-14	893	1484	1485	1488	1489	1494	5055
2.2 Branching type	Dimorphic	0	0	0	0	0	0	1	1	1	1	1	1	1
	Polymorphic	1	1	1	1	1	1	0	0	0	0	0	0	0
2.3 Shoot tip colour		1	1	1	1	1	1	1	1	1	1	1	1	1
2.5 Holding capacity	Weak	0	0	0	0	1	0	0	0	1	0	0	0	0
	Strong	1	1	1	1	0	1	1	1	0	1	1	1	1
2.6 Adventitious root production	Few	0	1	1	1	1	0	0	0	1	0	0	0	0
	Many	1	0	0	0	0	1	1	1	0	1	1	1	1
2.7 Lateral branch habit	Erect	1	1	1	1	1	0	0	0	1	0	0	0	0
	Horizontal	0	0	0	0	0	1	1	0	0	1	1	1	1
	Hanging	0	0	0	0	0	0	0	1	0	0	0	0	0
2.8 Lateral branch length (cm)		0	0	0	0	0	1	0	1	1	1	1	1	1
2.9 Number of nodes/lateral branch		0	0	0	0	0	0	1	1	1	1	1	1	1
2.10 Leaf petiole length (cm)		1	0	1	1	1	0	0	0	0	1	0	0	0
2.11 Leaf length (cm)		0	0	0	0	1	0	1	1	0	1	1	1	1
2.12 Leaf width (cm)		0	0	0	0	0	0	1	1	0	1	1	1	1
2.13 Leaf lamina shape	Ovate-elliptic	0	0	0	0	0	0	1	1	1	1	1	1	1
	Ovate-lanceolate	1	1	1	1	1	1	0	0	0	0	0	0	0

Table 36. Paired affinity indices of 6 Karimunda and 7 Kottanadan accessions expressed by morphological characters

Cultivar	KS-2	KS-50	KS-113	KS-120	KS-161	Subhakara	Acc-893	Acc-1484	Acc-1485	Acc-1488	Acc-1489	Acc-1494	Acc-5055
KS-2	1.0000000												
KS-50	0.8571429	1.0000000											
KS-113	0.8571429	0.9047619	1.0000000										
KS-120	0.8571429	0.9047619	1.0000000	1.0000000									
KS-161	0.7619048	0.8095238	0.8095238	0.8095238	1.0000000								
Subhakara	0.6190476	0.5714286	0.5714286	0.5714286	0.3809524	1.0000000							
Acc-893	0.5238095	0.4761905	0.3809524	0.3809524	0.3809524	0.4285714	1.0000000						
Acc-1484	0.3333333	0.2857143	0.1904762	0.1904762	0.1904762	0.4285714	0.7142857	1.0000000					
Acc-1485	0.2380952	0.3809524	0.3809524	0.3809524	0.3809524	0.4285714	0.3333333	0.5238095	1.0000000				
Acc-1488	0.3809524	0.2380952	0.3333333	0.3333333	0.2380952	0.5714286	0.7619048	0.6666667	0.4761905	1.0000000			
Acc-1489	0.4761905	0.4285714	0.3333333	0.3333333	0.3333333	0.4761905	0.9523810	0.7619048	0.3809524	0.8095238	1.0000000		
Acc-1494	0.1904762	0.3333333	0.2380952	0.2380952	0.3333333	0.4761905	0.4761905	0.5714286	0.7619048	0.5238095	0.5238095	1.0000000	
Acc-5055	0.2857143	0.2380952	0.1428571	0.1428571	0.1428571	0.5714286	0.7619048	0.8571429	0.5714286	0.8095238	0.8095238	0.7142857	1.0000000

Table 34. Morphological observations on Karimunda and Kottanadan accessions

Descriptor	KS-2	KS-50	KS-113	KS-120	KS-161	KS-14	893	1484	1485	1488	1489	1494	5055
2.2 Branching type	2	2	2	2	2	2	1	1	1	1	1	1	1
2.3 Shoot tip colour	2	2	2	2	2	2	2	2	2	2	2	2	2
2.4 Runner shoot production	2	2	1	1	1	2	2	2	1	1	1	1	2
2.5 Holding capacity	2	1	1	1	1	2	1	2	1	2	2	2	2
2.6 Adventitious root production	2	1	1	1	1	2	2	2	1	2	2	2	2
2.7 Lateral branch habit	1	1	1	1	1	2	2	3	1	2	2	2	2
2.8 Lateral branch length (cm)	28.6	21.7	15.5	37.5	29.6	45	38	54.4	46.6	52.2	44.5	26.0	45.5
2.9 No. of nodes/lateral branch	16	14	9.8	14	14.6	14	28	34	31.2	22	26	16.0	27
2.10 Leaf petiole length (cm)	2	1.6	2.25	2.83	2.5	1.6	1.8	1.6	1.2	2.4	1.9	1.4	1.9
2.11 Leaf length (cm)	9	8.3	10.87	9.37	13	12.3	13.5	16.3	9.75	16.1	14.5	14.0	14.5
2.12 Leaf width (cm)	7.16	4.5	7.25	5.87	6.8	6.5	9.4	10.1	5.4	9.8	8	9.5	9.6
2.13 Leaf lamina shape	3	3	3	3	3	3	2	2	2	2	2	2	2
2.14 Leaf base shape	1	1	1	1	1	1	1	1	1	1	1	1	1
2.15 Leaf margin	1	1	1	1	1	1	1	1	1	1	1	1	1
2.16 Type of veining	1	1	1	1	1	1	1	1	1	1	1	1	1
2.17 Leaf texture	1	1	1	1	1	1	1	1	1	1	1	1	1
3.4 Spike length (cm)	5.8	3.5	6.3	5.62	6.9	7.7	7.5	11.9	9.1	10.3	7.5	7.8	8.3
3.5 Type of hermaphroditism	3	3	3	3	3	3	3	6	6	6	6	6	6
3.6 Peduncle length (cm)	1.3	1.12	0.66	1.37	1.2	1.5	1.3	1.2	1.2	1.6	1.5	1.5	1.5
3.7 No. of spikes/lateral branch	9.6	5.5	5	7	7	22	5.6	10	11	7	8	14	14
3.8 Flower arrangement	1	1	1	1	1	1	1	1	1	1	1	1	1
3.9 No. of stamen	2	2	2	2	2	2	2	2	2	2	2	2	2
3.10 Spike texture	1	1	1	1	1	1	1	1	1	1	1	1	1
3.11Bract type	3	3	3	3	3	3	3	3	3	3	3	3	3
3.12 Flower nature	1	1	1	1	1	1	1	1	1	1	1	1	1
3.13 Fruit setting	60	40	60	70	70	67.9	50	60	95	80	40	65	87
3.15 No. of berries/ten spikes	232	100	327	294	287	684	235	351	405	698	314	595	742

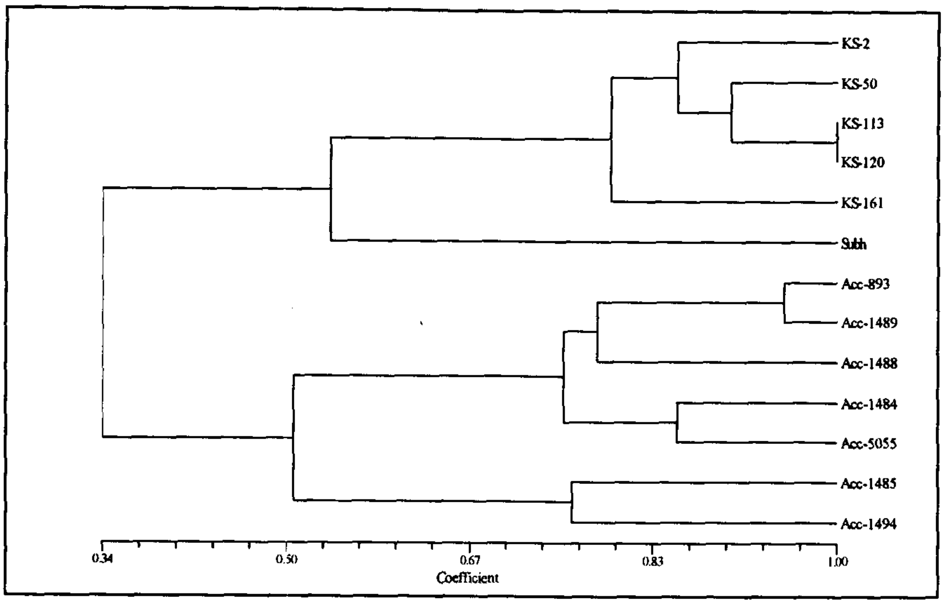


Fig. 47. Dendrogram of divergence of six Karimunda and seven Kottanadan accessions expressed by morphological characterization

Cluster-1	: Sub cluster-1	- KS-2, KS-50, KS-113, KS-120 and KS-161
	Sub cluster-2	- Subhakara
Cluster-2	: Sub cluster-1	- Acc. 893, 1489 and 1488
	Sub cluster-2	- Acc. 1484 and 5055
	Sub cluster-3	- Acc. 1485 and 1494

In the first cluster formed KS-113 and KS-120 showed 100% similarity coefficient and they have shown 85.5% and 83% similarity coefficients with KS-50 KS-2, respectively. The morphological affinity of these OTUs with KS-161, the relatively distant member of this sub cluster was 82.5. The improved variety Subhakara out grouped from sub cluster-1 with 52% similarity.

The second cluster comprised of all 'Kottanadan' selections further sub clustered into three. In the first sub cluster, Acc. 893 and 1489 grouped together with 92% similarity coefficient and the third member Acc. 1488 sowed only 71% affinity to the other members. The improved variety PLD-2 (Acc. 5055) clustered with Acc. 1484 and formed the second sub cluster with 86% similarity and the morphological affinity of these OTUs with sub cluster one was 72%. Accession No. 1485 shared

74% similarity with Acc. 1494 and this sub cluster showed only 50% similarity coefficient with sub cluster 1 and 2 of second cluster.

The dendrogram obtained through the analysis based on morphological characters revealed two major clusters, one comprising of collections of Karimunda and the other consisted of Kottanadan collections clearly separating these cultivars from each other, at the same time grouping different collections of the same cultivar together.

Molecular characterization

The phenotypic data is supplemented with more stable ISSR profiling as an index for genetic interrelationship. ISSR profiles were done using 10 primers viz. $(CAC)_8$ GC, $(CTC)_8$ GC, $(GACA)_3$, $(AGTG)_3$, $(AT)_7$ G, $(TA)_7$A, $(GA)_6$ GG, $(GT)_6$ GG, $(GATA)_3$ CC and $(GT)_6$ CC (Fig. 48 and 49). Thirty-one markers were scored of which twelve were polymorphic. Maximum amplification was observed with the ISSR primer $(CTC)_8$.

Similarity value for all the 13 accessions ranged from 0.66 to 100 (Table 37). The similarity matrix representing Jaccard's coefficient was used for cluster analysis. The resultant phenogram (Fig 50.) grouped into two major groups.

All the Karimunda and Kottanadan accessions formed a single major group with five sub clusters, but Acc.1488 out grouped and kept separate as the second major cluster as shown below:

224.A

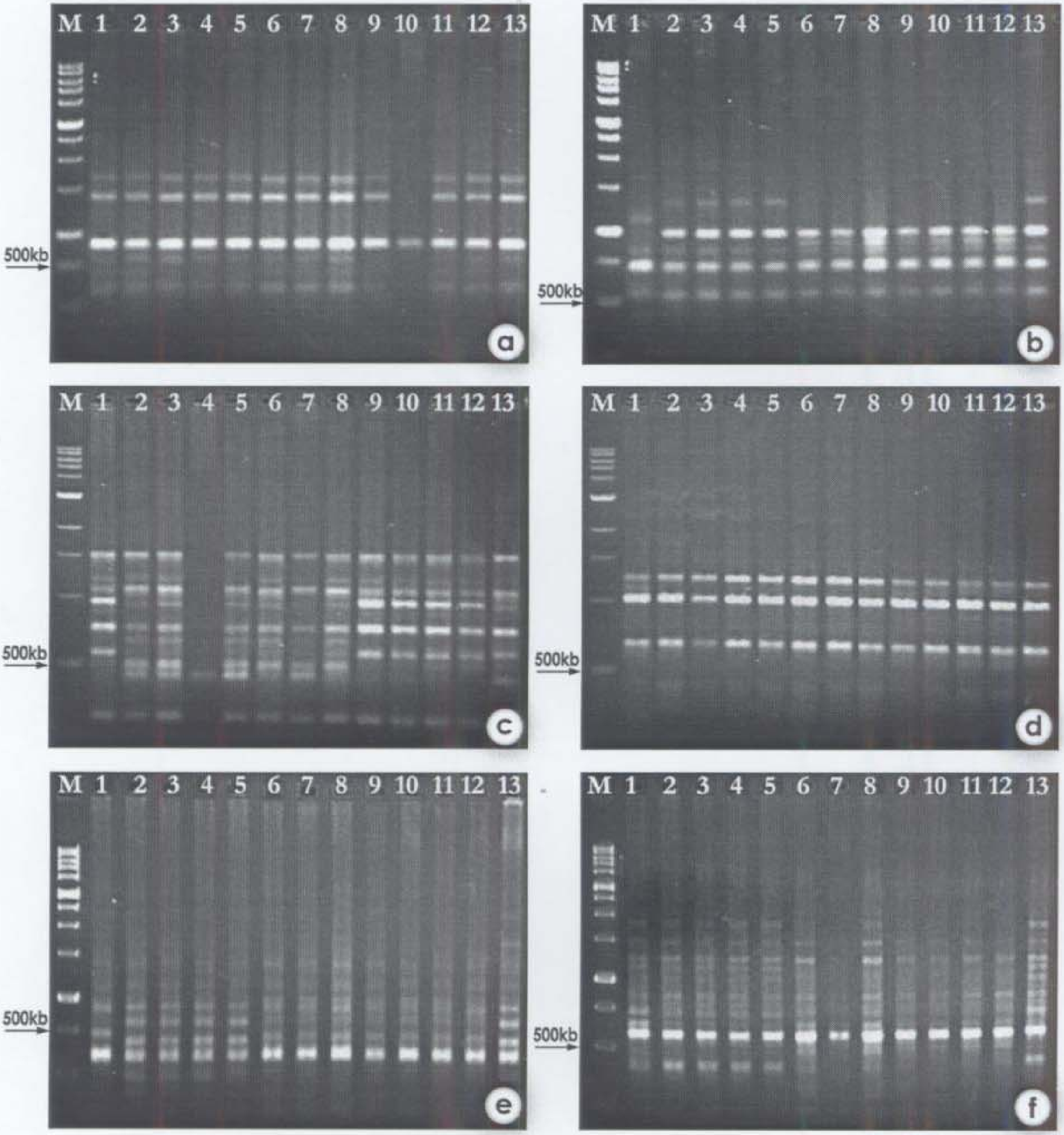


Fig. 48. ISSR profiles of thirteen Kottanadan & Karimunda accessions
Primers a) (CAC)8 GC, b) (CTC)8 GC, c) (GACA)3, d) (AGTG)3, e) (AT)7 G, f) (TA)7 A.

Lane M- Marker 1 Kb ladder, 1 KS-2, 2 KS-50, 3 KS-113, 4 KS-120, 5 KS-161, 6 Subhakara, 7 Coll. 893, 8 Coll. 1484, 9 Coll.1485, 10 Coll. 1488, 11 Coll. 1489, 12 Coll. 1494 and 13 Coll. 5055.

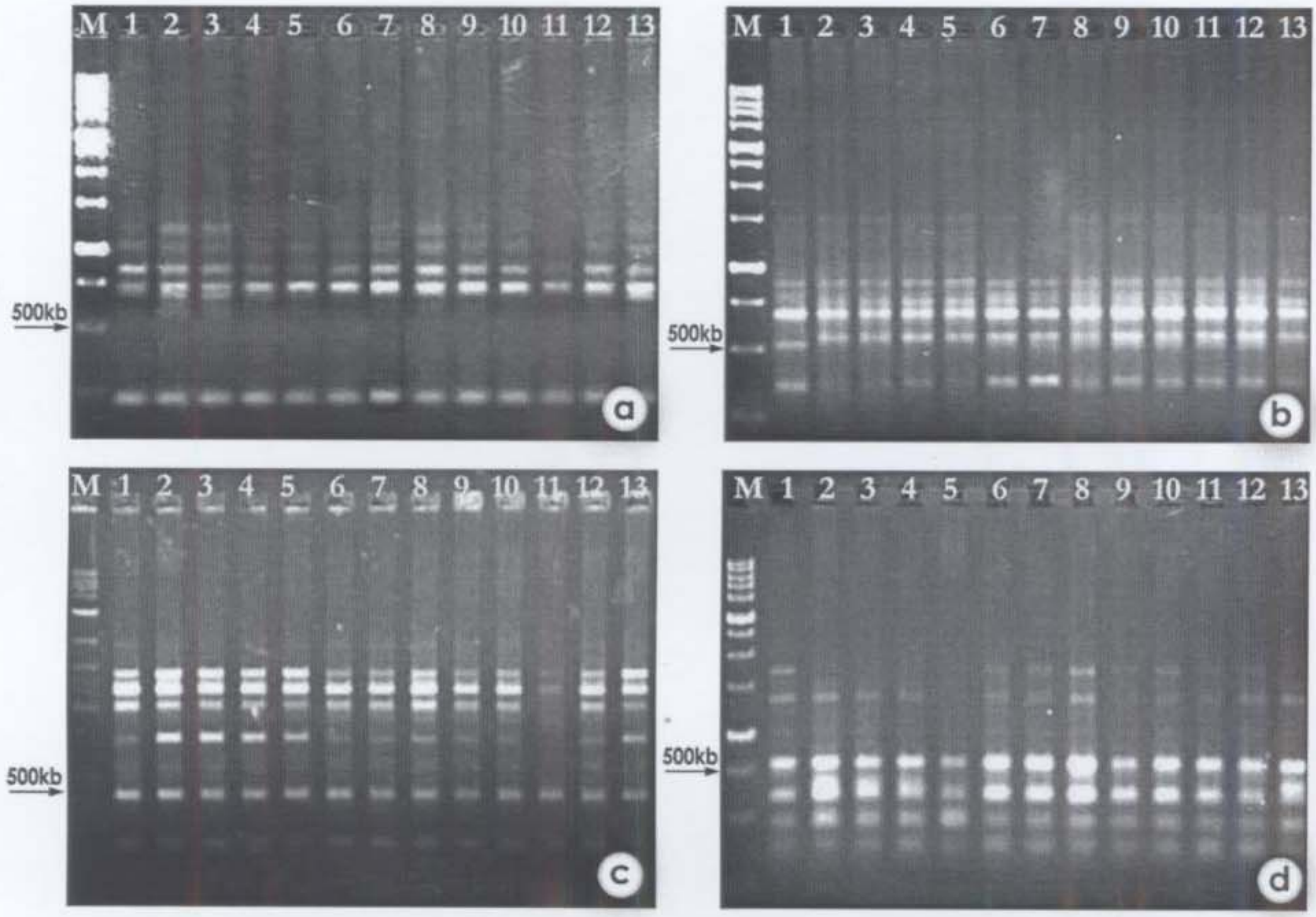


Fig. 49. ISSR profiles of 13 Kottanadan & Karimunda accessions
Primers a) (GA)6 GG, b) (GT)6 GG, c) (GATA)3 CC and d) (GT)6 CC.
Lane M- Marker 1 Kb ladder, 1 KS-2, 2 KS-50, 3 KS-113, 4 KS-120, 5 KS-161, 6 Subhakara, 7 Coll. 893, 8 Coll. 1484, 9 Coll.1485, 10 Coll. 1488, 11 Coll. 1489, 12 Coll. 1494 and 13 Coll. 5055.

Table 37. Paired affinity indices of 6 Karimunda and 7 Kottanadan accessions expressed by molecular markers

Cultivar	KS-2	KS-50	KS-113	KS-120	KS-161	Subhakara	Acc-893	Acc-1484	Acc-1485	Acc-1488	Acc-1489	Acc-1494	Acc-5055
KS-2	1.0000000												
KS-50	0.8333333	1.0000000											
KS-113	0.8333333	1.0000000	1.0000000										
KS-120	0.6666667	0.8333333	0.8333333	1.0000000									
KS-161	0.8333333	1.0000000	1.0000000	0.8333333	1.0000000								
Subhakara	0.8333333	0.8888889	0.8888889	0.7222222	0.8888889	1.0000000							
Acc-893	0.8333333	0.8888889	0.8888889	0.7222222	0.8888889	1.0000000	1.0000000						
Acc-1484	0.8333333	0.8888889	0.8888889	0.7222222	0.8888889	1.0000000	1.0000000	1.0000000					
Acc-1485	0.8888889	0.9444444	0.9444444	0.7777778	0.9444444	0.9444444	0.9444444	0.9444444	1.0000000				
Acc-1488	0.5555556	0.6111111	0.6111111	0.4444444	0.6111111	0.7222222	0.7222222	0.7222222	0.6666667	1.0000000			
Acc-1489	0.8333333	0.8888889	0.8888889	0.7222222	0.8888889	1.0000000	1.0000000	1.0000000	0.9444444	0.7222222	1.0000000		
Acc-1494	0.8333333	0.8888889	0.8888889	0.7222222	0.8888889	1.0000000	1.0000000	1.0000000	0.9444444	0.7222222	1.0000000	1.0000000	
Acc-5055	0.8333333	1.0000000	1.0000000	0.8333333	1.0000000	0.8888889	0.8888889	0.8888889	0.9444444	0.6111111	0.8888889	0.8888889	1.0000000

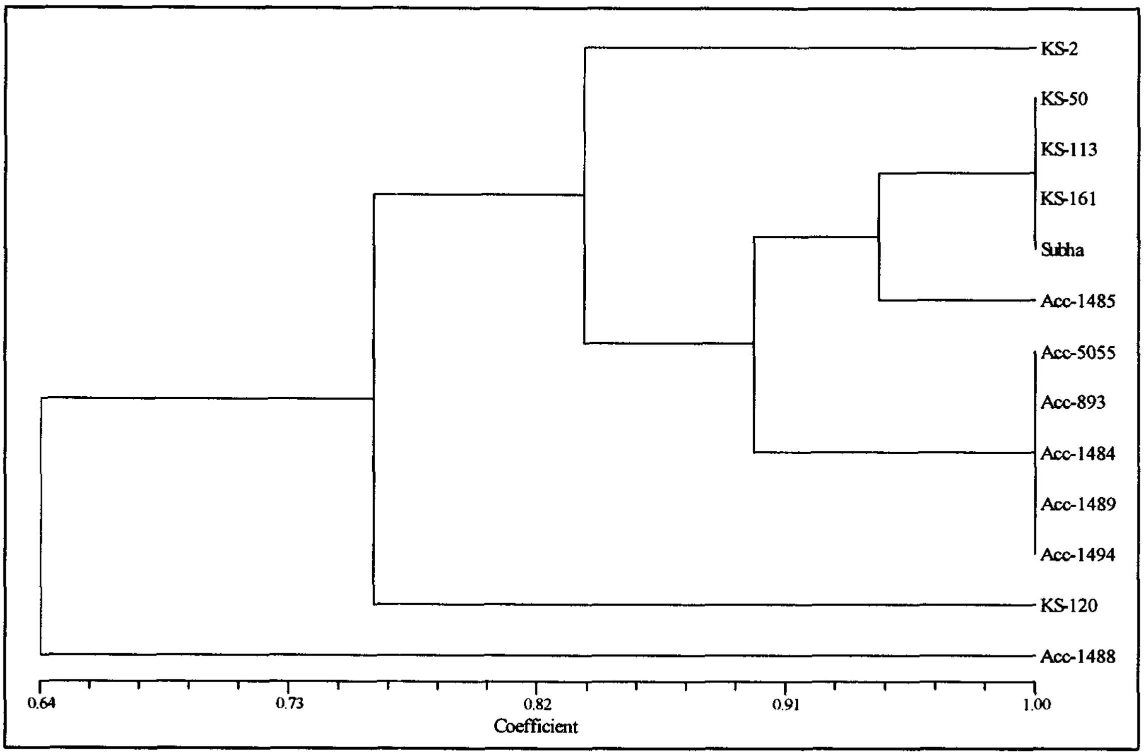


Fig. 50. Dendrogram of divergence of six Karimunda and seven Kottanadan accessions expressed by ISSR markers

Cluster-1 : Sub cluster-1 - KS-2
Sub cluster-2 - KS-50, KS-113, KS-161 and Subhakara
Sub cluster-3 - Acc. 1485
Sub cluster-4 - Acc. 5055, 893, 1484, 1489 and 1494
Sub cluster-5 - KS-120

Cluster-2 : Acc. 1488

Though most of the cultivars were grouped into a single cluster, they were sub clustered into different groups as expected. KS-2 the lone member in the first sub cluster out grouped from the remaining member with 83% similarity coefficient. In the second sub cluster all the Karimunda accessions including the improved one clustered together with 100% similarity. The third sub cluster was with one member *viz.* Acc. 1485 which out grouped from the second sub cluster. The fourth sub cluster was with five Kottanadan selections including the improved variety PLD-2 (Acc.

5055). They have shown 100% similarity to each other. The Karimunda accession, KS-120 out grouped from the other sub cluster with 76% similarity coefficient.

The second cluster consisted of only one member with a significant distance of 64% similarity coefficient indicating that this accession is genotypically different from the other OTUs studied.

```
          +----------------------------KS-2
          |
          |                        +---KS-50
          |                   +99.0
          |              +95.0     +---KS-113
          |              |   |
     +55.0          +60.0    +--------KS-161
     |    |         |    |
     |    |    +36.0     +------------Subhakara
     |    |    |    |
     |    |    |    +-----------------1485
     |    |    |
     |    |    |                 +---5055
     |    +49.0              +84.0
+67.0          |        +84.0    +---893
|    |         |        |   |
|    |         |   +65.0    +--------1484
|    |         |   |    |
|    |         +65.0    +------------1489
|    |             |
|    |             +-----------------1494
|    |
|    +--------------------------------KS-120
|
+-------------------------------------1488
```

Fig. 51. Dendrogram showing the genetic relationships among six accessions each of Karimunda and Kottanadan accessions expressed by ISSR markers derived from Jaccard coefficient of similarity. Bootstrap *P* values are given at the corresponding node for each cluster

Bootstrap analysis of molecular data also revealed a significant bootstrap 'P' value between KS-50 and KS-113 (99%) and this cluster was very close to KS-161 (95%). Significant bootstrap value was also observed between Acc. 5055 and Acc. 893 (84%) and with Acc. 1484 (84%).

229.A

Discussion

Piperaceae is considered to be one of the most primitive families of Angiosperms (Engler, 1893; Rendle, 1925) derived from the herbaceous proto-angiosperms with simple, minute flowers (Heywood and Fleming, 1986; Taylor and Hickery 1990, 1992). Hence, the classification and taxonomy of *Piper* and its species are heavily dependent upon few morphological and fewer floral characters. Characters like plant habit, pubescence, texture and leaf shape of juvenile and mature forms, orientation of the spike and length of peduncle, nature of bract and fruit colour are used as key distinguishing features in both male and female types to identify different species (Hooker, 1886; Kanjilal *et al.,* 1940; Gamble, 1925).

Habitat and distribution of the genus *Piper*

The genus *Piper* is one of the major components of the tropical forest ecosystem (Hartemink, 2001). They are abundant in low and mid-elevation forests, rarely reaching up to 2,500 m in elevation. The distribution of *Piper* ranges from sea level to Andes and the sub- Himalayas (Royle, 1839). The areas of *Piper* species diversity include Southeast Asia, Southern Mexico, the Andes, the Choco, Amazonia and the Atlantic forests of Brazil (Ravindran, 2000; Marquis, 2004).

The main centre of distribution for neotropical species is Central America (Trelease, 1929; Trelease and Yunker, 1950; Sasikumar *et al.*, 1999b). In the Central American forests, the genera is mainly distributed in four different habitats *viz.* edge of the semi deciduous forests, inside the semi deciduous forests, edge of the swampy forests and inside the swampy forests. Some are restricted to certain ecological niches while the others have wider distribution occurring in all habitats (De Figueiredo and Sazima, 2004).

According to Jaramillo and Callejas (2004), *Piper* is more diverse in the American tropics than in the Asian tropics (ca. 700 vs. 300 species, respectively). The paleotropic species mainly distributed in the moist evergreen forests and to a lesser extent in the semi-evergreen forests, mainly in Malaysia (about 400 species), Philippines (about 133 species), Indian sub continent (about 115 species) and to a certain extent in China (69 species) and South Pacific (40 species). About 15 species of *Piper* also occur in the African tropics (Jaramillo and Manos, 2001). The occurrence and distribution of *Piper* species around the world based on earlier reports is depicted in Fig. 1. The highest number of species occurs in Central America followed by Malaysia, Philippines and India. The species abundance in these regions indicates the origin of *Piper* in both New World (Central American region) and Old World (Malaysia, Philippines and India). Most of the species in New World can be grouped as 'neotropical' corresponding mostly of shrubs and rarely climbers and the paleotropic species, which are climbers, creepers or bushy forms indicating clear divergence among them with respect to habit and habitat. In general, most of the New World *Piper* species are monoecious while those in Asia and South Pacific are dioecious. It can be inferred from the above that based on the richness of *Piper* species, Central America, Tropical Asia and South Pacific can be considered as the three major regions in which the genus *Piper* could have originated.

The Phylogenetic analysis of genus *Piper* on worldwide samples further supported that the taxa representing major geographic areas could potentially have originated from three groups: Asia, the South Pacific and Central America (Jaramillo and Manos, 2001). However, the taxa from the South Pacific and Tropical Asia formed a monophyletic group, provisionally supporting a single origin of dioecy among the *Piper* species of these regions. The species from the South Pacific would have had the common origin from Asian (Malaysia and Indonesia) species.

No information is available about the origin of *Piper* species reported to be endemic to Tropical Africa (Jaramillo and Callejas, 2004). The endemic nature of these species itself points to their independent origin.

Hence, the available information on occurrence, richness and distribution of *Piper* species indicates two major centers of origin, one in Tropical America and the other in Tropical Asia including Philippines and South Pacific (Fig. 52). However, it is also possible that the African *Piper* may have had independent origin, which needs further investigation.

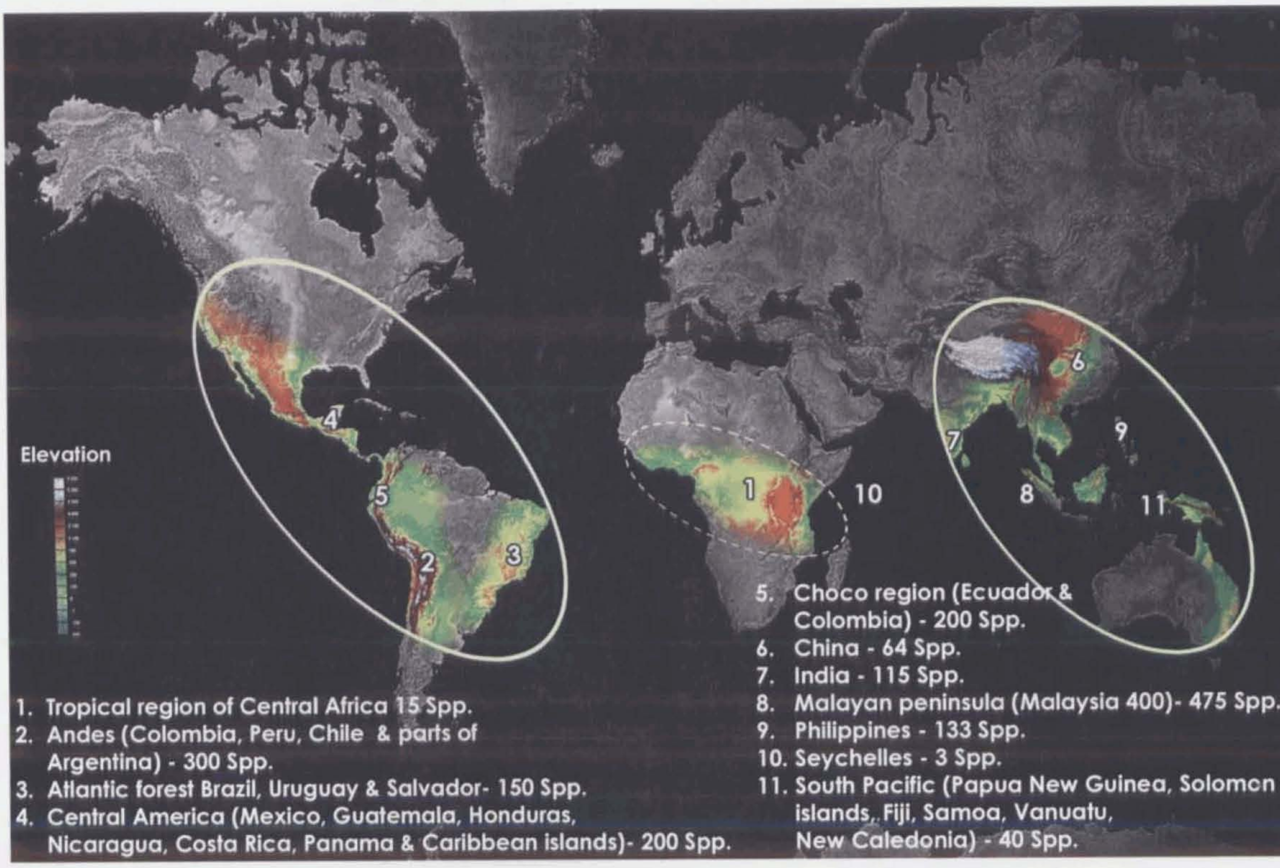


Fig. 52. Probable centers of origin of the genus *Piper*

Distribution of the genus *Piper* in India

From the Indian sub continent over 115 species have been reported (Hooker, 1886; IPNI, 2006; Rahiman, 1981) distributed mainly in Western Ghats of Indian Peninsula and North Eastern regions. This made Hooker (1886) to identify these regions as two independent centers of diversity for *Piper*. However, Rahiman (1987) in addition has proposed Eastern Ghats as the third center.

Since the species which occur in the Eastern Ghats region are those which also occur in much higher population and diversity in the Western Ghats regions of India, Hooker (1886) seems to be more correct in designating two major centers of *Piper* in India.

Diversity and Geographical distribution of South Indian *Piper* species

The Western Ghats in South India comprises the states of Kerala, Karnataka and Tamil Nadu of South India, running along the western border of the Deccan plateau, about 1400 km long with an elevation ranges from 915 to 2695m (Nair, 1991). This region has typically tropical climate with heavy winds and an annual rainfall of >3000 mm during both south west and the north east monsoons, thus making an ideal tract for *Piper*.

About 18 species are reported from South India (Gamble, 1925; Ravindran *et al.* 1987; Velayudhan and Amalraj, 1992; Nirmal Babu *et al.*, 1993 and Tyagi *et al.*, 2004), which are found to occur from almost sea level to an elevation of 2000m. The distribution of *Piper* is denser along footpaths, animal tracts, riversides and towards the periphery of the forests, where there is good light penetration. However, in disturbed forests they occur in good number even in the interior due to the increased light availability (Ravindran, 2000). *Piper* being a highly sensitive aerial plant and destruction through forest fires can destroy pepper population and there will be no rejuvenation as *Piper* seeds are recalcitrant and cannot withstand fire.

During collection surveys, very high fruit set was observed among the populations of female vines of *Piper* species in the absence of male vines in the near vicinity of these populations. This may point to the possibility of apomixis resulting in higher than the expected fruit set. Gentry (1955b) also suspected apomixis must have been playing a major role in black pepper.

All the *Piper* species occurring in South India, except *P. silentvalleyensis* are dioecious. However, during the collection surveys a few individuals with different degree of hermaphroditism were noticed mostly among the collections of *P. nigrum*, and to a certain extent in *P. sugandhi* and *P. attenuatum*.

Fifteen related *Piper* species collected from various parts of Western Ghats, fifteen collections of wild forms of *Piper nigrum* and eight collections of *P. longum* from different locations have also been used to study the inter and intra- species variability in these two economically important species.

Distribution and diversity of fifteen *Piper* species occurring in South India were studied based on the actual collection data supported by GIS. The patterns based on GIS indicated that: –

P. longum is the most widely distributed species among the *Piper* species and occurs at an altitude of 40 - 310 m in all districts of Kerala. Population density is maximum in Palaghat, Malappuram and Idukki regions and minimum in Kasaragod.

P. hapnium, has limited distribution and confined to Manalar regions of Kollam District at an elevation between 250 - 360 m. This was supported by the observations of Nayar and Sastry (1988) who considered this species as 'endangered' and recorded it in the 'Red' data book of the Botanical Survey of India.

P. mullesua, a species with globular female spike, is distributed in Kerala, Karnataka and Tamil Nadu at an altitude between 600 - 1740 m. The population density was maximum in Naduvattom region in Tamil Nadu, Silent Valley forests in Kerala and Thalacauvery region in Karnataka, which can be considered as the ecological niches for this species.

P. silentvalleyensis, a unique species with erect bisexual spikes is the rarest among the South Indian species of *Piper* and was collected only from a single location at an elevation of 1700 m at Paikara of Nilgiri District, Tamil Nadu. The only other collection of the species was made from the Silent Valley forests of Kerala by Ravindran *et al.* (1987), but could not be located in my study. This most endangered hermaphrodite would be an ideal case for ecorestoration, which is a challenging task and unless protected, will become extinct very soon.

P. attenuatum, P. argyrophyllum and *P. hymenophyllum* are the most common species of *Piper* with pendulous spikes and adnate bracts with free margins. Among these *P. attenuatum* is the most widely distributed and occurs in all the forest regions of Kerala, Karnataka and Tamil Nadu at an elevation of 40 - 990 m. The species abundance was high at lower elevations of Silent Valley forest of Palaghat, Neyyar and Peppara areas of Thiruvananthapuram District and nearby forests in Tirunelveli District, which can be considered as the ecological niches.

P. argyrophyllum is found to occur at similar elevations of 80 - 900 m. Species abundance was at maximum in Malappuram District followed by Wayanad and Idukki districts in Kerala, Kodagu District in Karnataka and Tirunelveli District in Tamil Nadu.

P. hymenophyllum, the most hirsute species among the three, is widely distributed in the wet evergreen forests of Kerala, Karnataka and Tamil Nadu at medium elevations (160 - 1100 m). Species abundance was maximum in Kodagu District of Karnataka followed by Wayanad and Palaghat districts of Kerala.

P. schmidtii and *P. wightii* are two species seen occurring only at higher elevations. The distribution of *P. wightii* ranged from 1750 - 2600 m while that of *P. schmidtii* is from 1700 - 2360 m. They are extensively distributed in the Shola forests of Nilgiri District of Tamil Nadu, which can be considered as the area of maximum diversity for these species. Though occurring intermingled, they are clearly distinct from each other in almost all morphological characters and no intermediate forms were observed indicating clear species separation. Ravindran *et al.* (2000), who actually used these criteria while preparing a key for South Indian *Piper*, also reported similar observations. The population of *P. schmidtii* gradually decreases as the elevation increases to above 2500 m. Manilal (1988) reported the sparse occurrence of these species in Silent Valley region in Kerala. In the present study, small populations of *P. schmidtii* and *P. wightii* were found occurring intermingled in Munnar region of Kerala at elevations above 1500 m.

P. galeatum and *P. trichostachyon* are clearly separated in their floral morphology from rest of the South Indian *Piper* species. These two species are characterized by stalked (stipitate) flowers with fused bracts to form a receptacle from which the flower arises, which is the most discriminating character of these two species. These species though broadly resembling *P. nigrum* in other characters differ from it in leaf, flower and fruit characters. *Piper galeatum* is a hardy vine growing to great heights occurring generally in medium to high elevation at an altitude of 420 - 1560 m in the wet evergreen forests of Kerala, Karnataka and Tamil Nadu. Population diversity was found to be maximum in Wayanad, Idukki and Silent Valley regions of Kerala and Coorg District of Karnataka.

P. trichostachyon and *P. galeatum* are very similar to each other in their morphological characters and often confused. The important discriminating characters for separating these species are the pubescent spikes in *P. trichostachyon*. However, the distribution of *P. trichostachyon* is comparatively limited and was found to occur at an elevation of 440 - 1150 m in Kerala, Karnataka and Tamil Nadu. Its population was maximum in Kodagu and Chickmagalur districts of Karnataka followed by Wayanad District of Kerala. These species are found intermingled with each other and many intermediary forms are occurring in regions of combined occurrence. It is quite possible that occasional crossing between these species resulting in intermediary forms. More information is needed to ascertain whether these two are clearly separate species or distinct forms of same species. Both have the reported chromosome number 2n = 52 (Rahiman and Nair, 1986); the same number that was found in *P. nigrum* and *P. sugandhi* (Mathew 1958, 1974; Rahiman and Nair, 1986, Ravindran and Nirmal Babu, 1994a, Mathew *et al.*, 1999)

P. sugandhi closely resembles *P. nigrum*, but for the slightly stalked flowers. It is found distributed among the populations of *P. trichostachyon*, *P. galeatum* and wild forms of *P. nigrum* at an altitude between 560 - 1500 m. Species abundance was maximum in Wayanad and Idukki districts of Kerala. A good population was located in Chickmagalur District of Karnataka also. *P. sugandhi* is another intermediary species resembling *P. nigrum* on the one hand and either *P. trichostachyon* or *P. galeatum* on the other. Nirmal Babu *et al.* (1993) first reported this species and suggested that *P. sugandhi* may be a natural hybrid involving *P. nigrum* and *P. galeatum*. The preset study supports this view. Velayudhan *et al.* (1999) also reported almost similar morphological forms resembling *P. nigrum*, which he named *P. pseudonigrum*. Though this species was not used in the present study, the information available from the morphological characters of the species indicates the probability that *P. sugandhi* and *P. pseudonigrum* may be distinct forms or variants of the same species. Velayudhan *et al.* (1999) also reported the occurrence of intermediary forms between *P. nigrum* and *P. pseudonigrum* (*P. sugandhi*) in Silent Valley forest above 900 m indicating the natural hybridization in these two species.

P. bababudani similar to *P. sugandhi* in phenotypic characters but with fleshy peduncle, bold yellow berries and the limited distribution make the species distinct. This species originally reported by Rahiman (1981) from Bababudan hills in Karnataka (600 - 1500 m) and could be collected only from two locations viz. Garwale forest of Kodagu District and Thirunelly forests (Pakshipathalam) of Wayanad District and can be considered endangered.

P. barberi is an unique species of *Piper* having leaves with reticulate venation and unusually long peduncle. No other South Indian species of *Piper* exhibit these characters. It has very limited distribution and could be collected only from a few locations viz. Anamalai and Kannikatti forests of Tamil Nadu at an elevation of 520-600 m. Even in these locations, only one or two plants were found making this species highly endangered. Nirmal Babu *et al.* (1992) also made similar observations.

The Western Ghats region of South India is considered as the center of origin of *P. nigrum* where the wild forms still exists in plenty (Ravindran, 2000; Ravindran. and Peter, 1995). Among the species of *Piper, P. nigrum* has the maximum diversity, adaptability and density and occurs at almost all areas of this region from sea level (40 m) to an altitude of 1100 m. The distribution of wild forms of *P. nigrum,* though abundant in almost all regions of Western Ghats, is maximum in Palaghat, Idukki and Pathanamthitta districts of Kerala, Hassan District and Jogg falls region of Karnataka. Occurrence of wild forms of *P. nigrum* at elevations above 1100 m was not noticed though the cultivation of black pepper was prevalent even up to an elevation of 2500 m.

Though *P. longum* has wide adaptation and distribution, the diversity is very limited especially due to lack of sexual reproduction and predominant vegetative propagation. Lebot *et al.* (1999) has found similar observations in Hawaiian collections of Kawa (*P. methistichum*). The production of runner shoots were less and decrease as the plant becomes older in some of the species like *P. hapnium*, *P. silentvalleyensis* and *P. barberi* resulting in reduced spread of these vines and making the population less in the forests than others (Subramanyam and Henry, 1970; .Ravindran *et al.*, 1987; Nayar and Sastry, 1988; Saji *et al*, 2001). This coupled with weak holding capacity which make the vine to slip down resulting in lower or no seed production (sexual reproduction) make the populations of certain less diverse and leading to population erosion. Since, both vegetative and sexual mode propagation in *Piper* contribute to population density, diversity (recombinants) and spread. Hence *P. bababudani*, P. *hapnium* and *P. silentvalleyensis* are to be given the highest priority for conservation, multiplication and reintroduction. Species like *P. hapnium, P. silentvalleyensis* and *P. barberi* are listed in the endangered category.

The nature of hermaphroditism indirectly affects fruit set, and subsequently number of propagules the plants can produce. This character also contributes to the decrease in population size of a given species. It was observed in our study that the species, which are in lesser population and are endangered, have less efficient vegetative (less number of runner shoots and weak holding capacity) and reproductive (number of fruits) characters.

Thus, in the present study the diversity and distribution of *Piper* species is estimated based on actual collections and plotted with DIVA – GIS. The locations of maximum diversity are represented in Fig 5. This helped in identifying the ecological niches of each species for developing future strategies for conservation and evolution of these species. The regions, which can be considered as ecological niches of different species of *Piper* as represented in Fig 53.

The community composition, species richness, relative abundance of different species and species diversity in a community could be indicated using Shannon's diversity index (Beals, 1998), and the Western Ghats region of South India could be divided into seven classes, based on relative abundance of different species and species diversity in a community. The hilly regions of Kerala and Tamil Nadu are the two areas with maximum diversity – especially the mountainous regions between the two States. This might be the possible centre of origin for the South Indian species of *Piper*. Based on the study, the contiguous regions comprising Palghat and Wayanad districts of Kerala, Kodagu District of Karnataka and Nilgiri District of Tamil Nadu form the center of gamma diversity and almost all the south Indian species can be conserved if the wild habitats in these districts are protected. Earlier studies by Parthasarathy *et al.* (2005) also support this view.

The study indicates that the diversity and evenness in the undisturbed habitat (hilly forests of Kerala /TN border) are much higher than in the site from the highly disturbed habitat (coastal regions, heavily populated). The diversity indices provide more information than simply the number of species present (i.e., they account for some species being rare and others being common), they serve as valuable tools that enable biologists to quantify diversity in a community and describe its numerical structure

In view of the rapid depletion of primary sources of *Piper* germplasm, there should be legislation to prevent any further damage though plant collectors and the use of digital herbaria may be encouraged. Need for type specimen should be restricted only to Kew herbarium for identification. Programmes for rapid multiplication of rare and endangered on the verge of extinction and restoration in original habitat should be supported on priority basis.

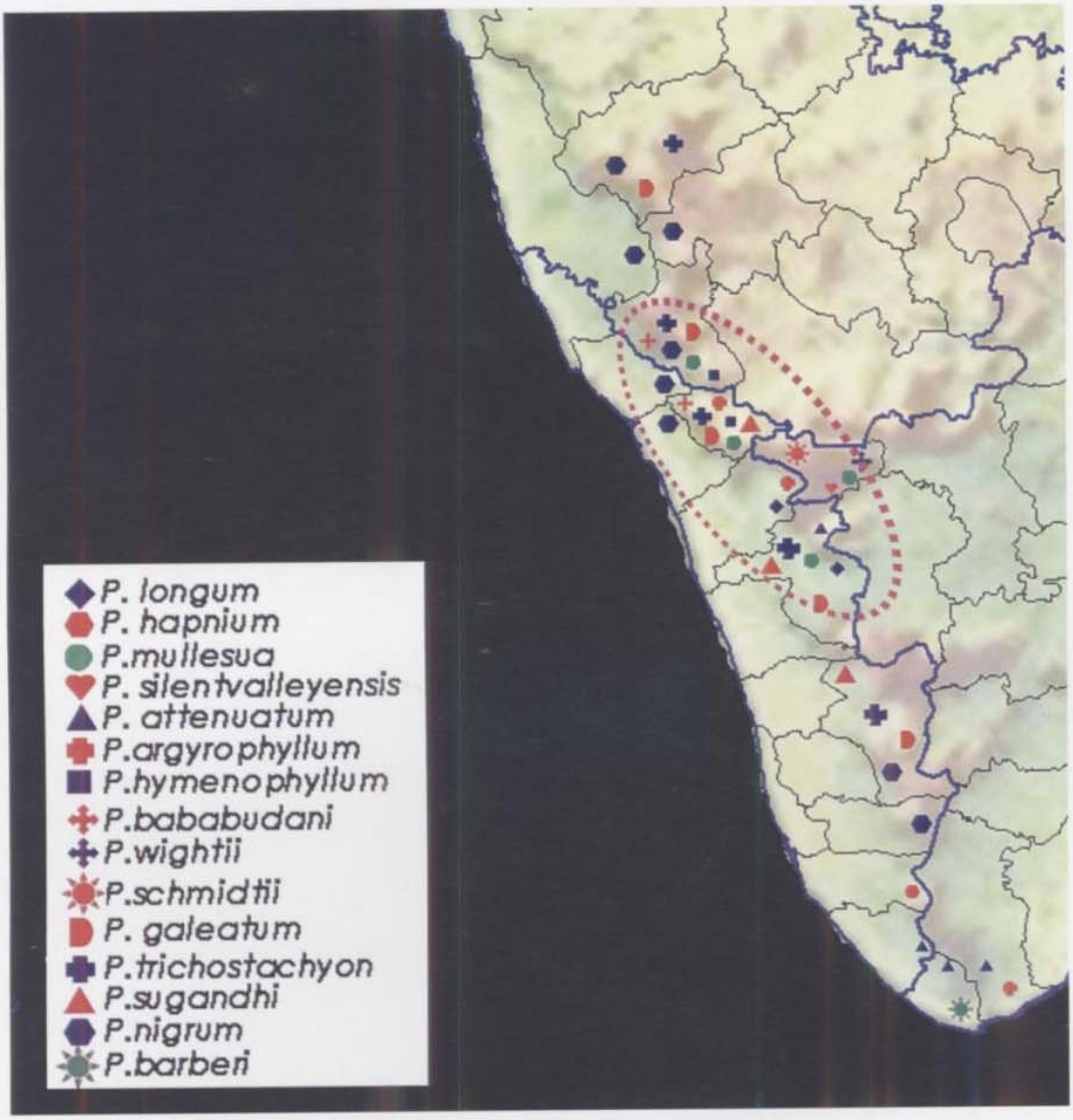


Fig. 53. Ecological niches of *Piper* species in South India the circled areas indicats the gamma diversity of *Piper* spp.

Taxonomy

Linnaeus (1753) was first to report 17 species of *Piper* in his '*Species Plantarum*'. The early classification systems proposed for the family Piperaceae were those of Kunth (1839) and Miquel (1843) who divided the family into 8 and 20 different genera respectively. Later, de Candolle (1869, 1923) proposed a new classification in which most of the genera recognized by Kunth and Miquel were included in two large genera - *Piper* and *Peperomia*, each with more than 1,000 species and several sections. He subdivided *Piper* into 11 sections, many of them corresponding to groupings recognized by Miquel and Kunth at the genus level. These early treatments had the advantage of including species from the whole geographic range of the family, thus presenting a more integrated picture of the classification. The taxonomy of *Piper* has been problematic since tropical exploration increased in the 18^{th} and 19^{th} centuries. Despite the attention of many notable botanists (Kunth, 1839; Miquel, 1843; de Candolle, 1869, 1923; Hooker, 1886), the taxonomy of *Piper* remains difficult and enigmatic (Yuncker, 1958; Bornstein 1989). Among the factors contributing to a difficult taxonomy are that many species have been described within the past 100 years based on sterile and fragmentary material (Trelease and Yunker, 1950) and several recent authors have applied drastically different species concepts (Trelease, 1929; Tebbs 1989, 1990, 1993). Howard (1973) states that the family Piperaceae is one of the "worst messes" in the plant taxonomy.

Digitized herbaria were prepared for the first time in *Piper*. These digitized live pictures can fulfill the requirement of observing live specimens at any given time. In view of the over exploitation of live specimens from forests for making herbaria, it would be advisable to minimize such live collections and instead use digitized herbaria for study rather than depleting the natural vegetation.

Inter species variability

In the present study, morphological characterization of 15 different South Indian *Piper* species was done using 33 discriminative characters. The results indicated extensive inter-specific variation with respect to growth habit, shoot tip colour, runner shoot production, holding capacity, adventitious root production, leaf size, leaf base, leaf margin, leaf venation, leaf hairiness, leaf texture and reproductive characters like spike orientation, spike shape, spike colour, spike length, type of hermaphroditism, peduncle length, number of spikes/lateral branches, flower arrangement, spike texture, bract type, flower nature, fruit shape, fruit size and fruit taste.

Morphometric analysis

Cluster analysis based on morphological observations revealed that the fifteen taxa used fall under four major clusters. The first major group contains two herbaceous species of *Piper* with erect spikes-*P. longum* and *P. hapnium.* All the remaining *Piper* species, which are climbing vines, are grouped together except *P. barberi* that is uniquely placed. This is due to the fact that *P. barberi* is the only South Indian species with reticulate venation, aphyllate juvenile shoots and unusually long peduncle. Spike characters coupled with leaf characters made a distinct role in separating the South Indian *Piper* species into three groupings. Thus, leaf characters like leaf base, margin, venation, and spike characters like spike orientation, shape, peduncle length, flower arrangement and bract type have played major role in differentiation and identification of South Indian *Piper*.

Ravindran (1991) and Ravindran and Nirmal Babu. (1996) were the first to group South Indian *Piper* using morphometric analysis and prepared a key for identification of South Indian *Piper* species. They (Ravindran *et al.*, 1992a, 1994b, 1996) also conducted numerical and chemo-taxonomical analysis of South Indian *Piper* before grouping them into allied groups. The present study though in general agrees with the findings of Ravindran (1991), did not fully agree with them. He subdivided the South Indian *Piper* in to two major groups, 'Pippali' with erect spikes and 'Maricha' with pendent spikes. In the present study, this grouping is not clear cut. However, *P. longum* and *P. hapnium* are uniquely placed as a separate group *P. mullesua* and *P. silentvalleyensis,* the other two species with erect spikes are placed along with the species with pendent spikes. This is essentially because, in the present study, both leaf as well as spike characters played a role in distinguishing the species of *Piper*, whereas Ravindran's (1991) study is solely dependent on the erect nature of the spike for major groupings. Hooker (1886) has placed *P. nigrum* along with *P. attenuatum*, *P. hymenophyllum* and *P. wightii* under the section Eupiper. However, the present study places *P. nigrum* along with *P. sugandhi*, *P.*

bababudani, Karimunda, *P. wightii*, *P. schmidtii*, *P. galeatum* and *P. trichostachyon* all are having acrodromous venation and looks similar in juvenile phase. Studies of Mathew and Mathew (2002) based phenotypic resemblances agree with the present groupings with respect to most of the species except *P. wightii* and *P. schmidtii*.

In other observations, the present study agreed with the studies of earlier workers (Ravindran *et al.*, 1992a; Ravindran and Nirmal Babu, 1996; Mathew and Mathew, 2002) broadly the classification of Gamble (1925) and partly the classification given by Hooker (1886). Hooker (1886) has placed *P. nigrum* along with *P. attenuatum*, *P. hymenophyllum* and *P. wightii* under the section Eupiper. However, the present study places *P. nigrum* along with *P. sugandhi*, *P. bababudani*, Karimunda and *P. wightii*, *P. schmidtii*, *P. galeatum* and *P. trichostachyon*, all are having acrodromous venation and looks similar in juvenile phase.

Molecular analysis

Molecular data was also used for further clarity in species interrelationships. RAPD and ISSR profiles of the 15 species of *Piper* were analyzed and phylograms were drawn. The molecular analysis resulted in a better resolution and identified five major clusters. The clustering pattern was similar to the morphological characterization except for cluster III and cluster-V.

The cluster III can be sub-grouped into five sub-clusters. *P. bababudani*, *P. schmidtii* and *P. barberi* formed independent clusters while *P. sugandhi*, *P. nigrum* and Karimunda formed one cluster and *P. trichostachyon* and *P. galeatum* formed the other cluster.

Molecular characterization which reflects more of genetic similarities and differences have separated *P. schmidtii* and *P. wightii* which were grouped together in morphological (phenotype) characterization. Both of them, though placed in different groups, showed their uniqueness and are placed separately within the grouping.

P. sugandhi, *P. nigrum* and Karimunda as expected were grouped together. These three species have black pepper like fruits, spikes and plant characters except that *P. sugandhi* has short stipitate flowers. These species also have somatic chromosome number 2n= 52 indicating common cytotaxonomy. Nirmal Babu *et al.* (1993) indicated the possible origin of *P. sugandhi* as a hybrid involving *P. nigrum* as one of the parents and either *P. trichostachyon* or *P. galeatum* as the other parent.

The present study at molecular level supports this view. Molecular characterization failed to distinguish between *P. galeatum* and *P. trichostachyon* indicating that these two may actually be same species after all. Earlier studies by Rahiman (1981) and Ravindran (1991) also indicated that these two species, separated only by the presence of minute hairs on spikes in *P. trichostachyon,* have high morphological and chemical affinity.

Similarly, *P. attenuatum* and *P. argyrophyllum*, which were separated by earlier taxonomists by the presence of minute hairs in the lower side of the leaves on veins, also could not be distinguished at molecular level. Thus, the present study questions the utility of presence and absence of hair alone as a taxonomic feature, used by the earlier workers, to distinguish the species of *Piper* unless this character is heritable. *P. attenuatum* and *P. argyrophyllum* could not be distinguished at molecular level raising doubts about their distinct species status. Presence of many intermediate forms between *P. attenuatum* and *P. argyrophyllum* also supports this view. Similar observations were made by Babu *et al.* (2003) using both RAPD and AFLP analysis of *Piper* species. They have studied the molecular profile of *P. argyrophyllum*, *P. attenuatum*, *P. nigrum* and *P. bababudani* along with other indigenous and exotic species using RAPD and AFLP markers. Sivarajan (1998) also made similar observations in the case of *Physalis* and concluded that hairiness may be considered a character due to geographical adaptation rather than a taxonomic discriminate character.

The present study substantiates that though *P. wightii* is earlier reported to be similar to *P. nigrum* with respect to morphological and chemotaxonomic characters (Ravindran *et al.*, 1994b) they are distinctly different at DNA level. At molecular level *P. wightii* is uniquely placed though distantly associated with *P. hymenophyllum*, *P. attenuatum* and *P. argyrophyllum*. This result agrees with Hooker (1886) who placed *P. wightii* under the Section Eupiper along with these species. The present study indicated that at DNA level, *P. wightii* is distinctly different from *P. nigrum* and distantly related to *P. hymenophyllum*, *P. attenuatum* and *P. argyrophyllum* on the other. This is further supported by the fact that these species are separated from each other by their distribution at different elevations in addition to the nature of bracts, which is considered by the *Piper* taxonomists as one of the major distinguishing characters of the genus *Piper*.

Thus morphological and molecular characterization clearly indicated that species like *P. longum* and *P. hapnium* are morphologically and genetically having very close similarity. Both are having erect and cylindrical spikes. Same is the case for *P. mullesua* and *P. silentvalleyensis*. Both these species look morphologically similar except for the bisexual nature of the later. Molecular profiling also revealed the similarity of all the four species having erect spike. Hooker (1886) placed *P. longum*, *P. hapnium* and *P. mullesua* under the section Chavica.

P. attenuatum, P. argyrophyllum and *P. hymenophyllum* are also having many similar characters like acrodromous venation, membranous leaves, sessile bracts and ovate berries and the colour change from green berries to black when ripe. Molecular studies also support the closeness of these three species as they are grouped in a single cluster. *P. attenuatum* and *P. argyrophyllum* could not be distinguished at molecular level raising doubts about their distinct species status. Presence of many intermediate forms between *P. attenuatum* and *P. argyrophyllum* also supports this view. During surveys occurrence of scented spikes were observed in some collections of *P. attenuatum* and *P. argyrophyllum* and the presence of insects and honey bees were found feeding on spikes, increasing the possibility of cross-pollination between male and female plants of the same species and between different species. Studies by De Figueiredo and Sazima (2000, 2004) also support entomophily in *Piper* species.

Genetic studies revealed that *P. wightii* have more similarity to this group than *P. schmidtii*. This supports Hooker's (1886) view of including *P. wightii* along with *P. attenuatum*, *P. argyrophyllum* and *P. hymenophyllum* under the Section Eupiper. All are having the green shoot tips with membranous leaves.

P. nigrum and *P. sugandhi* are very similar in vegetative characters except for the short stalked flowers and bold fruits. Similarity is also observed with *P. bababudani* and the cultivated type Karimunda (control). Morphologically they are all having acrodromous venation, cupular bract and round berries. The molecular profiling of these species supports this morphological similarity.

P. galeatum and *P. trichostachyon* are having very close similarity for many morphological characters but for the hirtellous nature of the spike in *P. trichostachyon*. Molecular studies also support the similarity between these two species.

The distinctness of *P. barberi, P. schmidtii, P. bababudani* and *P. wightii* from the rest of the South Indian species and they are the most divergent.

Based on information generated and using additional characters like geographical distribution, fruit colour, shape and taste, an improvised key was proposed for identification of South Indian *Piper* (Fig. 54)

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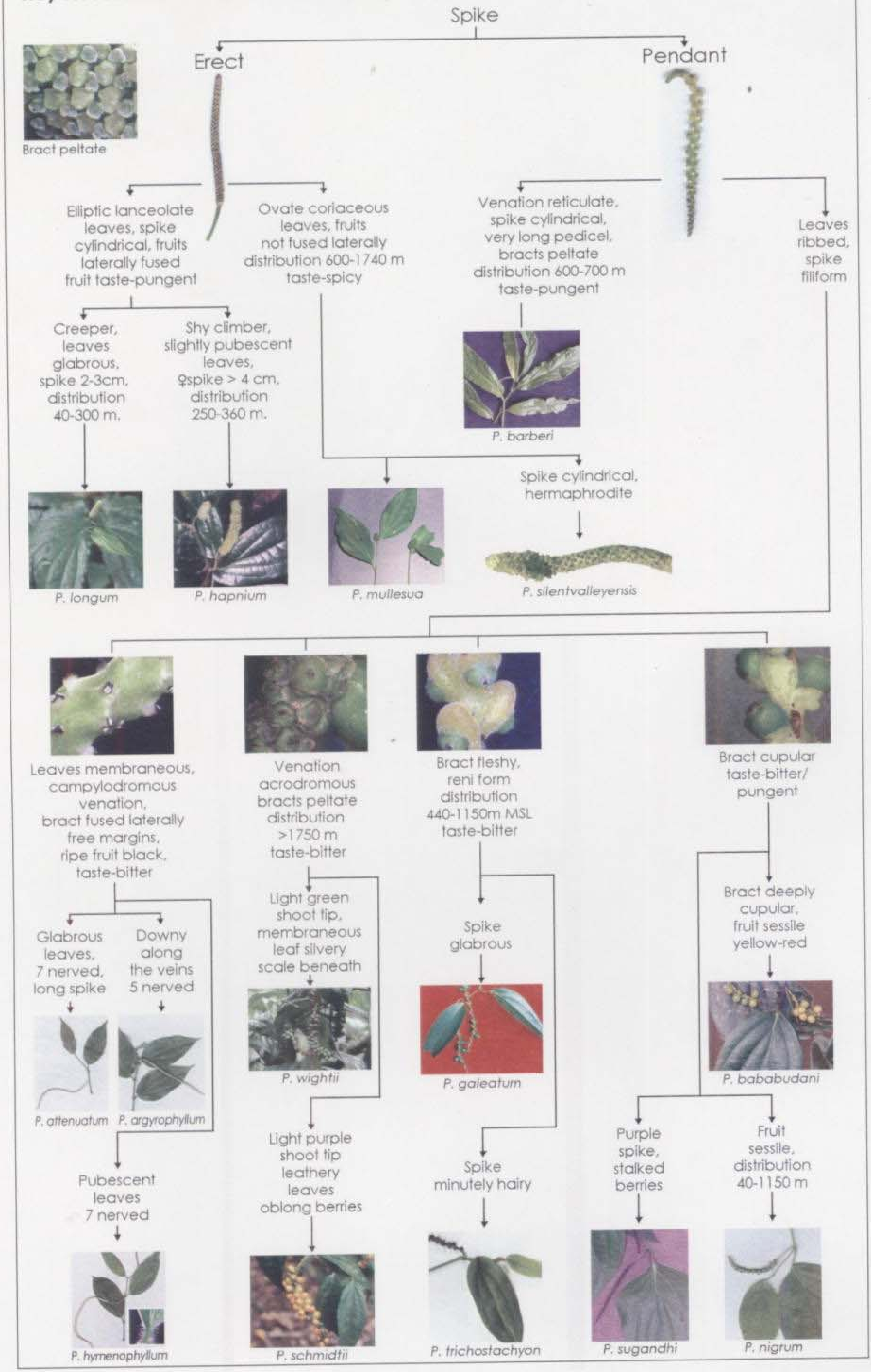
Key for identification of South Indian *Piper* spec



Intra-species variability

Though *Piper* is a large genus with over 3000 species very little work was done to study the variation existing within the species (intra species variability) except in very few economically important species of *Piper* like black pepper (*Piper nigrum*) and betel vine (*P. betle*) and Kava (*P. methysticum* Frost. f) (Lebot *et al.*, 1999; Jokhan and Mc Lenachan, 2004; Anjali *et al.*, 2004). Even these studies are confined more on inter cultivar variability rather than the variability existing in its wild forms. In the present study, an effort was made to understand the morphologic and molecular variation occurring within two most important and economically useful species viz. *P. nigrum* and *P. longum.*

P. nigrum

Fifteen wild forms (♀) of *Piper nigrum* collected from various locations viz. Karnataka, Kerala and Tamil Nadu were characterized both morphologically and at molecular level.

Morphological characterization

Morphological characterization indicated variations among the collections studied with respect to shoot tip colour, lateral branching habit and length, number of nodes, leaf petiole length, leaf size and shape and leaf base. Morphometric analysis, both cluster and numerical indicated good diversity among collections. The grouping of the collections based on morphological criteria did not show any relation with the geographical distribution of the collections.

Molecular characterization

The morphological characterization is supplemented with molecular data obtained through ISSR profiling. Cluster analysis of molecular data using Jaccard's (Jaccard, 1908) coefficient also showed that there is considerable variability among *P. nigrum* accessions collected from different locations.

This study revealed high intra species variability in *P. nigrum* as is expected in the region, which is the center of diversity of this species. This indicates that these collections would have originated initially as seed progenies, which were later multiplied by predominantly vegetative propagation. Similar observations were also made earlier by Ravindran *et al.* (1990), who observed that sexual reproduction coupled with vegetative clonal propagation is the driving force which decides the population structure in a given location and the evolution of *P. nigrum.*

According to Ravindran *et al.* (1990) active and efficient pollen and seed dispersal mechanisms ensure gene flow within and between population segments leading to the establishment of intergrading populations. The absence of any such mechanism in *Piper* thereby establishes effective isolation barriers between individuals and between population units. Within such units, variations could then depend upon segregation in the seedling progenies, accumulation of mutations and chance crossing followed by segregation. Any such variation arising in the population would get immediately fixed because of the prevailing vegetative mode of propagation and such a unit may be gradually diverged from their similar units. When more than one vine (of different types and species) climbs up a single tree chances of out-cross increase, resulting in hybrid seedlings. This further increases the chances of out-crossing with parental vine or its clone or other seedling progenies leading to considerable variability within the population. In the absence of free gene flow between populations, such population segments will remain discrete and isolated from similar populational segments in the neighborhood. These forces acting together might have contributed to the evolution of many cultivars in due course. Sasikumar *et al.* (1999a) have reported successful production of interspecific hybrids between *P. nigrum* and *P. attenuatum* with some of the hybrids, which are intermediate forms between the parents.

P. longum

Eight wild forms (♀) of *P. longum* mainly collected from different parts of Kerala and a collection from Sirsi (Karnataka) were characterized both morphologically and at molecular level.

Morphological characterization

Morphometric, both cluster and numerical, analysis indicated good diversity among collections. The grouping of the collections based on morphological criteria did not show any relation with their geographical distribution.

Morphological characterization indicated that, though some minor variations were noticed, in general these collections have similar vegetative and reproductive characters, except in two variants i.e., Acc. 4515 with extra bold spike and Acc. 5476 with light purple coloured tender spikes. Cluster analysis based on morphological observations showed that only Acc. 5476 with light purple spike is uniquely placed in a separate group.

Molecular characterization

Molecular profiling of these accessions was carried out using ten ISSR primers. UPGMA dendrogram showed that only Acc. 4515 is uniquely placed indicating a major genetic change from the rest of the populations with a bootstrap 'P' value of 100%, though this could not be detected in morphological analysis.

The results based on morphological and molecular studies indicated that there is not much variability in the genepool of *P. longum* occurring in South India. One *P. longum* accession collected from Trivandrum District with light purple spike was morphologically distinct, but genetically similar to other collections from different locations. However, Acc. No. 4515 collected from the Nilambur forests of Malappuram District with bold spike is genetically very distinct from other groups though it looks morphologically similar to other members except for the spike size. This high genetic similarity is expected in *P. longum* as there is no natural seed germination and the variants observed may be due to natural mutations conserved in the populations through vegetative propagation. Parani *et al.* (1997) suggested that micro propagation could be used as a useful tool for induction of variability in *P. longum*.

Morphological and molecular characterization of *Piper* species based on our observations in *P. nigrum* (sexually reproducing) and *P. longum* (no sexual reproduction) can also be used to deduce that among *Piper* species high intra species variability occurs among sexually reproducing species while there is very limited variability among species like *P. longum* which lack sexual reproduction and efficient sexual reproduction is the key factor in determining the intra-species variability.

This indicates that the intra species divergence in certain species is some times more than that of inter-species divergence. This is due to fact both vegetative as well as sexual reproduction is in operation in most of *Piper* with one of them being dominant and the higher divergence is reflective of sexual reproduction being dominant factor in the population build up.

Inter cultivar variability in black pepper

In black pepper, more than 100 cultivars are known to occur in different regions (Ravindran, 2000). Though the cultivated black pepper is considered bisexual, many of the primitive types are characterized more as predominantly male types or predominantly female types. But most of the improved varieties are predominantly bisexual with male and female phase coming into receptive stage simultaneously. Many of the cultivars exhibit protogyny and in some varieties the difference between male and female ratio is significant for hybridization (Ravindran *et al.*, 1981)

Morphological characterization

Thirty three cultivated black pepper accessions representing the existing diversity of black pepper cultivar germplasm were characterized based on 40 morphological and reproductive characters. Good inter-cultivar variability was noticed in many of the cultivars with respect to most of the characters studied. High variability was also noticed for yield contributing characters like runner shoot production, holding capacity, adventitious root production, lateral branch habit, spike length, type of hermaphroditism, number of spikes per lateral branch, fruit set, dry weight, essential oil, oleoresin and piperine content. Intra-cultivar variability was reported earlier and was used to characterize the cultivars of black pepper (Ratnambal *et al.*, 1985; Pillai *et al.*, 1987; Ravindran *et al.*, 1992a; Ravindran *et al.*, 1997b Sasikumar *et al.*, 1999a; Mathew and Mathew, 2002; Mathew *et al.*, 2005).

Though progenies of the same cross with Uthirankotta and Cheriyakanniakadan, Panniyur-1 and Panniyur-3 were found to be clearly divergent from each other indicating high amount of heterozygocity in the parents. Among the cultivars studied, Panniyur-1 was the only member with light green shoot tip colour (See description of Panniyur-1 in Table 28.15), whereas shoot tip colour was deep purple in the cultivars Kalluvally and Chumalakodi (Table 28.6 and 28.27). Inheritance of shoot tip colour was studied by Ravindran *et al.* (1992b) and inferred that two pairs of genes having complementary action seem to control the shoot tip colour in black pepper. Ibrahim *et al.* (1985a) reported the inheritance of anthocyanin pigmentation on "stipules" in pepper.

The capacity to hold the plant on its support is one of the key factors of its survival and establishment in the field. If the holding capacity is less the vines have a tendency to slip down from the supporting tree and hence cannot withstand large canopies. Development and maturity of fruits are related to the percentage of bisexual: female: male ratio (Sasikumar *et al.*, 1992).

The dendrograms based on UPGMA supported good variability in cultivars like Kalluvally, Chumalakodi, Karuthapirimunda, Cheriyakanniakadan, Kaniyakadan, Nedumchola, Balankotta, Panniyur-1 and Pournami. These cultivars can be utilized in convergent crosses for maximum heterosis in black pepper (Ibrahim *et al* 1985b, c).

Molecular characterization

To supplement the morphometric observations, molecular characterization using RAPD and ISSR markers was done. The phylograms did not show any clear patterns. Nazeem *et al.* (2005) observed close similarity between the improved varieties Panniyur-1 with Panniyur-3 (82%) and Sreekara with Subhakara (100%) respectively. Morphological characterization in the present study also showed clear divergence between Panniyur-1 and Panniyur-3 with respect to many morphological and reproductive characters. Studies of Pradeepkumar *et al.* (2003) also showed clear divergence of Panniyur-1 from Panniyur-3. These varieties did not show morphological and genetic similarities with their parents except in Pradeepkumar's (2003) study, where Panniyur-1 is closer to the male parent Cheriyakanniakadan. The present study also indicated similar pattern in that neither Panniyur-1 nor Panniyur-3 showed any similarity to their parents Uthirankotta and Cheriyakanniakadan morphologically. RAPD and ISSR profiling indicated Panniyur-1 is more similar to Uthirankotta, which is in disagreement with the observations of Pradeepkumar. Nazeem *et al.* (2005) however, observed that in RAPD profiles of Panniyur-1 and Panniyur-3 though similar to each other, they are distinctly different and widely separated from their parents Uthirankotta and Cheriyakanniakadan. Though Panniyur-1 and Panniyur-3 have same parentage, they are distinct in morphological and genetic characters (Ravindran, 2000). Panniyur-1 is with cordate leaf and light green shoot tip. Genes having complementary action (Ravindran, 1994a) control the shoot tip colour. In the present study, Panniyur-1 grouped with one of its parents viz. Uthirankotta having light yellow spike colour. Panniyur-3, which distantly grouped with other cultivars like Kottanadan and Kalluvally, showing its unique nature (Fig. 42). Though Sreekara and Subhakara are selections from the local cultivar Karimunda, they differed distinctly in their quality characters (Table 29.20 and 29.21). Nazeem *et al.* (2005) failed to differentiate between these two selections using RAPD. AFLP studies could differentiate between these two varieties. In the present study also these varieties could be separated each other indicating their common ancestry, but would have originated as vegetative mutants or selfed progenies. Pradeepkumar *et al.* (2003) also made similar observations.

Good genetic variability observed among the cultivars indicated that they are essentially seed -derived varieties and genetically any controlled cross involving any of the varieties studied can potentially give rise to high yielding varieties. The genotypes, which have originated from controlled crosses, indicated more divergence from the rest of the population. This is expected, as most of the other varieties would have originated as segregating progenies in a selfed cross leading to lesser diversity or mutant maintained through vegetative propagation. Lebot *et al.* (1999) using AFLP analysis indicated that propagation of 'Kawa' (*P. methysticum*) which is a predominantly vegetative propagated species has extremely narrow genetic base. According to Ravindran (2000), the present day cultivated types might have been the result of domestication and continuous, conscious selection for high yielding types from the wild types and their maintenance by vegetative propagation indicating they are of different origin.

Intra cultivar variability in Karimunda and Kottanadan accessions

Ratnambal *et al.* (1985) were the first to study the intra cultivar variability in the popular variety Karimunda with respect to various morphologic and agronomic features. They have collected over 200 'types' of Karimunda and after evaluation found reasonable variability within the cultivar which resulted in the selection of two high yielding varieties (Ratnambal *et al*, 1990). Reasonable amount of variability was also observed in other cultivars like Kottanadan, Narayakodi and Neelamundi (NRCS, 1989 a & b). In the present study, an effort was made to find out intra cultivar diversity at molecular level within the populations of two morphologically distinct popular cultivars *viz.* Karimunda (6 collections) and Kottanadan (7 collections).

Good variability was observed in runner shoot production, holding capacity, adventitious root production, lateral branch habit and length, number of nodes per lateral branches, leaf petiole length , leaf size and shape, spike length, type of hermaphroditism, number of spikes per lateral branch and fruit setting. Morphometric analysis using 13 morphological characters resulted in grouping these collections in different clusters indicating that while some of them are more similar to each other, others are divergent as is the case with Subhakara among Karimunda collections.

The dendrogram obtained through the analysis based on morphological characters revealed clear divergence between Karimunda and Kottanadan collections separating these cultivars from each other and at the same time grouping different collections of the same cultivar together.

The phenotypic data is supplemented with ISSR profiling as an index for genetic interrelationship. Molecular characterization in general, grouped different collections of Karimunda and Kottanadan selections in respective groups indicating their origin from a common ancestor and the possibility of introgression between these two important cultivars of black pepper, which could not be detected at morphological level. Bootstrapping also indicated similar patterns giving credence to the above hypothesis.

Thus, in the present study the distribution and diversity of South Indian species of *Piper* was studied and ecological niches of each of the species identified. Four species viz. *P. silentvalleyensis*, *P. hapnium*, *P. bababudani* and *P. barberi* are endangered and need special conservation efforts to protect them from extinction. Study on population density indicated that sexual reproduction coupled with vegetative propagation is the most important factor for maintaining the population size and diversity within the species, and the absence of sexual reproduction coupled with less efficient vegetative propagation makes the species endangered. The Shannon diversity index indicated the regions comprising Palghat and Wayanad districts of Kerala, Nilgiri District of Tamil Nadu and Kodagu District of Karnataka as the areas of gamma diversity of *Piper* species and these areas have to be protected to conserve South Indian *Piper* species except *P. hapnium*. Digital herbaria of each of the species were prepared and inter-relationships were studied using both morphological and molecular characterization. This study in general agreed with earlier findings except that *P. wightii* is distinct and not related to *P. nigrum*. Among the *Piper* species, *P. barberi* is the most divergent. Molecular characterization indicated no clear differences between *P. attenuatum* and *P. argyrophyllum* and between *P. trichostachyon* and *P. galeatum*, questioning their distinct species status. The study also supported the origin of *P. sugandhi* as a hybrid between *P. nigrum* and *P. galeatum*/ *P. trichostachyon* indicating the presence of many intermediate forms between these two species. A new improvised key was suggested for identifying South Indian *Piper* species.

Morphological and molecular characterization of 33 cultivars revealed good genetic variability between the cultivars indicating their origin as seed progenies followed by selection and vegetative propagation. Molecular characterization also supported intra- cultivar variability and the presence of intermediate forms between the cultivars. The present study coupled with earlier observations by various workers indicate that vegetative mutation, segregating selfed progenies, occasional crossed progenies and progenies of controlled crosses account for the existing variability in black pepper cultivars and the progenies of controlled crosses being most divergent followed by open pollinated progenies, segregating selfed progenies and vegetative mutants. It is suggested that crosses or hybridization between divergent genotypes can enhance the genetic variability within black pepper and hence can be used in crop improvement programmes. This study further indicate the possibility that in south Indian *Piper* the species isolation is not yet complete, with the occurrence of many intermediate forms and the possibility that many species are still crossable.

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* Original not seen

Summary

Black pepper (*Piper nigrum* L.), belongs to the genus *Piper* in the family Piperaceae, is one of the oldest spices known to the world and is indigenous to the forests of Western Ghats of Southern India. Though black pepper is a much sought after economically important crop, little is known about its exact distribution pattern, botany, taxonomy and evolution. Linnaeus established the genus *Piper* in his *Species Plantarum.* The taxonomy of *Piper,* despite the attention of many notable botanists remains difficult and enigmatic and the Family Piperaceae is one of the "worst messes" in the plant taxonomy according to Howard.

The main centers of distribution of genus *Piper* are in Central and South America and Southern Asia. In the areas of its occurrence - the neotropic species are mainly distributed both in the edge and inside of the semi deciduous as well as the swampy forests, while the paleotropic species are mainly distributed in the moist evergreen forests and to a lesser extent in the semi-evergreen forests. Some species are restricted to certain ecological niches while the others have wider distribution occurring in all habitats. A review of occurrence and distribution of *Piper* species around the world indicted that the highest number of species occurs in Central America followed by Malaysia, Philippines and India. *Piper* is more diverse in the American tropics than in the Asian tropics. The available information on occurrence, abundance, distribution, habit and reproductive biology of *Piper* species clearly indicates three major regions from which the genus *Piper* could have originated. These regions are, Tropical America, Tropical Asia and South Pacific. The phylogenetic analysis of worldwide samples of *Piper* supports this view and the taxa representing major geographic areas could have originated from three monophyletic groups: Asia, the South Pacific and the Central America. This study further suggested that the taxa from the South Pacific and South Asia formed a monophyletic group, provisionally supporting a single origin of dioecy among the *Piper* species of these regions. The species from the South Pacific would have had the common origin from Asian species (Malaysia and Indonesia). Though no clear information about the origin of *Piper* species from Tropical Africa is available, the endemic nature of *Piper* species from this region itself suggests their independent origin. This needs further investigation.

P. silentvalleyensis is the rarest among the species of *Piper* and was collected from a single location at an elevation of 1700 m at Paikara of Nilgiri District, Tamil Nadu. This species will become extinct soon if not conserved.

P. attenuatum, P. argyrophyllum and *P. hymenophyllum* are the most common species of *Piper*. Among these three, *P. attenuatum* is the most widely distributed and occurs in all the forest regions of Kerala, Karnataka and Tamil Nadu at an elevation of 40 - 990 m. Occurrence of plant types with scented spikes and many flies and insects on the spikes were noticed among the populations of *P. attenuatum* and *P. argyrophyllum* indicating the possibility of cross pollination. The species abundance was maximum at lower elevations of Silent Valley forest of Palghat, Neyyar and Peppara areas of Thiruvananthapuram District and nearby forests at Tirunelveli District, which can be considered as the ecological niches.

P. argyrophyllum was found to occur at an elevation of 80 - 900 m intermingled with *P. attenuatum*. Species abundance was at maximum in Malappuram District followed by Wayanad and Idukki districts in Kerala, Kodagu District in Karnataka and Tirunelveli District in Tamil Nadu.

P. hymenophyllum, the most hirsute species among the three, widely distributed in the wet evergreen forests of Kerala, Karnataka and Tamil Nadu at medium to high elevations (160 - 1100 m). Species abundance was at maximum in Kodagu District of Karnataka followed by Wayanad and Palghat districts of Kerala.

Piper schmidtii and P. wightii are two species seen occurring only at higher elevations. The distribution of *P. wightii* ranged from 1750 - 2600 m while that of *P. schmidtii* is from 1700 - 2360 m. They are extensively distributed in the Shola forests of Nilgiri District of Tamil Nadu, which can be considered as the area of maximum diversity for these species.

Piper galeatum and *P. trichostachyon* occurs intermingle and generally at an altitude of 420 - 1560 m in the wet evergreen forests of Kerala, Karnataka and Tamil Nadu. Species abundance was found maximum in Wayanad, Idukki and Silent Valley regions of Kerala and Coorg District of Karnataka.

Piper sugandhi is found distributed among the populations of *P. trichostachyon, P. galeatum* and wild forms of *P. nigrum* at an altitude between 560 - 1500 m. Species abundance was maximum in Wayanad and Idukki districts of Kerala. A good population was located at Chickmagalur District of Karnataka also.

Piper bababudani originally reported from Bababudan hills in Karnataka (600 - 1500 m) could be collected only from two locations viz. Garwale forest of Kodagu District and from the Thirunelly forests (Pakshipathalam) of Wayanad District and can be considered endangered.

Piper barberi is a unique species having very limited distribution and could be collected only from a few locations viz. Anamalai and Kannikatti forests of Tamil Nadu at an elevation of 520-600 m.

P. hapnium, P. silentvalleyensis, P. bababudani and *P. barberi* are critically endangered and need to be given highest priority for conservation, multiplication and reintroduction. *P. barberi* and *P. hapnium* are recorded in the Red Data book. Unless protected, these species will become extinct very soon.

The Western Ghats region of South India is the center of origin of *P. nigrum* where plenty of wild forms exist. Among the species of *Piper, P. nigrum* has the maximum diversity, adaptability and density and occurs at almost all areas of this region from sea level (40) to an altitude of 1100 m. The distribution of wild forms of *P. nigrum* though abundant in almost all regions of Western Ghats, is maximum in Palghat, Idukki and Pathanamthitta districts of Kerala, Hassan District and Jog falls region of Karnataka. Occurrence of wild forms of *P. nigrum* at elevations above 1100 m was not noticed though the cultivation of black pepper was prevalent even up to an elevation of 2500 m.

The community composition, species richness, relative abundance of different species and species diversity in a community could be indicated using Shannon's diversity index, and the Western Ghats region of South India could be divided into seven classes, based on relative abundance of different species and species diversity in a community. The hilly regions of Kerala and Tamil Nadu are the two areas with maximum diversity – especially the mountainous regions between the two States. This might be the possible centre of origin for the South Indian species of *Piper*. Based on the study, the contiguous regions comprising Palghat and Wayanad districts of Kerala, Kodagu District of Karnataka and Nilgiri District of Tamil Nadu form the center of gamma diversity and almost all the south Indian species can be conserved if the wild habitats in these districts are protected.

Thus, the diversity and distribution of *Piper* species is estimated based on actual collections and plotted with DIVA – GIS programme, the ecological niches of each species were identified and mapped. This would help in developing future strategies for conservation and utilization of these species in crop improvement.

Taxonomy

The taxonomy of *Piper* still remains a challenge due to the absence of clear cut discriminating morphological characters and the extreme reduction in floral characters. The earlier biosystematic studies were based on taxonomic, morphometrical, biometrical, numeric, chemotaxonomic, palynological, cytological and biochemical characterization. No studies are available on the diversity and variability existing in the wild species and local cultivated types. The major bottleneck was the non- availability of live specimens for the study.

In the present study, 15 different South Indian *Piper* species were taxonomically characterized and digitized herbaria were prepared for the first time in *Piper*. These digitized live pictures can fulfill the requirement of observing live specimens at any given time. In view of the over exploitation of live specimens from forests for making herbaria, it would be advisable to minimize such live collections and instead use digitized herbaria in colleges and universities rather than depleting the natural vegetation.

Morphological characterization

Morphological characterization of 15 different South Indian *Piper* species was done using 33 discriminative characters and each of the species was documented for these characters and electronic catalogues were prepared for the first time. Extensive inter-specific variation was observed. Cluster analysis of these morphological characters using NTSYS software grouped the fifteen taxa into four major clusters. The first major group contains two herbaceous species of *Piper* with erect spikes - *P. longum* and *P. hapnium*. All the remaining *Piper* species which are climbing vines are grouped together except *P. barberi.* This species with reticulate venation, aphyllate juvenile shoots and unusually long peduncle is uniquely placed. Spike characters like spike orientation, shape, peduncle length, flower arrangement and bract type coupled with leaf characters like leaf base, margin, venation played a distinct role in differentiation and identification of South Indian *Piper*.

Molecular analysis

RAPD and ISSR profiles of the 15 species of *Piper* were analyzed and phylograms were drawn. The molecular analysis resulted in five major clusters. The clustering pattern was similar to the morphological characterization except for cluster III and cluster-V, which was further resolved.

Molecular characterization which reflects more of genetic differences have separated *P. schmidtii* and *P. wightii* which were grouped together in morphological (phenotype) characterization. Although both of them are placed in different groups showed their uniqueness and separately places within the grouping.

P. sugandhi, P. nigrum (wild) and cultivar Karimunda which have black pepper-like fruits, spikes and plant characters and with a somatic chromosome number of 2n= 52, were grouped together indicating their common ancestry. The possible origin of *P. sugandhi* as a hybrid involving *P. nigrum* as one of the parents and either *P .trichostachyon* or *P. galeatum* as the other parent was suggested earlier.

Molecular characterization failed to distinguish between *P. galeatum* and *P. trichostachyon* indicating that these two may actually be the same species after all. Earlier studies by Rahiman and Ravindran also indicated that these two species, separated only by the presence of minute hairs on spikes in *P. trichostachyon,* have high morphological and chemical affinity. Similarly, *P. attenuatum* and *P. argyrophyllum*, which were separated by earlier taxonomists due to the presence of minute hairs in the lower side of the leaves along the veins, also could not be distinguished at the molecular level. Thus, the present study questions the utility of presence and absence of hairs as a taxonomic feature, unless it is heritable, used by the earlier workers, to distinguish the species of *Piper*.

The present study also substantiates that though *P. wightii* is earlier reported to be similar to *P. nigrum* with respect to morphological and chemotaxonomic characters; it is distinctly different at molecular level. In the present study, P. *wightii* is uniquely placed but distantly grouped with *P. hymenophyllum*, *P. attenuatum* and *P. argyrophyllum* as grouped by Hooker.

The results based on morphological and molecular profiles clearly indicated the distinctness of *P. barberi, P. schmidtii, P. bababudani* and *P. wightii.*

Molecular profiling indicated close similarities between *P. longum*, P. *hapnium P. mullesua* and *P. silentvalleyensis* which are characterized by erect spikes.

Based on information generated using additional characters like geographical distribution, fruit colour, shape and taste, an improvised key was proposed for identification of South Indian *Piper*.

Intra-species variation in *Piper*

In the present study, an effort was made to understand the morphologic and molecular variation within two most important and economically useful species viz. *P. nigrum* and *P. longum*.

P. nigrum

Morphometric and Molecular analysis of 15 wild forms (♀) of *Piper nigrum* collected from various locations in Karnataka, Kerala and Tamil Nadu revealed high intra-species variability in *P. nigrum* as is expected in the region, which is the center of diversity of this species. This indicates that these collections would have originated initially as seed progenies, which were later, multiplied predominantly by vegetative propagation.

P. longum

Eight wild forms (♀) of *Piper longum* collected mainly from different parts of Kerala and Karnataka. The results based on morphological and molecular data indicated that there is limited variability in the gene pool of *P. longum* occurring in South India. Only one collection is genetically distinct from the others. This can be attributed to lack of seed germination in *P. longum* and the variants observed may be due to natural mutations conserved in the populations through vegetative propagation

Morphological and molecular characterization can also be used to deduce that among *Piper* species of South India, high intra species variability occurs among sexually reproducing species while there is very limited variability among species like *P. longum*, which lack sexual reproduction.

Inter- cultivar variability in black pepper

Good inter-cultivar variability was noticed in many of the 33 cultivars studied with respect to most of the morphological and reproductive characters studied. High variability was also noticed for yield contributing characters like runner shoot production, holding capacity, adventitious root production, lateral branch habit, spike length, type of hermaphroditism, number of spikes per lateral branch, fruit set, dry weight, essential oil, oleoresin and piperine contents. The capacity to hold the plant on its support is one of the key factors of its survival and establishment in the field. The dendrograms developed based on UPGMA indicated cultivars like Kalluvally, Chumalakodi, Karuthapirimunda, Cheriyakanniakadan, Kaniyakadan, Nedumchola, Balankotta, Panniyur-1 and Pournami were most divergent.

Good genetic variability observed among the cultivars indicated that they are essentially seed derived and genetically any cross involving any of the varieties studied can potentially give rise to high yielding varieties. This supports the view that many of the present day cultivated types might have been the result of domestication and continuous conscious selection for high yielding types from the wild types and their maintenance by vegetative propagation.

Intra- cultivar variability in Karimunda and Kottanadan

Most of the pepper cultivars are not pure lines but are arbitrarily named based on place of collection or identifying characters or name of the collector etc. Earlier workers reported high morphological variability among the cultivars popularly named 'Karimunda' and 'Kottanadan'.

Though good intra-cultivar variability was observed with respect to most of the morphological characters studied, the dendrogram revealed clear divergence between Karimunda and Kottanadan collections separating these cultivars from each other and at the same time grouping different collections of the same cultivar together. However, molecular characterization indicated their origin from a common ancestor and also the possibility of introgression between these two important cultivars of black pepper, which could not be detected at morphological level. Bootstrapping also indicated similar patterns giving credence to the above hypothesis.

Conclusion

The distribution and diversity of South Indian species of black pepper was studied and ecological niches of each of the species identified. Four species viz. *P. silentvalleyensis*, *P. hapnium*, *P. bababudani*, *P. barberi* are endangered and need special conservation efforts to protect these species from extinction. Study on population density indicated that sexual reproduction coupled with vegetative propagation is the most important factor for population size and diversity within the species and absence of sexual reproduction coupled with less efficient vegetative propagation makes the species endangered. The Shannon diversity index indicated the regions comprising Palghat and Wayanad districts of Kerala, Nilgiri District of Tamil Nadu and Kodagu District of Karnataka indicate the area of gamma diversity of *Piper* species and needs to be protected to conserve all the species of South Indian *Piper* except *P. hapnium*. Digital herbaria of each of the species were prepared and inter-relations studied using both morphological and molecular characterization. This study in general agreed with our earlier understanding except that *P. wightii* is distinct and not related to *P. nigrum*. Among the *Piper* species *P. barberi* is the most divergent. Molecular characterization indicated no clear differences between *P. attenuatum* and *P. argyrophyllum* and also between *P. trichostachyon* and *P. galeatum*, questioning their distinct species status. The study also supported the origin of *P. sugandhi* as a hybrid between *P. nigrum* and *P. galeatum*/ *P. trichostachyon* indicating the presence of intermediate forms between these two species. A new improvised key was suggested for identifying South Indian *Piper*.

Morphological and molecular characterization of 33 cultivars revealed good genetic variability between the cultivars indicating their origin as seed progenies followed by selection and vegetative propagation. Molecular characterization also supported intra- cultivar variability and the presence of intermediate forms between the cultivars. The present study coupled with earlier observations by various workers indicate that vegetative mutation, segregating selfed progenies, occasional crossed progenies and progenies of controlled crosses account for the existing variability in black pepper cultivars and the progenies of controlled crosses being most divergent followed by open pollinated progenies, segregating selfed progenies and vegetative mutants. It is suggested that crosses or hybridization between divergent genotypes can enhance the genetic variability within black pepper and hence can be used in crop improvement programmes. This study further indicate the possibility that in south Indian *Piper* the species isolation is not yet complete, with the occurrence of many intermediate forms and the possibility that many species are still crossable.

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Origin and distribution of the genus *Piper* in India

From Indian Sub-Continent, over 115 species have been reported, and distributed mainly in Western Ghats of Indian Peninsula and North Eastern regions. This made Hooker to identify these regions as two independent centers of diversity for *Piper*. However, Rahiman proposes three centers viz. the sub- Himalayan and North East Indian centre, the Western Ghats centre and the Eastern Ghats. Since the species, which occur in the Eastern Ghats region, are those, which already occur, in much higher population and diversity in the Western Ghats regions of India, Hooker seems to be more correct in designating two major centers of *Piper* in India.

The present study is aimed at characterizing the fifteen species of South Indian *Piper* and 33 most important cultivars representing the diversity in cultivated black pepper, with detailed taxonomic and morphological characterization and distribution patterns based on GIS. This was supplemented with more recent molecular taxonomy for a better understanding of cultivar diversity in black pepper and the other species of *Piper* with which it co exists and the species inter-relationships based on molecular phylogeny.

Diversity and geographical distribution of South Indian *Piper*.

The genus *Piper* occurs from almost sea level to an elevation of 2000m in India. Distribution and diversity of fifteen *Piper* species occurring in South India were studied based on the actual collection data supported by GIS. The study indicated that:

Piper longum is the most widely distributed species among the *Piper* species and occurs at an altitude of 40 - 310 m. in all districts of Kerala. Species abundance is maximum in Palghat, Malappuram and Idukki regions and minimum in Kasaragod.

P. hapnium has very limited distribution confined to Manalar region of Kollam District at an elevation between 250 - 360 m. This species is with limited population.

P. mullesua is well distributed in the states of Kerala, Karnataka and Tamil Nadu at an altitude between 600 - 1740 m. The population density was at maximum in Naduvattom region in Tamil Nadu, Silent Valley forests in Kerala and Thalacauvery region in Karnataka, which can be considered as the ecological niches for the species.

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* Original not seen