STUDIES ON BLACK PEPPER (*Piper nigrum* L.) AND SOME OF ITS WILD RELATIVES

Thesis submitted to
The University of Calicut
as part fulfilment
for the requirements of the Degree of
Doctor of Philosophy

P. N. RAVINDRAN NAYAR
(National Research Centre For Spices, Calicut)

University of Calicut
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(P.N. RAVINDRAN)
National Research Centre for Spices
Calicut - 673 Ø12.

Dr. M.K. NAIR M.Sc (Agri) Ph.D
Director,
Central Plantation Crops Research Institute,
Kasargod, Kerala

CERTIFICATE

I hereby certify that the thesis entitled "Studies on Black Pepper (*Piper nigrum* L.) and some of its wild relatives" contains the results of bonafide research work done by Mr. P.N. Ravindran Nayar at the National Research Centre for Spices, Calicut, under my supervision and guidance. I further certify that this thesis or part of it has not been submitted to any University for the award of any other degree or diploma. Certified that he has also passed the required qualifying examination.

13/7/90

Dr. M.K. NAIR
(Guide and Supervising Teacher)

DECLARATION

I, P.N. RAVINDRAN NAYAR, hereby declare that this thesis entitled "Studies on Black Pepper (*Piper nigrum* L) and some of its Wild Relatives" embodies the results of bonafide research carried out by me at the National Research Centre for Spices, Calicut, under the guidance of Dr. M.K. Nair, Director, Central Plantation Crops Research Institute, Kasargod. No part of this thesis has ever been submitted previously to any University for any degree or diploma.

(P.N. RAVINDRAN NAYAR)
National Research Centre for Spices,
Calicut - 673 012

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INTRODUCTION

CHAPTER I

INTRODUCTION

Black pepper, christened as the "King of Spices", is world's most important and most universally used spice. The source of the spice is the dried mature fruits of the tropical perennial climber, *Piper nigrum* L., native to the humid ever green forests of the Malabar coast of India.

Black pepper is known to be in use for over 3000 years and references to black pepper and long pepper are available in the vedic literature. The ancient Ayurvedic texts of Charaka and Susrutha, considered to be more than 2000 years old, contained the medicinal uses of long pepper and black pepper. Theophrastus, who lived in the fourth century A.D described two kinds of peppers, the long and the black pepper. Pliny in his travel accounts (1st century A.D) mentioned about the black and long pepper trade in India. Black pepper was the earliest article of commerce between India and the West. In the middle ages, pepper was used as barter currency in place of money. It was the lure of the spices that led to the discovery of the sea route to India by Vaso-da-Gama in 1498, an event that changed the course of history of the Indian Sub continent. With this Portugal secured the monopoly of spices trade. By 18th century, this monopoly passed on to Holland and then to France and finally to England.

For centuries India was holding the monopoly on the production and export of black pepper, but in recent times Malaysia, Indonesia and Brazil emerged as competitors to India in the production and trade of pepper. Presently, the world production of black pepper is around 160,000 tons, the major producing countries being India, Malaysia, Indonesia and Brazil. The annual production in India is around 40,000 tons, more than 95% of which comes from the Kerala State. Black pepper plays an important role in the economy of the country and earns about Rs. 2500 million worth of valuable foreign exchange annually.

Black pepper belongs to the genus Piper of the family Piperaceae. The genus is distributed in Central America, Northern South America and Southern Asia. This is a very large genus and more than 3000 binomials have been reported under the genus (Index Kewensis, 1895-1970), many of which could be duplications. Taxonomically Piper is a very difficult and confusing genus and no monographic study has so far gone into it in the recent times. The genus includes in addition to P.nigrum, such important species as P.cubeba (the tailed pepper), P.longum (long pepper) P.officinarum, P.retrofactum and P.methysticum (kawa). P.betle (betle leaf) is an important masticatory grown in many Asian countries.

The ever green forests of the Western Ghats of South India is considered the centre of origin of P.nigrum, the black pepper. From here it is presumed to have spread to Sri Lanka, Thailand, Malaysia, Indonesia and Phillipines. The species was under domestication in the Western coastal and upland areas of South Western India comprising of the states of Kerala and Karnataka, for many centuries.

In spite of the immense economic importance of P.nigrum, practically very little is known about the botany of the species occurring in this region. The variability existing in the cultivated and wild types of Piper nigrum and allied taxa has never been studied critically. Such a study is an essential pre-requisite not only to gain insight into the genus and its interrelationships but also to chalk out meaningful breeding strategies to evolve better yielding and adapatable plant types.

The present work is an effort to study P.nigrum and its allied taxa occurring in the Kerala region of the Western Ghats and adjoining areas. An integrated approach involving morphology, chemistry and numerical methods is applied to gain insight into the nature, variability and interrelationships among black pepper cultivars and allied taxa occurring in the region.

REVIEW OF LITERATURE

CHAPTER II

REVIEW OF LITERATURE

The Piperaceae is a large family containing over 3000 or more binomials falling mainly under the two main genera *Piper* and *Peperomia*. The family is pantropical in distribution, concentrated mainly in northern South America, Central America and the South America and the South Asia. From these regions the members have spread to many neighbouring areas giving the family the present pantropic nature.

The taxonomic study of *Piper* started with the publication of *Species Plantarum* by Linnaeus (1753) in which he recognised 17 species in the family, all of which were included in the genus *Piper*, the genus name coined in memory of the American Naturalist C.V.Piper. The second genus in the family, *Peperomia* was introduced in 1794 by Ruiz and Pavon. The family name Piperaceae was first used by L.C. Rich in Humboldt, Bonpland and kunth's *Nova Genera et Species Plantarum* in 1815 (Yuncker, 1958). In the years that followed a number of additional genera, mostly segregates from *Piper* were described by Sprengel, Kunth, Miquel and others. Among the early studies the important ones were those of Ruiz and Pavon (1798) on Flora of Peru and Chile; Humboldt, Bonpland and Kunth (1815) based on their collections from South America, and that of Blume (1826) on East Indian species. Kunth (1839) published an important paper on 136 Latin American species mainly of Piper and some segregate genera. However the first monographic study was that of F.A.W. Miquel. His classic Systema Piperacearum (1843-44) included all the species known in the family at that time. Miquel subdivided the family into the two tribes Pipereae and Peperomeae, the former consisted of 15 genera including 304 species and the latter 5 genera with 209 species.

In 1869 Casimir de Candolle monographed the family in its entirety for the Prodromus. In this he recognised slightly more than 1000 species in the two genera of Piper and Peperomia. De Candolle continued to work on Piperaceae till his death in 1918. The key to the family prepared by him was published in 1923 posthumously under the name "Piperacearum Clavis Analytica". In this work keys were provided for something over 3000 species and varieties. William Trelease continued the studies on Piperaceae from where De Candolle left. He made extensive collections of American Piperaceae and these led to the revision of the northern South America by Trealease and Yuncker (1950). It is thus evident that Miquel, De Candolle and Trelease where almost exclusively responsible for the systematics of Piperaceae for more than a century.

During the second half of the century renewed interest were seen in the study of Piperaceae. Yuncker (1953) published treatment of the family for Panama, Trinidad and Tobago, Jamaica (1960) and for Netherlands Antilles (1966). Burger has published monographs on the Piperaceae of Costa Rica (1971) and Howard (1973) studied the Piperaceae of Lesser Antilles. Recently some detailed studies have been carried out on the pedicillate Piper (Bornstein, 1989) and on the climbing species of New World Piper (Tebbs, 1989).

Taxonomic History of Indian Piper

The earliest record of the desriptions of Piper spp. of Indian Subcontinent was by Van Rheede (1678) in his Hortus Indicus Malabaricus, the first printed document on the plants of Malabar coast of India. Here Rheede has described five types of wild pepper, four of which with illustrations. Linneaus included 17 species from India in his Species Plantarum. Roxburgh (1832) described seven species of Piper from Indian Peninsula. Miquel included seven wild species in his monograph on Piper. Wight (1853) in his Iconas Plantarum Indiae Orientalis illustrated 16 species 15 of which were from Indian Peninsula. De Candolle included 52 species from where almost exclusively responsible for the systematics of Piperaceae for more than a century.

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India in his monographic work.

The first major study on the Indian Piper spp. was by Hooker (1886) in his Flora of British India, in which he pointed out the problems encountering in the floristic study of Piper. He writes "Wallich's Herbarium and the diagnosis in Vahl's "Enumeration" and in Roxburgh's Flora Indica form the basis of the work of the only two authors who attempted the revision of the Indian species namely Miquel and De Candolle". Hooker pointed out that Wallich's specimens are so mixed up; while Vahl's diagnosis is insufficient to identify the plant he means; and of Roxburgh's only one or two species are recognisable. The only considerable collection made since that of Wallich were Wight's Peninsular, Griffith's Transgangetic Indian, Thomson's and Hooker's collections from Sikkim, Bengal and Khasia mountains. Wight's publications were based mainly on the identification given by Miquel and to some extent that of Roxburgh's unpublished Icones. Griffith's specimens were hurriedly collected with no attempt to match the sexes or the flowering with the fruiting specimens (Hooker, 1886).

Hooker divided the genus Piper into six sections as follows (along with the species represented in South India).

Section I Muldera. This section includes five species. The South Indian representatives are *P.galeatum* and *P.trichostachyon*.

Section II Cubeba. Six species are included in this and none of them occurs in Southern India.

Section III Chavica. Sixteen species are included in this section, the South Indian representatives being *P.longum*, *P.betle* (cultivated species) *P.hapnium* and *P.brachystachyum* (syn. *P.mullesua*).

Section IV Pseudo Chavica. Six species are included in this section, the representatives from South India being *P.Hookeri* and *P.schmidtii*.

Section V Eupiper. Eleven species are included in this section. The species reported from South India are *P.nigrum*, *P.attenuatum*, *P.hymenophyllum*, *P.argyrophyllum* and *P.wightii*.

Section VI Heckeria includes *Piper subpltata*, now included under the genus *Heckeria* (or *Pothomorphe*).

In his Flora, Hooker has also given a long list of undeterminable or doubtful species.

While writing on *Piper* Hooker pointed out that on the spot study should be carried out by local botanists with a view to matching the sexes, and the flowering and fruiting specimens to observe the transition from young to old foliage and the effect of locality and climate on the characters of each specimen.

Many regional floristic studies came out during the first quarter of the present century. Cooke (1906) in his flora of the Presidency of Bombay reported P.trichostachyon, P.nigrum, P.hookeri and P.longum in addition to the cultivated P.betle and the related genus Pothomorphe subpeltata. Rama Rao in his Flowering Plants of Travancore (1914) listed the following species from Western Ghats: P.galeatum, P.trichostachyon, P.longum, P.brachystachyum, P.hookeri, P.nigrum, P.sylvestre, P.hymenophyllum, P.argyrophyllum, P.wightii, P.subpeltatum and P.longicaule.

Fischer (1921) described six species from Anamalai hills. Fyson (1932) in his Flora or Nilgiris and Pulney hill tops reported P.brachystachyum, P.schmidtii, P.nigrum and P.wightii. Burkill (1923) included 13 spp. in his Flora of Abhor Hills of North Eastern India; while Kanjilal et al. (1940) in their Flora of Assam Region reported three species. Bains (1903) described eight species in his Flora of Bengal.

Duthie in the flora of Upper Gangetic Plains and the adjacent Sivalik and Sub-Himalayan tracts published between 1903-1920 included P.longum, P.betle, P.mullesua, P.napalense and P.nigrum. Hains (1924) in his Botany of Bihar and Orissa reported P.longum, P.peepuloides, P.chaba, P.attenuatum, P.nigrum and the cultivated species of P.betle. The most authoritative floristic study of the Western Ghat was that of Gamble who in his Flora of the Presidency of Madras (1925) has included the following species along with the keys. P.galeatum, P.trichostachyon, P.longum, P.hapnium, P.brachystachyum, P.hookeri, P.hymenophyllum, P.attenuatum, P.argyrophyllum, P.schmidtii and P.Wightii and P.barberi. After the publication of Gamble's Flora practically there was no addition to the list of Piper spp. from the Western Ghats and adjacent region. Much later Rahiman (1981) found a new species of P.bababudani, from the Bababudan Hills of Karnataka but this species was not validly published. He also concluded from his study of the species from Karnataka that P.hymenophyllum and P.hookeri are conspecific. Recently Ravindran, Nair and Nair (1986) has reported two new taxa from the Silent Valley forests of Kerala, namely P.silentvalleyensis and P.nigrum var. hirtellosum.

The other floristic enumerations of Piper spp. were those of Santapau (1960), Parker (1924), Sharma and Tiagi (1979), Saldanha and Nicholson (1976) Rao and Razi (1961) and Rahiman (1981, 1987).

Botanical studies on *Piper*:

Botanical studies on *Piper* are rather meagre inspite of the great economic importance of the genus and its wide distribution. The information available on various aspects are fragmentary, the more important of these are reviewed here.

The vascular organisation of the *Piper* has attracted the attention of botanists from early times. The anomalous structure of the stem was studied by Karsten (1847), Weins (1876), Debray (1886) Ironside (1911), Chibber (1913), Johnson (1914), Hoffstadt (1916), Rousseau (1927) Bond (1931) and Kaplan (1936, 1936). Later Metcalfe and Chalk (1950) has also outlined the salient anatomical features of *Piper* spp. Goebel (1931) described the vegetative and flowering stems of *Piper* species and interpreted the stipules as axillary. Balfour (1957 and 1958) studied the vascular system of seedlings and mature shoot apices of *Macropiper excelsum*. He noticed that there are two types of meristems namely the central cauline meristem which gives rise to the midrib bundle and the medullary bundles and the peripheral cauline meristem which gives rise to peripheral cauline bundles confined to one internode only. Murty (1959) studied the vegetative anatomy of *Piper betle*, *P. longum* and *P. subrubrispicum* and reported similar anatomical features for all three species. The axis is sympodial, generally more than five leaf traces are present which may or may not be of the same size. Piper is exceptional in having only one prophyll. He showed that the variation in the number and arrangement of bundles in the internode and the behaviour of the mucilage canal are characteristically different in different species thereby lending support to the earlier findings of Solereder (1908) and Metcalfe and Chalk (1950). Pal (1961) studied the origin and development of the vascular system in the shoot apices of six species of Piper. He has discussed the nature and origin of the medullary and peripheral vascular bundles of Piper spp. from their ontogenetic and histogenetic stand point.

Datta and Dasgupta (1977a, 1977b, 1979) studied the vegetative anatomy of Piper and Peperomia. Based on vascular anatomy these authors came to the conclusion that P.cubeba is more primitive than other species studied by them (P. betle, P.brachystachyum P.longum, P.napalense, P.nigrum and P.pedicellosum). They are also of opinion (1977b) that leaf anatomical characters are useful distinguishing characters in the genus Piper.

Stomata in Piper was shown to be variable in nature but usually reported to be of the tetracytic type, surrounded by a ring of usually four cells smaller than other epidermal cells (Pant and Banerji 1965; Datta and Dasgupta, 1977; Mohandas and Shaw, 1980). The development was reported by these workers as mesoperigenous or occassionally mesogenous in *P. longum* and *P. betle*.

Datta and Dasgupta (1977c) also studied the root anatomy of *P. betle*, *P. cubeba*, *P. longum*, *P. magnificum* and *P. nigrum*. They found that 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 migration from hills to moist low lands.

Tucker (1928a, b) studied the inflorescence development and floral ontogeny of *Piper aduncum*, *P. amalago* and *P. marginatum*. The flower of these species has tricarpellate, syncarpous gynoecium and 4-6 stamens. The active apex of the spike produces bract primordia and in its axil a floral apex is initiated, both are initiated by periclinal divisions in cells of the subsurface layer. The floral primordium widens and the first pair of stamens are initiated at either side. The median anterior stamens form first and the median posterior later. The carpels arise simultaneously, they are soon elevated on a gynoecial ring by the growth of the receptacle below the level of attachment of the carpel to produce a syncarpous gynoecium. The floral apex lastly produces the solitary basal ovule and is used up in its formation.

Some confusion existed on the carpel number in _Piper_. The carpel number was reported to be one (Baillon, 1872), two (Joshi, 1944) and three (Johnson, 1902; Eckardt, 1937; Murthy, 1959). The proponents of the tricarpellate gynoecium support their argument on the number of stigmas and or carpellary vascular bundles. Tucker (1982) provided evidence for tricarpellary nature from developmental studies. In _Peperomia_ (Tucker, 1980) developmental evidence supports the interpretation of gynoecium as unicarpellate. _Peperomia_ with its single carpel and unitegmic ovule is generally thought to be specialised through reduction from _Piper_ like ancestor with three carpels and a tritegmic ovule (Tucker, 1982). The gynoecium of _Piper_ according to this worker initiates as three lobes, but develops as a cup shaped syncarpous structure with three free styles.

Johnson (1902) reported that in _P.medium_ and in _P.aduncum_ and also in two species of _Heckeria_, there was only one primary archisporial cell and the embryosac development was that of the "Lilium type". The meagaspore mother cell was found to form no tetrad of meagaspores but as a result of three free nuclear divisions followed by cell formation gave rise to a 7-celled, 8-nucleate embryosac (currently designated as the Adoxa type of embryosac). Later Johnson (1910) studied the embryosac of P.betel var.monoicum and found the same type of embryosac development in this species also. Fischer (1914) and Palm (1915) investigated the embryosac development in P.tuberculatum and P.subpeltatum respectively and their results agreed with those of Johnson. But later workers (Schnarf, 1936; Maheswari, 1937) suspected the "Adoxa type" of embryosac in Piper and they based on the published figures came to the conclusion that the embryosac development followed the "Fritillaria type". This was later supported by Swamy (1944) in P.betel and Joshi (1944) in P.longum.

Maugini (1950) studied the female gametophyte in P.geniculatum and P.unguiculatum and interpreted the development to be of "Euphorbia dulcis type", characterised by triploidy in its chalazal half and that the 8-nucleated gametophyte originated from the secondary tetranucleated gametophyte.

Kanta (1962) has studied the embryology of *P.nigrum*. She reported that the embryosac development conforms to the "Fritillaria type". The endosperm was reported to be nuclear and formed a top shaped structure at maturity. The behaviour of the pro-embryo was reported to be variable so that the embryogeny did not fit into any of the existing types.

Corner (1976) studied the structure of the *Piper* seed. The seed is exarillate with copious perisperm and smaller endosperm. The testa gets crushed during development, tegmen distinct, round the endosperm at the micropylar end. The perisperm fills most of the seed, the cells thin walled and filled with starch grains and having many large oil cells. The outer and inner integument is about 3 cells thick in *P.longum* and 3-5 cells in *P.nigrum*. The seeds of *P.nigrum* are viable (though the plant itself is commercially propagated through stem cuttings) and varying degrees of germination were reported for various cultivars (Ravindran et al. 1987). The seeds germinate epigeally in about 25-40 days.

Piper spp. are generally dioecious, while a few are bisexual (Ravindran, Nair and Nair - in Press). The cultivated types of black pepper (*P.nigrum*) are monoecious.

Cytology and Cytogenetics

Cytological and cytogentical studies were very meagre in the genus *Piper*. The available studies were mostly confined to chromosome number determination of various species. Contributions to the cytology of *Piper* were made by Johnson (1902), Johansen (1931) Janaki Ammal (1945), Tjio (1948), Maugini (1951), Mathew (1958, 1972), Sharma and Battacharya (1959), Dasgupta and Datta (1976), Jose and Sharma (1983, 1984, 1988), Rahiman (1981), Bai and Subramonian (1985), Samuel (1986) and Okada (1986). Only very few of these workers attempted to study the chromosome morphology (Mathew 1972; Sharma and Bhattacharya, 1959; Dasgupta and Datta (1976) and Jose 1981, 1984, 1988).

The cytologically investigated South Indian species are *P.argyrophyllum*, *P.attenuatum*, *P.galeatum*, *P.hymenophyllum*, *P.longum*, *P.nigrum*, *P.mullesua*, *P.trichostachyon*, *P.schmidtii* and *P.wightii*. Mathew studied (1958, 1972) elevan cultivated and six wild *P.nigrum* and found that in all the cultivated types the somatic number was 2n=52, while in the wild types the numbers were 2n=104. The chromosome length ranged from 1.0 to 3.0 µ. Sharma and Bhattacharya (1959) reported 2n = 48 in *P.nigrum*. Dasgupta and Datta (1976) reported 2n = 36 for *P.nigrum* collected from north eastern India and 2n = 60 for the south Indian specimens.

In P.longum Tjio (1948) observed a heteromorphic bivalent in the somatic cells and interpreted the same as the sex chromosomes. Mathew (1958) reported a hetermorphic bivalent in the male plants of P.longum, which he has interpreted as X and Y chromosome. He postulated that the male is XY and the female XX.

The studies in general pointed to the existance of a polyploid series in the genus. The reported chromosome numbers include 2n = 24, 26, 36, 39, 40, 48, 52, 60, 64, 65, 68, 80, 96, 104, and 132. All the species studied from South India and Sri Lanka could be traced to a common basic number of x = 13, while the north Indian species seems to have a basic number of x = 12. It has been suggested that x = 13 reported consistently for the genus has to be taken as the valid basic number for the genus and that this probably might have arisen by hybridisation of types with x = 6 and x = 7 (Mathew 1958). The species with 2n = 26 are then diploids, and those with 2n = 52 may be considered tetraplioide; the 2n = 104 types are octoploids. The highest number so far reported is in P.mullesua (2n = 132) which may be a decaploid.

Bai and Subramanian (1985) are of opinion that P.galeatum (2n = 40) and P. betel (2n = 64) are aneuploids, while _P.attenuatum_ (2n = 36), _P.longum_ (2n = 60) _P. schmidtii_ (2n = 96), _P.wightii_ (2n = 48) _P.mullesua_ (2n = 132) and _P.hookeri_ (2n = 60) are higher polyploids.

The lack of uniformity in chromosome number reports of different workers indicates the existance of many cytotypes in these taxa. For example, in the case of _P.longum_ the reported somatic chromosome numbers range from 2n = 24 to 2n = 96.

Based on cytology Okada (1986) has suggested three evolutionary trends in Piperaceae leading respectively to _Peperomia_, _Piper_, _Pothomorphe_ and _Zippelia_. He suggested x = 11 as the basic number (seen in _Peperomia_) from which the aneuploid basic numbers of x = 13 of _Piper_ and _Pothomorphe_ were derived, while x = 19 of _Zippelia_ had arisen by doubling of x = 11 followed by aneuloid reduction.

Microsporogenesis was studied by Mathew (1958). Sharma and Bhattacharya (1958) noticed meiotic abnormalities and secondary association. Normal pairing and occassional quadrivalent formation were reported by Gregory and Martin (1962).

Pollen grain morphology of _Piper_ were reported by

Mitroiu (1970), Smith (1975) and Rahiman (1981). Rahiman (1981) did not observe any noticeable variation in pollen grain morphology of South Indian species. The pollen grains are small, subprolate, to prolate, monosulate and measuring 8.6 - 9.6 μ in diameter (polar view).

Chemical Studies on Piper

Many detailed chemcial studies have been carried out in species such as *Piper nigrum*, *P. longum*, *P. betle*, *P. methysticum* etc. These studies were more intensive in the case of odour and flavour components of black pepper. In black pepper the pungency is contributed by the presence of the alkaloid piperine in the fruit; while the flavour and aroma are due to volatile oil present. Because of its commercial importance extensive studies have been carried out on the flavour components.

The volatile oil of black pepper is mainly comprised of monoterpene hydrocarbons together with smaller amount of sesquiterpene hydrocarbons and oxygenated compounds. The oil of black pepper obtained by steam distillation is a pale greenish grey liquid which becomes viscous on standing. The odour is described as fresh dry-woody, warm spicy and similar to that of black pepper corn (Arctander, 1960). The volatile oil composition range from 1-2.6% (Goldmeister and Hoffman, 1956). In the study of a large number of black pepper cultivars Raju, Ravindran and Nair (1981) and Gopalam and Ravindran (1987) reported much variations in essential oil and grouped the cultivars into high, medium and low quality ones based on piperine, essential oil and oleoresin contents.

The composition of the volatile oils have been investigated by many workers. The oil contains monoterpene hydrocarbons such as camphene, Δ-3 - carene, p - cymene, limonene, myrcene, cis-ocimene, α-phellandrene, β - phellandrene, α - pinene, β - Pinene, etc. (Ikeda et al, 1962; Nigam and Handa, 1964; Lewis et al 1969 b; Richard and Jennings, 1971; Russel and Else, 1973; Debrauwere and Verzele, 1976 etc.). The sesquiterpene hydrocarbons reported include α - cis-bergamontene, β -bisabolene, δ -cadinene, β - caryophyllene, α - cubebene, ar-curcumene, β -farnasene etc. (Muller et al 1968; Lewis et al 1969 b; Richard et al 1971; Richard 1972; Debruwere and Verzele, 1976). The oxygenated monoterpenes reported include borneol, camphor, carveol, i-r-cineole, P-cymene- 8-ol, linalol etc. (Debruwere and Verzele, 1976; Russel and Jennings, 1969 etc). Phenyl esters include eugenol, methyl, eugenol, myristicin and safrole (Russel and Jennings, 1970; Richard and Jennings, 1971). In addition to the above components many miscellaneous compounds were also met with in the oil of *P.nigrum* - such as butyric acid, benzoic acid, methyl heptanoate, 2-undecane, piperonal etc (Debrauwere and Verzele, 1975). The flavour, quality and profile aspects were discussed by Govindrajan and Narasimhan (1989).

Altogether more than 150 chemical constituents have been isolated and identified in pepper oil (Purseglove _et al_ 1981).

In addition to the volatile oil components, a large number of chemical compounds were isolated from different _Piper_ Species. These compounds include hydrocarbons and their derivatives, phenylpropides, lignans, flavones, isobutylamides, alkaloids and various other miscellaneous compounds. The chemistry of Indian _Piper_ has been reviewed by Atal, Dhar and Singh (1975) and recently by Sengupta and Ray (1987).

Hydrocarbons and their derivates:

Gokhale, Phanikar and Bhide (1948) isolated undecyl - 3, 4-methylenedioxy benzene from _P.nigrum_ from the steam distilled residue of ether extract. Pipataline was isolated from the fruits of _P.peepuloides_ by Atal, Dhar and Pelter (1969). Synthesis of Pipataline was achieved by Yoshimosi _et al_ (1969) and the compound was reported to be a catechol melanin precursor.

Triacontane and its corresponding alcholol, triacontanol, two unsaturated aliphatic compounds widely distributed in plants have been isolated from *Piper hookeri* and *P. brachystachyum* (Singh, and Atal, 1969) Caryophyllene oxide was also isolated from the same species (Thappa *et al*, 1970).

Phenyl propides:

Apiole has been isolated from *P. brachystachyum* (Singh *et al* 1969 b). Phenyl ethanol benzoate was obtained from the leaves of *P. hookeri* (Singh and Atal, 1969 a).

Lignans:

Sesamin, originally obtained from *Sesamum indicum* (Pedaliaceae) has been isolated from the stems and fruits of *P. longum* by chromatography over alumina (Atal, Dhar and Girotra, 1966). + - diaeudesmin, the first naturally occurring diaxially substituted lignan was obtained from the fruits of *P. peepuloides* by chromatography of the petroleum ether extract (Atal, Dhar and Pelter, 1967). Cubebin was isolated from the unripe fruits of *P. cubeba* (Gildmeister and Hoffman, 1956). Gottlieb *et al* (1989) reported neolignans in various members of Piperaceae.

Flavones:

5 - hydroxy - 3 - 4 - 7 - trimethoxyflavone was isolated

from P *peepuloides* by Dhar, Atal and Pelter (1970). 5 hydroxy - 4 - 7 - dimethoxyflavone was also isolated from *peepuloides* by the same authors. Flavones were reported by Gottlieb *et al* (1989) in various members of Piperaceae.

Isobutylamides

N - isobutyl - deca - trans - 2 - trans - 4 - dienamide was isolated from *P.longum* and *P.peepuloides* (Dhar and Atal, 1967). This compound causes profound salivation and numbness of the tongue. Atal and colleagues found this to possess *in vitro* and *in vivo* antitubercular activity (Atal, Dhar and Singh, 1975). Piper-longuminine was isolated by Chatterjee and Dutta (1966) from the roots of *P.longum*. Twenty isobutylamides had been isolated from different *Piper* spp. during the last two decades (Sengupta and Roy, 1987) *P.longum* and *P.trichostachyon* were the two South Indian species from which these compounds were reported.

Alkaloids:

Piper is rich in alkaloids. The important economic use of black pepper is due to the presence of the piperine alkaloid that contributes to the pungency of black pepper. Other important alkaloids reported include piperitine, trichostachine, peepuloidin, trichonine etc. Piperine, the pungent alkaloid, occurs in *P.nigrum*, *P.chaba*, *P.longum*, *P.retrofactum* etc (Atal and Banga

1962, 1963; Guest, Smith and Chapman, 1963; Mishra and Tiwari, 1964).

Other compounds;

In addition to the compounds mentioned many other compounds have been reported by various workers (Singh and Atal, 1969; Singh, Dhar and Atal, 1969; 1970; 1971; Sengupta and Ray, 1987; Gottlieb et al 1989 etc.).

Taxonomic position, evolutionary trends and affinities:

Benthem and Hooker (1880; 1883) included Piperaceae in the Sub class Monochlamydeae in the series Microembryeae along with families such as Chloranthaceae, Myristicaceae and Monimiaceae. Engler and Prantl (1875) considered Piperales to be among the most primitive flowering plants and they placed this at the beginning of the series. Rendle (1925) believed them to be related to Polygoniales (segregated from the Caryophyllales) because he thought the flower to be fundamentally 3-merous. It is to be noted that in both Piperales and Polygonials the ovule is characteristically solitary and orthotropus.

The genus Piper show extreme reduction of floral characters. Piper is closely related to Saururus and also to Chloranthus and all the three show common characters such as achlamydous flower, 1-celled, 1-

ovuled ovary, sessile stigma, orthotropous ovule and albuminous seed. (Lemount and Decarenes, 1976; Heywood, 1978). All are regarded as simplification of Magnoliales, Laurales or Ranales. But none of these orders display the primitive vegetative evolution from Pachycaul to leptocaul which with a primitively vascular system is found in Piper (Corner, 1976). Piperales emerge as an order distinguished by the retention of the perisperm (Corner, 1976) and the loss of the testa. Saururaceae and Piperaceae are the specialised relics, with Piper yet emerging from the pachycaul stage. Corner (1976) goes on to say that Piperals become another phyletic line the origin of which is lost, but which seems to have led primitively to the parasitism of Rafflesiaceae and Santalaceae. Lawrence also opined "contrary to the views of Engler and Rendle, it is now held generally that the family while is of undeterminate origin is not one of the most primitive dicots, but probably is an independent and terminal off-shoot of direct Ranalian ancestry" a view supported by Hallier (1912), Bessy (1915) and Hutchinson (1928).

Phytogeographical distribution shows that Piper and Peperomia have probably originated in tropical America at a comparatively high altitude and dry condition. Peperomia thrived later on drier and higher Andes zones, Piper in comparatively lower and damper Brazil and later spread to part of Asia and other regions (Dutta and

Dasgupta, 1977). These authors were also of opinion that evolution of Piper and Peperomia were related to adaptation with two different conditions, Piper adapted gradually with the damper and lower lands with elaboration of the vascular arrangements; Peperomia evolved in drier and higher lands which required, reduction of bundle surfaces or surface volume ratio, a xerophytic adaptation (Dutta and Dasgupta, 1977).

Uses of Piper

India has long been known as the land of spices. Spices played an important role in the life and rituals of Indian people. Of all the spices produced and exported from India, black pepper occupies the most prominent position and is often referred to as the "King of Spices", and as the "black gold".

Black pepper as a spice in cookery:-

The most widespread use of black pepper is in cookery as a spice; it is in fact the most widely used spice. It is often used three times in the same dish before food is eaten; first in the kitchen as an ingredient in the dish; second to correct or improve the overall seasoning during cooking; and thirdly at the dining table to add more spice and flavour to the prepared dishes. Both white pepper and black pepper are used in the same way in the foods. They are used whole, cracked, coarsely ground or finely ground (Anon, 1981). Green pepper is also used in a number of dishes in the households in Kerala. Piperine, the pungent alkaloid of black pepper, has been used to impart a pungent taste to brandy. The oil of pepper is a valuable adjunct in the flavouring of sausages, canned meats, soups, table sauces, and certain beverages and liquors. (Lewis, 1980)

Black pepper in indigenous medicine:-

P.nigrum and P.longum (black pepper and long pepper) are extensively used in the indegenous systems of medicines known as Ayurveda and Unani. Ayurvedic texts written in Sanskrit such as Dhanwantari nighantu, Rajanighantu, Bhavaprakasha etc. give the usage of black pepper, known as "Maricha" in sanskrit. According to these, black pepper is considered "pungent, bitter, hot light, sharp, dry corosive, sweet smellish and germicidal". It increases the digestive power, gives relish for the food and augments "pitha". It emaciates the body and is not an aphrodisiac. On digestion it is pungent generally. It cures cough, dyspnoca, cardiac diseases, colic, worms, diabetes, piles, and almost all diseases caused by Vatha" (rhutamism) and "kapha" (phlegm) (Warrier, 1988).

Dey (1980) in his book on Indian medicinal plants used in Ayurvedic preparations state that black pepper is "alexipharmic, alternative, antiperodic, carminative, digestive, diuretic, emmenagogue, resolvent, rubifacint, stimulent and stomachic; indicated in arthritic diseases, black fever, cough and cold, dysentry, malarial and intermittent fever, indigestion, hiccough and hysteria; stimulent to cholera, stomachic in dyspepsia, and flatulence". Useful in relaxed throat, piles and skin diseases, tonic to uterine masculation after delivery and promote the secretion of bile.

According to the Unani system of medicine black pepper is useful in tooth ache, inflammation, pains in the liver and of musceles, diseases of the spleen, leucoderma, lumbago, chronic fevers, paralysis, facilitates menstration, and dries the humors of the body (Kirtikar and Basu, 1933).

Black pepper is essential ingredient in many indigenou (Ayurvedic) medicinal preparations such as: Sethajwarari Kashayam (for treatment of different varieties of intermittant fevers) Marichadi thailam (for rhinities, or Coryza for external use) Jeerakadi Kashayam (for intermittant fever), Vilangadi Kashayam (for worms) Nayanamritha varthy (for use in eye diseases), Ramabana gulika (or Sarvajwara vinasini for fevers) etc.

In modern western medicine black pepper is no more used except perhaps indirectly as an ingredient of some combined preparations.

Other Uses

The oleresin of pepper has bacteriostatic and fungistatic properties. The oleoresin at Ø.5% inhibits the growth of Micrococcus pyrogenes var. aureus and Aspergillus versicolor. Pepper oleoresin in concentrations of Ø.1% or less lowered the phagocytic activity of leucocytes. Extracts of pepper are found to have a hypercoagulative effect in vitro; they lessen clotting time by accelerating the thrombin activation and lowering the heparin level in clotting systems.

Pepper retards the development of rancedity in oil and fats, frozen ground pork, beaf and lard. This activity has been attributed to the presence of tocopherols in the oleoresin.

Piperine was formerly official in U.S.P; but it has no marked physiological action and is no longer used in medicine.

Black pepper has been reported to have oral and contact toxicity against stored food products insects (Lathrop and Scierstead, 1946; Su, 1977; 1978). Scott and

Mckibben (1978) showed that ground pepper and its extracts were highly toxic when they were applied topically to 3-5 day old insects. The 24 hour LD_{50} value was reported as 9.6 g/insect. Crude extract of black pepper gave 100% killing of boll worms at a dosage of 27.0 g/insect and above. The toxicity was attributed to the presence of piperine in black pepper. Su and Horvat (1981) isolated three substances from black pepper which exhibited toxic effects to insects. These were isobutyl analogs of piperine with varying alkyl side chains of peepuloidin, guinensine and pipericide. Of these guinensine is the most toxic to insects (Govindarajan, 1981).

Pharamacological properties of piperine were investigated by many workers, and was shown to have CNS depressant action (Shin and Woo, 1980, Pei, 1983). A detailed study by Lee, Shin and Woo (1984) had shown that piperine has CNS depresant activity characterised by muscle relaxant activity in mice, antipyretic activity in typhoid vaccinated rabbits; analgesic activity in mice and anti inflammatory activity in the case of induced edema in rats.

Oil of pepper is used in perfumery particularly in bouquets of the oriental type to which it imparts a spicy note, difficult to identify.

Uses of other species of Piper

P. longum

P. longum is the source of the long pepper of commerce. Known as "Pipali" in Sanskrit, long pepper is an important medicinal plant in Ayurveda. The root-known as pipalamool is pungent, stomachic, laxative, antihelminthic, carminative, improves appetite, useful in bronchitis, abdominal pains, diseases of the spleen, ascites, and causes bilousness. The dried unripe fruit (pipali) is pungent, spicey cooling, stomachic, aphrodisiac, alternative, laxative, antidiarrhoeic, antidysentric, useful in "Vata" (rhumatism) and "Kapha" (phlegm), asthma, brochitis, abdominal complaints, fevers, leucoderma, diseases of the spleen etc. In the Unani medicine the root of long pepper is used in the plasy, gout and lumbago; the fruit in cases of inflammation of the liver, pains in the joints, lumbago, snake-bite, scorpion bite and night blindness (Kirtikar and Basu, 1933).

P. attenuatum root macerated in water is an excellent diuretic (Chopra, Nayar and Chopra, 1956). P. Chaba is used in place of P. longum in coughs, cold and haemorrhoidal afflictions. P. cubeba oil is used in gastro-urinary diseases like cystitis, gonorrohoea and gout (Chopra, Nayar and Chopra, 1956).

P. betle is extensively used in India, Bangladesh and in many other South Asian countries as a masticatory, for chewing together with arecanut and lime. The trading in *P. betle* leaves is a 700 crore industry in India. It is used in the indigenous system of medicine and is used in improving appetite, as a tonic to the brain, heart and liver; and also to relieve cerebral congestion, satyriasis, and for afflictions of the eye. Apart from the above many wild relatives are used in tribal medicines by the tribal people.

MATERIALS AND METHODS

CHAPTER III

MATERIALS AND METHODS

For the present study 44 cultivars of black pepper. (*P.nigrum*) and 13 related taxa were used. Seven lines of wild *P.nigrum* were also included in the study. The cultivars were collected from the cultivators' gardens and the wild taxa from the various forest areas of Western Ghats and they were grown in the germplasm conservatory of the National Research Centre for Spices (NRCS) farm at Peruvannamuzhi, Calicut District, Kerala. All the species included in the study are available at the NRCS herbarium. Duplicates will be deposited at the Herbarium of the Botanical Survey of India, Southern circle, Coimbatore in due course.

Survey and collection of *Piper* spp. were carried out in the Western Ghat forests, mainly from the Kerala region and adjoining areas. Some of these areas were surveyed more than once to collect flowering and fruiting specimens for taxonomic study and for harbarium. Necessary field notes were also prepared during the survey. Runner shoots were collected for planting and establishment in the nursery. Fruiting and flowering shoots were collected for herbarium preparation. Spikes were preserved in fixatives (FAA) for microscopic study.

Field observations, herbarium specimens and fixed materials were all used in the taxonomic study of Piper spp. Piper specimens available in the nearby Herbaria were also utilised for the study. Specially useful were the herbarium of the Botanical Survey of India, Southern Circle, Coimbatore (MH). MH has the largest collection of South Indian species of Piper. It has specimens collected by Hooker, Wight, Barber and Gamble. Table III.1 gives the taxa used in the present study.

The cultivars of black pepper were collected through surveys in various pepper growing areas. These were planted in the experimental farm of the NRCS at Peruvannamuzhi in a germplasm conservatory, which incidentally is the largest germplasm collection of black pepper in the world. All the observations used in the study were recorded from the vines growing at this conservatory. Table III.2 gives the black pepper cultivars used in the present study.

Morphological Studies

Leaf anatomical characters were studied from cross sections stained in safranine in the conventional way from five leaves and from each leaf two sections were used for recording data. Five readings from each section were recorded and the data used in all analysis were mean of fifty measurements.

Table III.1 : Piper spp. used in the present study

Species Code No.	Species
1	P. attenuatum
2	P. argyrophyllum
3	P. galeatum
4	P. hymenophyllum
5	P. longum
6	P. mullesua
7	P. schmidtii
8	P. silentvalleyensis
9	P. trichostachyon
10	P. wightii
11	P. nigrum (1)
12	P. nigrum (2)
13	P. nigrum (3)
14	P. nigrum (4)
15	P. nigrum (5)
16	P. nigrum (6)
17	P. nigrum (7)
18	P. nigrum var. hirtellosum.
19	P. sugandhi
20	P. sugandhi var. leiospicata

Table III.2 : Black pepper cultivars used in the study

Cultivar code No	Cultivar name
1	Aimpiriyan
2	Arakkulam munda
3	Arimulaku
4	Balancotta
5	Bilimalligesara
6	Cheriyakaniakkadan
7	Cheppukulamundi
8	Cholamundi
9	Jeerakamundi
10	Karimunda
11	Kaniakkadan
12	Karivilanchy
13	Karimkotta
14	Kalluvally (1)
15	Kalluvally (2)
16	Kallubalancotta
17	Kottanadan
18	Kuching
19	Kuriyalmundi
20	Kuthiravally
21	Kurimalai
22	Malamundi
23	Mundi
24	Narayakkodi

25	Neelamundi
26	Nedumchola
27	Neyyattinkaramundi
28	Ottaplackal (1)
29	Panniyur I
30	Perambramunda
31	Perumkodi
32	Poonjaranmunda
33	Sagar Local
34	Thevanmundi
35	Thommankodi
36	Thulamundi
37	Udakkere
38	Uthirankotta
39	Vadakkan
40	Valiakaniakkadan
41	Vattamundi
42	Vellanamban
43	Velliyaranmunda
44	Vokkalu
45	P. nigrum wild (Acc. 2077)
46	P. nigrum wild (Acc. 2071)
47	P. nigrum wild (Acc. 2009)
48	P. nigrum wild (Acc. 2059)
49	P. nigrum wild (Acc. 2060)
50	P. nigrum wild (Acc. 2015)
51	P. nigrum wild (Acc. 2062)

Stomatal characters were carried out from isolated lower epidermal peels. For this small bits from the middle portion of the leaf were cut and kept in 40% nitric acid and boiled over spirit lamp flame. The epidermis got separated. These were then washed in water, neutralised in 10% alkali, washed again and stained in safranine and mounted in glycerol. For stomatal measurements mean of one hundred stomata from five epidermal peels taken from five leaves were measured in an Olympus research microscope using a micrometer eyepiece. Stomatal frequency was taken from one hundred microscope fields under the high power of the microscope and mean calculated.

The stomatal ontogeny was studied in the representative genera, P.nigrum and P.longum. For this epidermal peels from leaves of varying developmental stages were taken, stained in haematoxylin and studied under the high power and oil immersion of an Olympus microscope.

For general anatomy, materials were processed in the conventional way for microtomy. Sections were cut at 10 μ and stained in safranine-fast green-or safranine-fastgreen-orange G. Both free hand and mocrotome sections were used in the present study. Phototgraphs were taken using an Olympus 35mm camera fitted with an exposure meter.

The anatomical studies were limited to the type species and compared with the representative wild taxa.

Chemical studies on Piper: Extraction of triterpenoids, steroids and flavonoids.

The leaves collected from the various pepper cultivars and wild taxa were dried in shade, cut into small pieces and powdered using mortar and pestle. Ten grams of the leaf powder taken in a conical flask was first extracted with petroleum ether (60-80) for 48 hrs at room temperature. The extract was removed, fresh petroleum ether was added and then the flask was fitted with a reflux condenser and heated over a water bath and the extraction continued for one hour. The hot petroleum ether is decanted off, mixed with the earlier extract and concentrated under vacuum and the concentrated extract was used for the study of pertoleum ether soluble compounds using TLC.

The leaf sample after extraction with petroleum ether was then extracted first with pure methanol for 48 hours at room temperature and then with 80:20 methanol-water for 24 hours. After this the flasks were refluxed over a water bath for one hour. Then the flasks were cooled, the extract decanted and mixed with the earlier methanol extract and filtered through coarse filter paper to remove suspended impurities. In order to remove fatty materials and chlorophyll, the extract was refluxed with benzene for one hour and then separated in a separating funnel. The lower portion was separated, washed with hot benzene and again separated in a separating funnel. The lower brown portion was drained off, concentrated in vacuum and used for the analysis of flavonoids by paper chromatography.

Chromatographic analysis of petroleum ether extract

The concentrated petroleum ether extracts from the various varieties and species were analysed by thin layer chromatography (TLC) using silica gel-G (E.Merck), following the method of Harborne (1973). Unidirectional separation was used as only a few spots were present. The solvent used was benzene-ethyl acetate (3:1). All analyses were carrried out in this solvent system using standard size plates (20x20cm) and the thickness of the silica gel coating was kept uniform at 0.2 mm. The silica gel plates were activated by heating at 100°C in an oven for 30 minutes. A small volume of the petroleum ether extract (100 μl) was applied with a micropipette on the plate approximately 2.0 cm above the bottom edge of the plate using a spotting guide. The plates were developed in TLC glass tanks using the solvent mentioned. The solvent was allowed to move a distance of 15 cm from the spot. After the run, the plates were dried in air and then sprayed with 20% sulphuric acid and heated at 8ØoC for about thirty minutes. Three replications were used in each case and all the Rf values presented are mean of three readings. In addition of the Rf, the spot colours were also recorded. The steriod compound present in *Piper* was analysed by co-chromatography with authentic phytosterols.

Analysis of methanol extract

The methanol extract was analysed using paper chromatography following standard procedures (Mabry, Markham and Thomas, 1976; Markham, 1982). Paper chromatography was carried out in a chromatographic cabinet using Whataman 3mm paper (56 x 48 mm). About 2ØØ μl of the methanolic extract was loaded on the paper, and the paper after spotting developed descendingly using T-butanol: acetic acid: water mixture in the ratio 6:1:3. The running time was around 18 hrs at the ambiant termperature of 3Ø ± 2°C. Unidirectional separation was used in all cases as the spot numbers were less and good separation was obtained, in the solvent system employed. The solvent was allowed to run down to a distance of 45cms. Then the papers were removed, dried in air and viewed under long uv light (366 nm). The chromatograms were exposed to ammonia vapours and also sprayed with 1% Aluminium chloride. Tha analysis was carried out in duplicate and the Rf values given are mean of two chromatograms.

Two dimensional chromatograms were used for separating the flavonoids of some Piper species in order to get a better picture of the flavonoid composition. The spots were marked by viewing in uv light and they were later cut out and eluted in chromatographic grade methanol and used for recording the uv absorption maxima. The absorption profiles were recorded in a Beckman uv spectrophotometer. The shifts in absorption maxima were recorded after the addition of 10% NaOH and 1% $AlCl_3$. All chemicals used in present study were of analytical grade, chromatographic grade chemicals were used as solvents.

The chromatographic spot patterns were used for computing paired affinity indices (PAI). The PAI between A and B was calculated as:

$$PAI = \frac{\text{No. of spots similar to A and B}}{\text{Total No. of spots in A and B}} \times 100$$

Where A and B stand for two collections. PAI is a measure of chemical affinity between any two taxa.

Numerical Taxonomic Studies

Numerical Taxonomic studies were carried out using the data on morphological characters collected from 51

P.nigrum collections (51 OTU s) and from 13 related *Piper* taxa. Tables III.3 and III.4 give the characters and their states used in the case of black pepper and *Piper* spp. respectively.

Three different analysis were carried out. Cluster analysis-average linkage - was used for grouping the characters. Centroid linkage was used for grouping the cultivars as well as the *Piper* taxa (OTU s). Factor analysis (Principal component analysis) was used to study the role played by various characters in the cultivar or species differentiation. The methodology used for the average linkage analysis was that of Hartigan (1981). The centroid - linkage analysis was based on the method explained by Engleman (1981) and that the factor analysis was based on the technique outlined by Frane and Hill (1976) and Frane, Jenrich and Sampson (1981).

The computer analysis was carried out at the computer centre of the Carnegie - Mellon University, Pittsburgh, USA. The programme package known as BMDP-81 was made use of in the analysis. This programme package was originally developed by the Department of Biomathematics, University of California, Los Angeles and adapted for use in Fortran by the Pittsburgh Computer Centre, Pittsburgh, Pennsylvania, USA. The

Table III.3 : Characters and their states used in the study of black pepper (*P. nigrum*)

Character Code No.	Character and its state
1	Leaf length (in mm)
2	Leaf breadth (in mm)
3	Leaf length / Leaf breadth
4	Leaf size index (L.L x L.B / 100)
5	Leaf thickness (in mm)
6	Lower epidermal thickness (in mm)
7	Upper epidermal thickness (in mm)
8	Mesophyll thickness (per mm^2)
9	Stomatal frequency (per mm^2)
10	Guard cell length (in mm)
11	Guard cell breadth (in mm)
12	Spike length (in mm)
13	Peduncle length (in mm)
14	L.L - Spike length relation (L.L / Sp.L)
15	Leaf shape (of lateral branch) 1: ovate 2: cordate 3: ovate-elliptic 4: ovate-lanceolate
16	Leaf base 1: round 2: cordate 3: acute (even slightly obliquely placed)
17	Leaf margin 1: even 2: wavy
18	Leaf shape (of orthotropic shoot) 1: ovate 2: cordate
19	Fruit shape 1: round 2: oblong 3: obovate
20	Fruit size 1: bold 2: medium 3: small
21	Colour of the emerging shoot (runner) 1: purple 2: whitish green
22	Spike shape 1: straight 2: curved (or twisted)

Table III.4 : Characters and their states used in the study of *Piper* spp.

Character Code number	Details of characters
1	Leaf length in mm
2	Leaf breadth in mm
3	Leaf length / Leaf breadth
4	Leaf size index
5	Petiole length in mm
6	Spike length in mm
7	Peduncle length in mm
8	Leaf length / Spike length
9	Stomatal density per mm^2
10	Guard cell length in mm
11	Guard cell breadth in mm
12	Distance from leaf base to the 2nd pair of ribs
13	Number of ribs
14	Leaf shape (1: ovate to ovate-elliptic; 2: cordate; 3: ovate-lanceolate; 4: elliptic to elliptic-lanceolate)
15	Leaf base (1: round; 2: cordate; 3: acute to attenuate
16	Leaf texture (1: Glabrous; 2: Sparsely hairy mainly on the veins; 3: hirsute)
17	Leaf nature (1: membraneous; 2: coriaceous)
18	Spike shape (1: filiform; 2: cylindrical; 3: globose)
19	Spike orientation (1: pendulous; 2: erect)

20	Spike texture (1: glabrous; 2: hirtellous)
21	Bract type (1: sessile, adnate to rachis; 2: Stalked, pelatate, orbicular; 3: cupulaar with decurrent base; 4: Fleshy, connate, cup-like; 5: oblong, angular and free all around)
22	Stamen number (1:two; 2: three or four)
23	Fruit nature (1: free; 2: fused)
24	Fruit shape (1: ovate-oblong; 2: spherical 3: elliptical 4: obovate)
25	Fruit colour change on ripening (1: green to orange and red; 2: green to yellow; 3: green to black)
26	Fruit taste (1: pungent; 2: Spicy and mildly pungent; 3: bitter)
27	Plant type (1: dioecious; 2: monoecious 3: predominantly monoecious)
28	Growth habit (1: shrubby climber; 2: stout woody climber 3: no climbing habit and trailing on the ground)
29	Distribution in the natural habitat (1: plains to lower elevations (from 0 - 500 m); 2: plains to higher elevations (from 0 - 1500 m) 3: lower elevations to higher elevations (from 500 - 1500 m); 4: found only at high elevations (above 1500 m).
30	Presence of Thrips infestation (1: present; 2: absent)

programmes employed are:

B M D P 1 M : Cluster analysis of variables - Average linkage

B M D P 2 M : Cluster analysis of variables - Centroid linkage

B M D P 4 M : Factor analysis - Principal Component analysis

Numeric and graphic print outs were interpreted and incorporated in this study.

An explanatory note on the numerical taxonomic methods used is given below.

A Note on the Numerical Taxonomic techniques used in the present study

1. Cluster Analysis

The objective of cluster analysis is to device a classificatory scheme for grouping a given set of variables or individuals (each of which is described by a set of numerical measures) into a number of classes such that the objects within classes are similar in some respect and different from those in other classes.

In general the raw data to be subjected to cluster analysis of an (N x P) matrix of measurements on the objects under study. The first stage of cluster analysis is to convert the raw data matrix into a matrix of inter-individual similarity, dissimilarity or distance measures and based on the magnitude of these measures to arrive at a certain number of groups or cluster types or classes of individuals.

2. The measurement of similarity and distances:-

The majority of clustering techniques begin with the calculation of matrix of similarities or distances between individuals. A clustering analysis may be thought of as an attempt to summerise the information on the relationship between individuals which is given in a similarity matrix, so that the relationship may be easily comprehended and communicated. Obviously the output of the clustering technique will be as meaningful as the input similarities and distances.

3. Similarity measures

A similarity coefficient measures th relationship between the individuals, given the values of a set of "p" variates common to both. In general they take values in the range of Ø to 1. Sneath and Sokal (1973) gives a full discussion of similarity coefficients for the use with binary data (where the variates are "presence" or "absence" types). For quantitive data the most commonly used measure of similarity between the individuals is the product moment correlation coefficient, which is used in the present study.

4. Distance measures:-

The most commonly used distance measure and the most familiar is the Euclidian distance, where the distance between points i and j denoted by dij is defined as:-

$$d_{ij}^2 = \sum_{k=1}^{P} (x_{ik} - x_{jk})^2$$

Where x_{ik} is the value of the k_{th} variable for the i_{th} entity. Euclidian distance used on raw data may be very unsatisfactory since it is badly affected by changing the scale of a variable. Because of this the variables are standardised before employing

Euclidian distance by taking $Z_{ik} = \frac{x_{ik}}{k}$ where σk is the standard deviation of the k^{th} variable.

Another measure known as Mahalanobis D^2 is also used in clustering technique as a distance measure. This measure is given by :

$$d^2 = (x^i - x^j) \Sigma^{-1} (x^i - x^j)$$

Where Σ^{-1} is the inverse of the within group variance - covariance matrix and x^i and x^j are the vectors of scores for individuals i and j. Mahalanobis D^2 has the advantage over the Euclidian measure that it allows correlations between variables.

There are different methods of clustering available, the common ones being single linkage (nearest neighbour) method; complete linkage (farthest neighbour) method; average linkage method and centroid linkage. The basic procedure with all these methods is similar. They begin with the computation of a similarity or distance matrix between the entities and end with a dendrogram or tree diagram showing the successive fusions of individuals which culminates at a stage where all the individuals are in one group. At any particular stage the methods fuse individuals or groups of individuals which are closest (or most similar). Differences between methods arise because of the differences in the ways of defining distance (or similarity) between individual and a group containing several individuals or between groups of individuals.

In the present study the average linkage technique was used for clustering the characters (variables) and centroid linkage method was employed for clustering the cases or OTU s.

5. Average Linkage Method:-

In this method the distance between two groups is defined as the average of the distances between all pairs of individuals of the two groups. This method is not dependent on the extreme values for defining clusters. Many average linkage methods have been developed. Among these the unweighted pair group method using arithmetic averages (UPGMA) is the most frequently used. It rests on the plausibility of the concept of an average similarity and dissimilarity coefficient.

Average correlations between OTU s have usually been computed as average of their transformed values which are then back-transformed into correlation measures. The methodology of this cluster analysis is given by Hartigan (1981).

6. Centroid Linkage for Clustering Cases:-

The centroid linkage method or the Unweighted Pair Group Centroid Method (UPGCM) is perhaps one of the most attractive technique of clustering used in taxonomic studies. The method computes the centroid of the OTU's that join to form clusters. Distances are then computed between these centroids. The centroid is the point in phenetic space whose coordinates are the mean values of each character over the given cluster of OTU s. It is also the centre of gravity of the cluster of OTU's. If the characters are of the binary type, the centroid represents a point within the phenetic hypercube and the co-ordinates are simply the observed frequencies of the various characters. The method applied here is explained by Engleman (1981).

In the present study centroid linkage was used for establishing similarities (or distances) among the OTU s studied. The distance between any two OTU s is defined as the square root of:

$$Dij - \sum_{k-1}^{22/30} (x_{ik} - x_{jk})^2$$

where the index k is the number of characters used in the analysis and Dij is the distance measure between the i^{th} and j^{th} OTU, and x^{ik} and x^{jk} denote the numerical measurement of k^{th} character for i^{th} and J^{th} OTU respectively. In the centroid linkage the distances between groups or clusters is defined as distance between group centroids or equilibrium points.

In the present study the data were standardised before analysis to give allowances for varying scales for different character. The standardised variable is calculated by the equation

$$Z_i = \frac{x_i - X_i - \bar{X}_i}{\sigma_i}$$

where Z_i is the standardised form of variable X_i, with mean X_i and standard deviation σ_i.

6. Factor Analysis

Factor analysis is a useful tool in exploring taxonomic relationships and is being employed with the following objectives:

1. To group the variables (characters) under study into factors such that the variables within each factor are highly correlated.
2. To interpret each factor according to the variables belonging to it.
3. To summarise many variables/characters by a

few factors.

The usual factor analysis model expresses each variable as a function of factors common to several variables and a factor unique to the variable. In other words, if we denote "Z_j" as the j_{th} character (in standrardised form) and "m" the number of factors common to all factors under study. "f_i" the common factors (i ranging from 1 to m), u_j the factor unique to the variable z_j and a_{ji}, the factor loadings, then the factor analysis model is given by:

$$z_j = a_{ji} f_i + a_{j2} f_2 + \dots\dots\dots a_{jm} f_m + u_j,$$

The number of factors m should be small, and the contribution of the unique factors should also be small. The individual factor loadings, a_{ji} for each variable should be either very large or very small so that each variable/character is associated with minimum number of factors.

Variables with high loadings on a factor tends to be highly correlated with each other, and variables that do not have the same loading patterns tends to be less highly correlated. Each factor is interpreted according to the magnitude of the loadings associated with it. That is, in other words, the original variables/characters may be replaced by the factors. This is done by computing what is known as factor scores for each factor. The i^{th} factor score is computed as:

$f_i = b_{i1}z_i + b_{i2}z_2 + \ldots\ldots\ldots\ldots b_{ip} z_p$

Where b_{i1} is factor score coefficient with regard to the i^{th} factor, and z_1 is the standardised form of the variable/character under study.

Thus the variations between observations can be explicitly represented in terms of the variation in factor scores. The factor scores will have mean zero and standardised deviation unity.

There are four main steps in factor analysis:

1. The computation of correlation matrix of the characters under study.
2. Estimation of factor loadings; these infact indicate how far each character is correlated with others.
3. The rotation of factors to obtain a simple interpretation by making the loadings either large or small so that each factor can be taken to be representatives of a few sets of interrelated characters. The rotation is a mathematical transformation so that the overall relationships between the characters are not affected.
4. The computation of factor scores for each case or observation. The factor score is a numerical measure which expresses the degree to which each case or observation possesses the property that the factor describes. For example, if one factor is highly related to floral characters, and another factor is

highly related to leaf characteristics, then for any two species under observation factor score 1 will give a numerical measure of floral characters and factor score 2 will give a numerical measure of leaf characters, and hence if there is a large difference in factor score 1 between the two species under study, it can be interpreted that the two species mainly differ in floral characters. The methodology followed in the present study is that of Frane and Hill (1976) and Frane, Jenrich and Sampson (1981).

OBSERVATIONS AND RESULTS

CHAPTER IV

TAXONOMIC TREATMENT

Piper Linn. Gen. Pl. ed.1 : 333, 1737. Species of this genus, as represented in the region under study, are perennial scandent or woody climbers or creepers. Branching dimorphic. Leaves alternate, petiolate, simple, entire, often unequal sided, petiole groved. A single lateral prophyll present at flowering nodes, the prophyll often modified to form a cap like structure enclosing the shoot apex and spike. The base of the leaves (petioles) at sterile nodes (in the runner shoots and orthotropic shoots) develops into a sheath which protects the bud. In the erect growing orthotropic shoots as well as in the runner shoots the leaves are borne on longer petioles, lamina often larger, ovate, widely ovate or cordate in shape; in certain species the juvenile leaves on the growths are small and ivy-like. In the lateral shoots the leaves are usually ovate, but variable to some extent, base round, acute or cordate, tip acuminate, margin straight or wavy, hairs present or absent, when present simple and multicellular. Leaves ribbed (veins originating from the base or near the base and ascending to the tips), very rarely pinnately reticulate.

Mostly dioecious. Flowers borne on solitary leaf-opposed spikes, morphologically terminal, spikes erect or pendent; usually filiform, rarely cylindrical or globose; flowers bisexual in a few, usually unisexual; each in the axil of a bract, sessile or shortly stipitate; bracts variable in shape depending on species. Perianth 0, stamens 2-4; filaments short, anthers 2-celled, ovary 1-celled, ovule solitary, placentation basal; style 0, stigmas 2-5; fruits drupaceous, small, ovoid or globose, 1-seeded, seeds usually globose, surface smooth and glabrous. The species included in the present study are treated under two subgenera, namely Subg.*Pippali* Ravindran Subg. nova and *Maricha* Ravindran Subg. nova. The major diagnostic character between the subgenera is the orientation of the spike - erect in the case of former and pendent in the case of latter. These subgeneric epithets have derived from the Sanskrit names for the type species (*P.longum* and *P.nigrum* respectively). A news key is devised for the South Indian species of *Piper*.

The genus in general is characterised by very small, highly reduced flowers closely packed to form spikes. Most of the South Indian Taxa are dioecious. Hooker (1886) has included 108 species grouped under six sections in his Flora of British India. Out of these only eleven are from South India. Gamble (1925) has later described 13 species, mostly from the Western Ghats, but did not use any subgeneric classification.

A new dichotomous key has been formulated for the South Indian Taxa of *Piper* during the present study.

Key to the Piper species of South India

1.	a.	Spikes erect	...	S.g. Pippali	(2)
	b.	Spikes pendent	...	S.g. Maricha	(4)
2.	a.	Fruits laterally fused-spikes cylindrical	...	P.longum	
	b.	Fruits not laterally fused	...		(3)
3.	a.	Spike globose	...	P.mullesua	
	b.	Spike filiform	...	P.silentvalleyensis	
4.	a.	Leaves ribbed, venation comptodromous	...		(5)
		Leaves not ribbed, venation pinnately reticulate	...		(13)
5.	a.	Fruits turn black from green on ripening	...		(6)
	b.	Fruits yellow or red on ripening	...		(8)
6.	a.	Leaves, shoots prominently pubescent	...	P.hymenophyllum	
	b.	Leaves and shoots glabrous or glabrescent	...		(7)
7.	a.	Leaves 7-ribbed from base	...	P.attenuatum	
	b.	Leaves 5-ribbed at the base	...	P.argyrophyllum	
8.	a.	Bracts fleshy, connate, boat shaped	...		(9)
	b.	Bracts not fleshy, boat shaped	...		(10)
9.	a.	Spike glabrous, flowers			

shortly stipitate ... *P. galeatum*

b. Spikes minutely pubescent ... *P. trichostachyon*

10.a. Bracts cupular ... (11)

b. Bracts peltate ... (12)

11.a. Bracts cupular, decurrent at base ... *P. nigrum*

b. Bracts deeply cupular, flowers shortly stipitate ... *P. sugandhi*

12.a. Bracts oblong, leaves thin with silvery scales beneath ... *P. wightii*

b. Bracts orbicular, leaves very thick without scales ... *P. schmidtii*

13. Leaves not ribbed, pinnately reticulate ... *P. barberi*

Piper Linn. *Pippali* Ravindran Subg. nova

Spikes erect. Includes three species: *P. longum*, *P. mullesua* and *P. silentvalleyensis* (Plate IV.1)

P. longum Linn., Sp. Pl. 29, 1753; Vahl, Enum. 1:334, 1804; Roxb., Fl. Ind. 1 : 154, 1832; Wall., Cat. 6640, 1832; Wight, IC t. 1938, 1853; Miq., Fl. Ind. Bat. 1(2):440, 1859; C.DC., in DC Prodr., 16(1):355, 1869; Hooker f., Fl. Br. India V, 93, 1886; Watt, Dic. Eco. Pro. India, 6:1892; Trimen, Fl. Ceylon, 3:424, 1895; Prain, Bengal Pl., 2 : 668, 1903; Cooke, Fl. Bombay, 3:19, 1908; Duthie, Fl. Upper Gang. Plains, 1903 - 1920; Hains, For. Fl. Chotanagpur, 384, 1910; Haines, Bot. Bihar & Orissa, 3 : 757, 1924; Rao, Fl. Pl. Travancore, 336, 1914; Fischer, Rec. Bot. Sur. India, 9(1): 151, 1921; Gamble, Fl. Presidency of Madras, 843, 1925; Kanjilal et al. Fl. Assam, 4:34, 1940; Raizada, Suppl. Fl. Upper Gang. Plains, 242, 1976 ; Rahiman Piper in Karnataka, J. Bombay Nat. His. Soc. 84: 46, 1987; Huber, in Rev. Handb. Fl. Ceylon, 288, 1987:

Cattu thippali - Rheede, Hor. Mal. 7: 5. 14,1678

P. sarmentosum Wall., Cat. 6641, 1832

P. latifolium Hunter, As. Res. 9: 390, 1809

P. turbinarium Noronha, Verb. Batav. Gen. 5: 1790

Chavica Roxburghii Miq., Hook. Lon. J. Bot., 4: 433, 1845

A slender, perennial creeping undershrub, dioecious. Vegetative branches creeps and spreads on the ground, fruiting branches erect, young branches puberulous, hairs minute, multicellular, deciduous, older branches totally glabrous; leaves distinctly dimorphic, those on creeping shoot cordate, glabrous, petiole very long, groved; leaves approx. 7x5 cm, petioles 2-3 cm. Leaves on the fruiting branches oblong, lanceolate, base unequally cordate, with pronounced auricle, tip acuminate, 3-4 pairs of lateral ribs arise right from the base, lower side puberulous or downy when young, petioles very short or even absent. Spikes cylindric, erect, about 2-4 cm long, creamy white to yellowish white when young, peduncle about 1 - 1.5 cm long, downy; male spikes much longer, about 6 - 10 cm long, yellow on maturity. Bracts peltate, orbicular, glabrous, pedicelled; flowers laterally fused; stamens 3-4, carpel single, ovary obovate, style O, stigma 3-4 lobed, short, papillate. Fruits very small, fused laterally, spicy and pungent; seeds very small. Spikes on ripening turns green to balck, deciduous. (Plate 4.1)

Specimens Examined:

Western Ghats (South India) Barber, 6656, 7161, 3175, 8728, 8703, 8701, 8702; Bourdillon 449; Vajravelu, 26277, 33372, 48844, 48900kj3; Mohanan, 59520; Nair, 50772, 64667; Ramamurthy, 47644; Sebastine, 727, 25369; Ellis and Ramamurthy, 8796; Subba Rao, 68503; Henry, 41603, 41602; Subramonian, 3489; Ramachandran, 61924, 56705; Ansari, 69968, 64852, 42451; Joseph 7825 (BSI Herbarium - MH). P.N.R.: Dhoni, Palghat: 101, 106, 477, 479; Nilambur: 435, 606; Calicut; 693, 695; Nagercoil; 0518; Thenmalai, 0628, (NRCS Herbarium). 2018, 2034, 2042, 2043 (NRCS Germplasm conservatory).

P.mullesua Ham. ex D. Don., Prodr. Fl. Nep., 20, 1825; C.DC in DC., Prodr. 14(1), 338, 1869.

P.brachystachyum Wall., Cat. 6656, 1832; Wight, IC. t. 1931, 1853; Hooker f., Fl. Brit. India, VI: 87, 1886; Rao, Fl. plants of Travancore, 336, 1914; Gamble, Fl. Presi. Madras, 1205, 1925; Fyson, Fl.South India Hill St. 1, 1932; Fl. Nilgiris and Pulney Hill tops, 1 : 334, 1915; Rahiman, Piper of Karnataka, J. Bombay Nat. His. Soc. 84, 66, 1987; Manilal, Fl. Silent Valley, 231, 1988.

P.*guigual* Ham., ex. D. Don., Prodr. Fl. Nep. 20, 1825

P.*vasculosum* Miq., Syst. Pip. 280, 1843; Wall., Cat. 6660, 1832

Chavica guigual Miq., Syst. Pip. 280, 1843

C.*mullesua* Miq., Syst. Pip. 280, 1843

C.*sphaerostachya* Miq., Syst. Pip., 279, 1843

A slender extensively branched climber, branches glabrous; juvenile shoots puberulous or glabrous, juvenile leaves very small, ivy-like, cordate; leaves on the flowering shoot small, coriaceous, elliptic, approximately 8x3 cm; base acute and often oblique, tip acuminate; 2 pairs of prominent ribs, lower one from the base, upper 1-2 cm above the base; veins prominent on the ventral side. (Plater IV.1)

Spikes filiform in male, 3-5 cm long; female globose or oblong, about 1.0 cm long, peduncle short, less than 0.5 cm; bracts orbicular, peltate and pedicelled. Stamens 2, filament short, anther lobes single, reniform, dorsifixed ; pollen sacs 2, dehiscing by longitudinal slits; carpel single, ovary ellipsoid, style O, stigma 3-lobed, minute, pappillate. Fruits very small, almost ellipsoidal, seeds minute, ellipsoidal, spicy and pungent.

It is a high elevation species, occurring usually above 1000m, the species often spreads through the ground and climbs up shrubs and tree trunks or rocks. The leaves on the juvenile runner shoot and orthotropic shoot very small, typically cordate and ivy-like. The juvenile shoots often have crisp hairs which are deciduous; such shoots sometimes coloured light purple. Flowering May-June, fruit ripening Feb-March.

Specimens Examined:

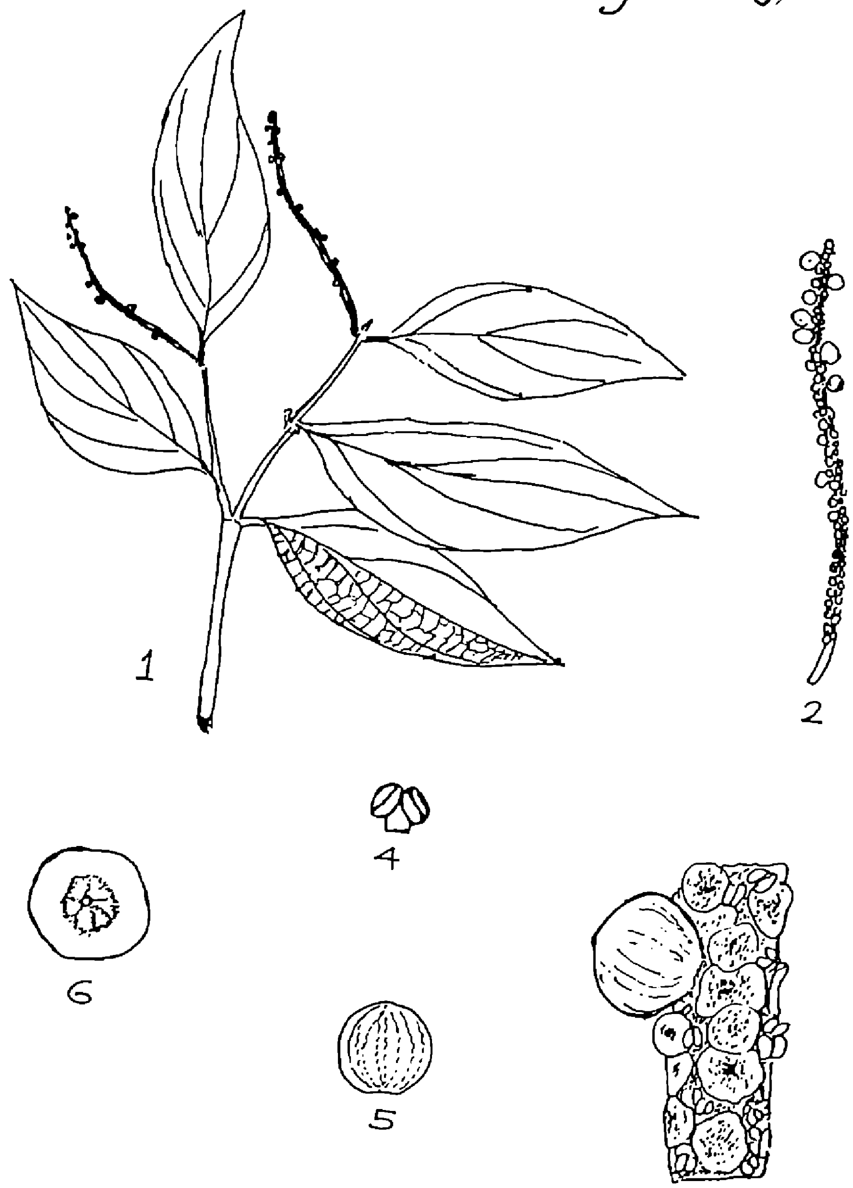
Western Ghats (South India)

Wall.,43080,16453; Barber, 7220, 7219, 7319, 7314, 7578, 7208,7578, 7208, 7220, 7315, 7206, 7207, 5447, 5437, 5436, 5438, 5448, 5472, 6547; Narayanaswamy, 4440, 53801; Viswanathan, 807, 975; Ramamurthy, 18129; Jacob, 16069, 17562; Shetty 10343, 11918, 34111, 37537; Balakrishnan, 139; Sebasitne 2561, 3212; Vajravelu, 35110, 36333, 38213, 38234; Ellis, 34727; Srinivasan, 65915, 63692 (MH) PNR: Silentvalley - 052, 0192, 0257, 0261, 0265, 0649, 0655, 0669. Idukki- 0138, 0139, 0574; Kodaikanal- 0573, 0575; Nelliampathy- 0467; Naduvattom, 0412, 0413, 0418; Anamalais, 0712.

P.silentvlleyensis Ravindran et Asokan, J.Econ. Tax. Bot. 10(1): 167 - 169, 1987.

Slender climber, stem about 0.5 to 1.0 cm thick, swollen at the nodes, branches terete, entirely glabrous, petiole short, about 3-6 mm, groved, sheaths minutely pubescent, leaves alternate, elliptic-lanceolate, somewhat coriaceous, lamina 5-8.5 cm long (mean 2.2 cm), glabrous on both sides, base acute, more or less asymmetric, tip caudate - acuminate, lamina prominently ribbed, lateral ribs 2 pairs, the first

P. Silentvalleyensis.



1. A Twig
2. A Spike
3. Spike - enlarged
4. stamen
5. Ovary
6. Ovary - T.S.

from the base and the second about Ø.5 cm above the base.

Spikes 2.5 - 5.5 cm long, erect and flexuous, peduncle very short Ø.1 - Ø.3 cm long; glabrous, furrowed when dry, never longer than petiole; bracts orbicular, peltate, stalked, about Ø.Ø7 cm in diameter, flowers bisexual, stamens two very short, anthers 2-lobed, reniform, and attached transversely at the tip of the filament, dehiscing by longitudinal slit, ovary globoid, style Ø, stigma minute, 3-lobed; fruit very small, mature one about Ø.1 cm. across, obovate with striations, spicy and pungent.

A bisexual species resembling P.mullesua in external appearance, but differs from it in having elongated erect fruiting spikes and bisexual nature. This is the only bisexual wild species reported from the Western Ghats. Rare, so far collected only from one locality.

Specimens examined:

PNR: Silent valley, Palghat 186 (holotype) NRCS Herbarium.

Sub g. Maricha Ravindran Sub g. nova.

Spikes pendent, almost always filiform, rarely cylindrical.

(Plates IV.2-7)

P.hymenophyllum Miq., Hook. London J. Bot., 5: 554, 1846; C. DC., in DC.Prodromus 16 (1) 364, 1869; Wight Ic.6:2, t. 1942, 1853; 336 - 337, 1914; C.DC, Candollea, 1:22Ø, 1923; Gamble, Fl. Presi. Madras, 12Ø5, 1925; Mathew, Fl. Tamil Nadu Karnatic, 3 : 1351, 1983; Saldanha, Fl. Karnataka, 1:79, 1984; Huber, in Rev. Handb. Fl. Ceylon, VI, 280, 1987; Rahiman, Piper in Karnataka, J. Bombay Nat. His. Soc. 84: 66, 1987; Manilal, Fl. Silent Valley, 231, 1988.

P. malamiris Wall., Cat. 6642, G &H, 1832.

P. nilghirianum Cas. DC., in Prodr. 16(1), 364, 1869

P. lanatum Wight ex. Miq., Hook. Lon. J. Bot. v, 533, 1846

P. wightii Miq., in Hook. Lon. J. Bot. V, 552, 1846.

A scandent, slender climber, dioecious, having prominently pubescent branchlets and leaves, hairs more pronounced on the young shoots. Leaves thin, dried ones chartaceous, sometimes thinly coriaceous; shape and size much variable, ovate to ovate - elliptic, or elliptic - lanceolate; the leaves on the emerging juvenile shoot (runner shoot) small, cordate or semi-cordate. Leaves on the lateral shoots vary in size, around 9 x 3.6 cm on an average, base acute or obtuse; cordate or semi-cordate in the case of leaves on the juvenile shoots; tip acuminate; 2-3 pairs of lateral ribs arising from the base or near to it; both sides pubescent, petiole groved, pubescent. (Plate IV.2)

Spike thin, filiform, male spikes 5-13 cm long, female spikes 6-16 cm long, lengthening in maturity, peduncle pubescent, bracts sessile, adnate to the rachis, obovate to elliptic; stamens 3, anther dithecous; style 0, ovary oval, stigma 3-4 lobed, recurved and pappillate. Fruits oval, mature ones often becomes spherical, dark green, on ripening turns black;

taste bitter. The scars ciliate.

Specimens Examined:

Western Ghats (South India): Barber, 7559, 7563, 7560, 7346, 5489, 5450, 6112, 6085; Subba Rao, 31999, 31997, 36519; Jacob, 17666, 391, 427; Ramamurthy, 18188, 32882; Sebastine, 17252, 25054, 25058, 25009, 2569, 3188, 5458, 4389, 25077; Shetty, 34405; Vajravelu, 24863, 62983, 26124, 27699, 33213, 49800; Nair, 69772, 65478, 68\9869, 56692, 64035; Nair (VJ), 67235, 6730407; Ramachandran, 61944, 62290, 64055 (MH).

PNR: Silent Valley- 003, 0017, 0036, 0049, 0053, 0069, 0187, 0189, 0191, 0202, 0238, 0244, 0256, 0344, 0356, 0357, 0358, 0646, 0658, 06711 Thirunelli- 0306, 0397; Coorg, 0334, 0537; Anamalais, 0694, 0709, 0710. (NRCS Herbarium).

P.attenuatum Ham. ex. Miq. Miquel, Syst. Pip., 306, 1843; Fl. Indica Bat. 1(2): 451, 1859; C.DC., in Prodr. 16(1): 363, 1869; Wight, Ic.5. 1933, 1853; Hook., f., Fl. Brit. India, 5: 92, 1886; Burkill, Rec. Bot. Sur. India, 10(2): 347, 1925; Gamble, Fl. Presi. Madras, 848: 1925; Kanjilal et al., Fl. Assam 4:37 1944; Hains, Bot. Bihar and Orissa, 3: 790, 1924; Rahiman, Piper in Karnataka, J. Bombay Nat. His. Soc. 84: 66, 1987.

P.diffusum Vahl, Enum. 1 : 333, 1804

P.karok Blume, Cat. Gew. Buitenz.33, 1823

P.malamiris Roxb., Fl. Ind. 1: 160, 1832

P.sirium C.DC., in DC Prodr. 16: 160, 1869.

Dioecious, scandent climber, leaves thin, papery when dry, glabrous, ovate to elliptic in the fruiting branches, ovate to broadly ovate to cordate in the runner shoot, about 11 x 5 cms; petiole long, about 8.5 cm; groved, leaf base attenuate, tip acuminate, 7-ribbed from the base, the outer pair reaching only 1/2 - 2/3 of the leaf, the others reaching almost to the tip. (Plate IV.3)

Spike thin, long, filiform, pendent; female 7-15 cm long, male 8-18 cm, peduncle about 2 cm, spike glabrous. Bracts sessile, adnate to the rachis, obovate to elliptic, margins free, glabrous; stamens 3-4 dithecous, dehiscing longitudinally, style O, ovary 1, oblong, stigma 3-4 lobed, recurved, pappillate, ovule single. Developing fruit oblong, mature ones round to oblong, 0.25 to 0.4 cm; turn from green to black on ripening, deciduous, taste bitter. The scars left by fallen fruits ciliate. The flowering season is May-June, fruit ripens in December-January. Off season flowering very common. This species is very common in all the forests except at the higher elevations and in sea-level forests.

Specimens Examined:

Western Ghats : Barber, 5051; Subba Rao, 24528, 19647, 30052, 32877, 42575, 44384, 44400, 40472; Balakrishnan, 10881; Narayanaswamy, 5372, 3537; Shetty, 28055; 28026, 32327; Henry, 48263, 17394; Sebastine, 16520, 25055; Subramonian, 3846, 9066; Vajravelu, 41724, 32181; Raju and Ranganathan, 18026. 15723, 18156, 18146, 18201, Ramachandran, 62065, 62602; Nair 81262, 81153, 81159; Joseph, 17190, 44458; Nair

(V.J), 67291 67304 (MH)
PNR: Walayar- 0107, 0122; Thirunelli - 0396, 0397; Nelliampathy-0459; Nagercoil- 0508, 0509, 0513, 0519; Nilambur, 04255, 0442; Vengalam, Trivandrum- 0619 (NRCS Herbarium)
Acc. Nos. 2031, 2040, 2050, 2038, 2039, 2006, 2007, 2088 (NRCS germplasm conservatory).

P.argyrophyllum Miquel, Syst. Pip, 330, 1843; C.DC., in DC., Prodr. 16(1); 365, 1869; Hooker f., Fl. Brit. India 5:93, 1886; Wight, Ic. t. 1941, 1853; Trimen, Fl. Ceylon, 3:428, 1895; Rao, Fl. Travancore, 338, 1914; Gamble, Fl. Presi. Madras, 1205, 1925; Fischer, Rec. Bot. Sur. India, 9(1): 151, 1921; Saldanha & Nicholson, Fl. Hassan, 53, 1976; Rao & Razi, Fl. Mysore, 177, 1981; Rahiman, Piper in Karnatakam J. Bombay Nat. His. Soc. 84; 66, 1987.

P.malamiri Wall., Cat. 6642 E, F & I, 1832
P.wightii Miq., in Hook. Lond. J. Bot. 5, 552, 1846
P.walkeri Miq., in Hook. Lond. J. Bot. 4, 438, 1845.

A slender, scandent, perennial climbing shrub, dioecious, main stem and branches glabrous, the young shoot puberulous; leaves thin, papery when dry, ovate to elliptic, about 12 x 7 cms, base round, often cordate in the leaves of the runner shoot, tip acuminate, 5-ribbed at the base, another pair arising about 0.5-1.0 cm above the base, the outer pairof the ribs running to 2/3 of the leaf, the inner ones reaching to the tip, glabrous or puberulous, younger leaves often minutely hairy, especially along the veins on the lower side of the leaf, sometimes silvery scales present on the lower side, petiole about 1-1.5cm, groved, glabrous or minutley puberulous. (Plater IV.2)

Spike thin, filiform, pendulous, length highly variable, male spikes 8-16 cms, female 5-10 cms, glabrous or puberulous. Bracts sessile, and adnate and almost confluent with the rachis, obovate to elliptic; stamens 3, anther dithecous, carpel single, style O, ovary oblong, stigma 4-lobed, rarely 3-lobed, short, recurved and papillate. Berry (fruit) ovate, becomes spherical in full maturity, on ripening turns black directly from green, decidous, taste bitter. The scars left by fallen fruits ciliate.

Externally very similar to P. attenuatum, but differs from it in having 5-nerved (ribbed) nature of leaf base and shorter, white fruiting spikes.

Specimens examined:

Western Ghats: Ellis, 38502, 37874; Barber, 7313, 7595, 7344, 7577, Subba Rao, 36517; Kartikeyan, 26834; Vajravelu, 33840; Subramonyan, 5547 (MH).

PNR: Silent Valley- 006, 0024, 0059, 0064, 0069, 00201, 00206, 0354, 0380, 0653; Dhoni (Palghat) 0100; Wynad - 0306, 0307, 0309, 0310, 0687, 0675, 0676; Nagercoil- 0515; Thenmala, 0627. (NRCS Herbarium).

A long spiked variety of P. argyrophyllum was also noticed during the study. This one appears very similar to P.

attenuatum, but for the 5-ribbed nature of the leaf base, and the minutely puberulous nature of the young leaves and shoot tip.

Flowering time May-June; fruiting Dec-Jan, off season flowering is common.

P. galeatum (Miq) C. DC, in DC prodr. 16(1): 242, 1869; Hooker f., Fl. Brit. India, 5:80, 1886; Rao, Fl. pl. Travancore, 336, 1914; Gamble, Fl. Presi. Madras, 1206, 1925; Sald. & Nicol., Fl. Hassan, 54, 1976; Sald., Fl. Karnataka, 1:80, 1984; Rahiman, *Piper* in Karnataka, J. Bombay Nat. His. Soc. 84:66, 1987; Manilal, Fl. Silent Valley, 231, 1988.

Muldera galeata Miq. in Hook. Lon. J. Bot. 5, 557, 1846 *Muldera wightiana* Wight, Ic. t. 1943, 1853 (right hand figure) *P. talbotti* C. DC in Fedd. Report. 10:523, 1912.

A stout woody climber, common at medium elevations of 500-800 m. Dioecious, leaves usually elliptic-lanceolate to lanceolate or elliptic; thick, glabrous, about 10 x 4 cms, size smaller in male vines, base acute, two pairs of lateral ribs from the base, the third pair about 1-2 cm above the base, and often placed unequally, nervules more prominent on the lower side.

Spike filiform, pendulous, young ones green or pale purple, mature yellowish white, glabrous, peduncle short, glabrous, spikes long about 10-15 cms, male even longer sometimes reaching upto 25 cms; bracts prominent, connate, forming a fleshy cup or boat shaped structure, shortly stipitate, and recurved; bract glabrous; style 0, stamens 2, anther lobes 2, carpel single, ovary obovate, stigma 3-4 lobed. Fruits green, on ripening turn bright yellow and then to orange red; oblong, or spherical, bold, taste bitter first and slightly pungent later. (Plate IV.4)

Specimens examined:

Western Ghats-Barber 5484, 5456, Nair (V.J), 67246, Nair (N.C), 61141; Ramamurhty, 16145 (MH).

PNR: Silent Valley - 0012, 0347, 0349, 0378, 0672, 0673;

Idukki - 0162, 0163, 0567, 0568, 0570, 0571, 0685;

Wynad - 0316, 0541. (NRCS Herbarim).
Flowering time May - June, fruit maturing Dec. - Jan.

P. trichostachyon (Miq) C.DC in DC Prodr. 16(1):242, 1869; Hooker f., Fl. Brit. India, 5:80, 1886; Cooke, Fl. Bombay 18, 1903; Rao, Fl. Pl. Travancore, 336, 1914; Gamble, Fl.Presi. Madras, 1206, 1925; Fischer, Rec. Bot. Sur. India, 9(1); 1921; Santapau, Rec. Bot. Sur. India, 18(1): 257, 1960; Rahiman, Piper in Karnataka, J. Bombay Nat. His. Soc. 84:66, 1987.

Muldera trichostachya Miq., in Hook. Lon. J. Bot., 5: 556, 1846; Wight, IC. t. 1944, 1853.

A stout woody climber, growing to a height of 10 - 12 metres, common at elevations upto about 1000 metres, Leaves thick, coriaceous, glabrous, elliptic to elliptic-lanceolate, rarely ovate, much variable in size, length ranges from 8-18 cm, breadth from 6 - 1Ø cms; size larger in young plants, much smaller on older vines and in male vines, base round or acute, tip acuminate, margins often recurved. Leaves on the orthotropic shoot more or less cordate. Ribs 2-3 pairs, the upper most arises 1-2 cms above the leaf base. Spike filiform, minutely hairy, male spike about 4-1Ø cms, female 4-9 cms, lengthens in maturity; peduncle glabrous, bracts decurrent, connate, forming a fleshy cup or boat shaped structure, hirtellous; stamen 2, short, dithecous, carpel-l, style O, stigma 3-4 lobed, lobes short, papillate. Fruits bold, spherial or oblong, taste bitter first, pungent later; colour changes from green to yellow and then to orange red on ripening. (Plate IV.4)

Specimens examined:

Western Ghats - Barber, 74Ø6, 74Ø4, 7418, 5948, 5441, 5467, 5426, 872Ø, 8721, 8722, 6Ø8, 6Ø83, 7Ø53; Narayanaswamy, 54Ø7, 3538; Joseph, 12793, 127Ø5; Henry, 16282; Ramachandran, 62Ø64; Nair (NC), 7Ø179; Vevekanandan, 45642; Vajravelu, 629Ø2, 277Ø3; Subramonyan, 7876 (MH)

PNR: Silent Valley - ØØØ2, ØØ15m ØØ26, ØØ65, Ø166, Ø169, Ø17Ø, Ø171, Ø172, Ø177, Ø378, Ø674; Idukki, Ø162, Ø5Ø4; Wynad, Ø4Ø5, Ø4Ø7, Ø549 (NRCS Herbarium)

P.nigrum Linn., Sp. Pl. 28, 1753; Vahl, Enum. 1:329, 18Ø4; Roxb., Fl. Ind. 1:15Ø, 1832; Miq., Syst. Pip., 33Ø, 1843; Wall., Cat. 6643 A, B and C, 1832; C.DC., in DC., Prodr. 16(1): 242, 1869; Hook. f., Fl. Brit. India, 5:9Ø, 1886;

Watt., Dict. Econ. Prod. India, 1892; Trimen, Fl. Ceylon, 3, 427, 1895; Prain, Bengal Pl. 668, 1903; Duthie, Fl. Upper Gang. Plains, 1903 - 1920; Fyson, Fl. Nilgiris and Pulney Hill tops, 1:334, 1915; Fischer, Rec. Bot. Sur. India, 9(1): 151, 1921; Haines, Bot. Bihar & Orissa, 3 : 789, 1924; Burkill, Rec. Bot. Sur. India, 10(2): 347, 1925; Gamble, Fl. Presi. Madras, 1204, 1925; Kanjilal, et al., Fl. Assam, 4:37, 1940; Santapau, Rec. Bot. Sur. India, 16(1), 1957; Trelease & Yuncker, Pip. N.S. Amer. 81, 1950; Backer & Brink, Fl. Java, 18, 1963; Rao, Bull. Bot. Sur. India, Suppl. 2:10, 1968; Howard, J. Arnold Arbor. 54(3), 377, 1973; Sald. & Nicol. Fl. Hassan Dist., 54, 1976; Rahiman, Piper in Karnataka, J. Bombay Nat. His. Soc. 84:66, 1987.

Molagukodi, Rheede, Hort. Mal. 7 : 23-24, 1678

P. trioecum Miq., Sys. Pip. 310, 1843; Hook. Lon. J. Bot., 4:438, 1845; Wight, Ic. t. 1935, 1852;

P. nigrum var. trioecum C.DC., in Prodr. 16(1):363, 1869;

P. bacatum C.DC., ibid, 242, 1869

P. colonum Presl. Bot. Bemerk., 112, 1844

P. fallax Vahl, Enum. 1:335; 1804

P. glyphicum Hoffm., ex Kunth, Linnaea 13:573, 1839

P. malaborense C.DC., in DC Prodr. 16(1):242, 1869

P. spurium Link. Enum. Hort. Berol. 1: 37, 1821

Muldera multinervis Miq., in Hook. Lon. J. Bot., 5:557, 1846

M. wightiana Miq., ibid, 558

P. rotendum nigrum Casparus Fl. Mal. 54, 1696

P. aromaticum Lam. Llius. 1:79, 1791

The common black pepper, found extensively in the evergreen forests of Western Ghats, and in the adjoining areas, almost from sea level up to an elevation of 2000m. :Perennial climber, climbing by means of ivy-like roots which adheres to the support tree. Vigorous vine, old stem thick and rough, branches numerous, runner shoots arise from the base. Leaves thick, coriaceous, glabrous, shape much variable, commonly ovate, elliptic or elliptic-lanceolate; size varies from small to large, base round, acute or cordate, tip acuminate; lateral ribs 2 or 3 pairs, prominent, the upper most one 1-2.5 cms above the leaf base, upper surface dark green to light green, lower surface dull green; petioles short or long, groved, leaf margins wavy or even. Pearl glands (wax glands) present on the under surface of leaves and on young shoots and petioles.

Spikes filiform; pendulous, young ones green, whitish green, or purple; mature ones green or pale yellow. Spike length varies much among the collections studied. Peduncle glabrous, bracts oblong, decurrent, sessile with free upper margin, develop into a shallow cup in female spikes, rachis and bracts glabrous; stamens 2, anther dithecous, carpel single, ovary spherical, style 0, stigma 3-5 lobed, pappilate. Fruit a drupe, changes to red on ripening, seed mostly spherical, pungent.

Wild forms usually dioecious; cultivated ones bisexual.

Specimens Examined:

Western Ghats - (South India): Barber, 2590, 3231, 2959, 7396, 830, 821, 5945, 3003, 2978, 2977, 2989, 2997, 5950, 836, 3235, 5952, 3286, 3238, 3228, 3223, 3219, 3243, 3104, 3106, 3107, 3111, 3114, 30007, 30002, 5945, 2975, 2969, 2980, 2963, 2960, 2971. 5943, 5941, 2962; Joseph, 16166, 12798, 15584; Sebastine, 15688, 5877, 9633, 18419; Henry, 48127, 47521, 61520; Subba Rao, 68510, 68534; Ellis, 22210, 19926, 470, 8709, 8708, 8705, 8707 (MH)

PNR: Silent Valley - 001,007, 0011, 062, 064, 0167, 0170, 0184, 0188, 0195, 0196, 0204, 0236, 0262, 0269, 02\343, 0364, 0370, 0374, 0381, 0391, 0654 Walayar - 0121; Idukki - 0141, 0157, 0497, 0498, 0499, 0502, 0569; Wynad - 0315, 0393, 0401, 0544, 0635, 0679, 0688, 0690; Coorg - 0324, 0330, 0337 Nagercoil - 0507, 0517; North Kanara - 0550, 0551, 0552, 0555; (NRCS Herbarium)

Acc. Nos. 2009, 2015, 2059, 2060, 2062, 2071, 2077 (NRCS germplasm Conservatory)

P.nigrum var. *hirtellosum* Asokan & Ravindran Eco. Tax. Bot., 10; 167, 1987.

Similar to *P.nigrum*, but spikes minutely hairy and partially bisexual. (Plate IV.5)

Specimen examined: Holotype, Silent Valley 386 (NRCS Herbarium)

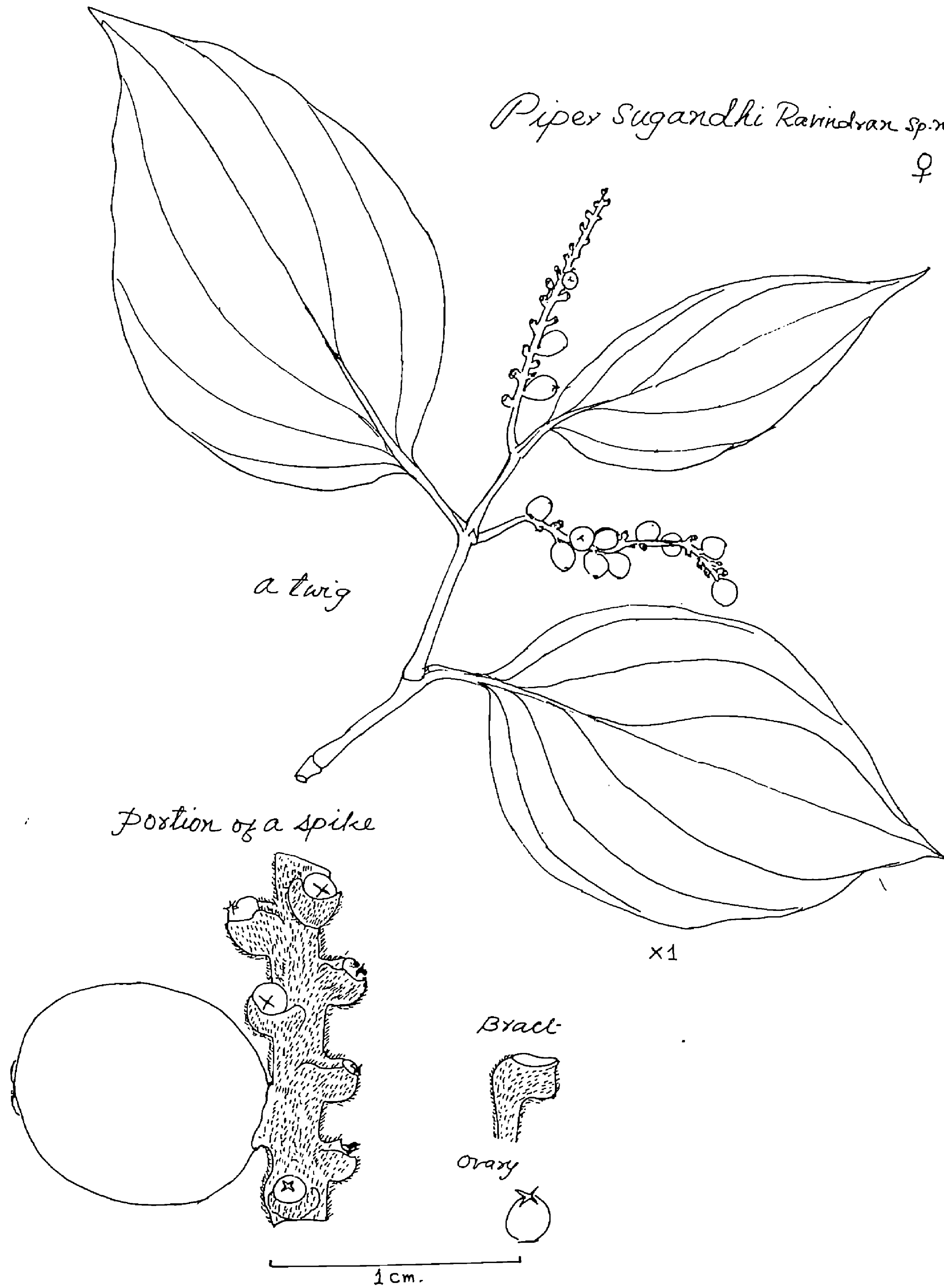
P.sugandhi Ravindran Sp. nova

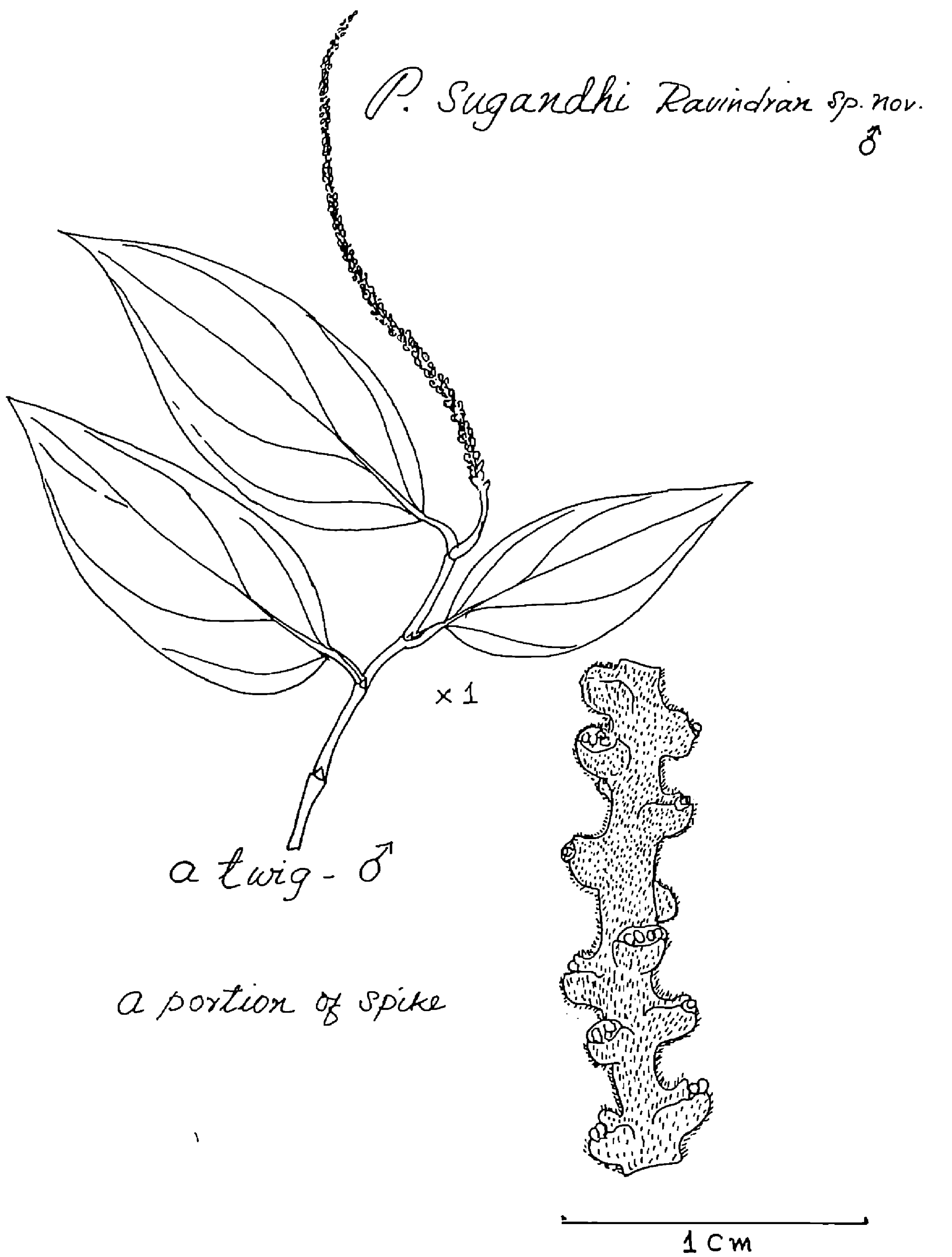
P.nigro L. affine, sed differt floribus stipitatis, bracteis minute pubescentibus penitus cupulatis. P.trichostachyeni affinis sed facile distinguenda floribus stipitatis, bractearum formisque. Holotypi lecti ed locum Sugandhagiri, Wynad et positi in Herabaria NRCS, Calicut.

Allied to P.nigrum L. but differs from it in having stipitate flowers, and bracts that are minutely pubescent and deeply cupular; also allied to P.trichostachyon but distinguishable from this by the shortly stipitate flowers and by the shape of the bracts. (Fig IV.1; Plate IV.5)

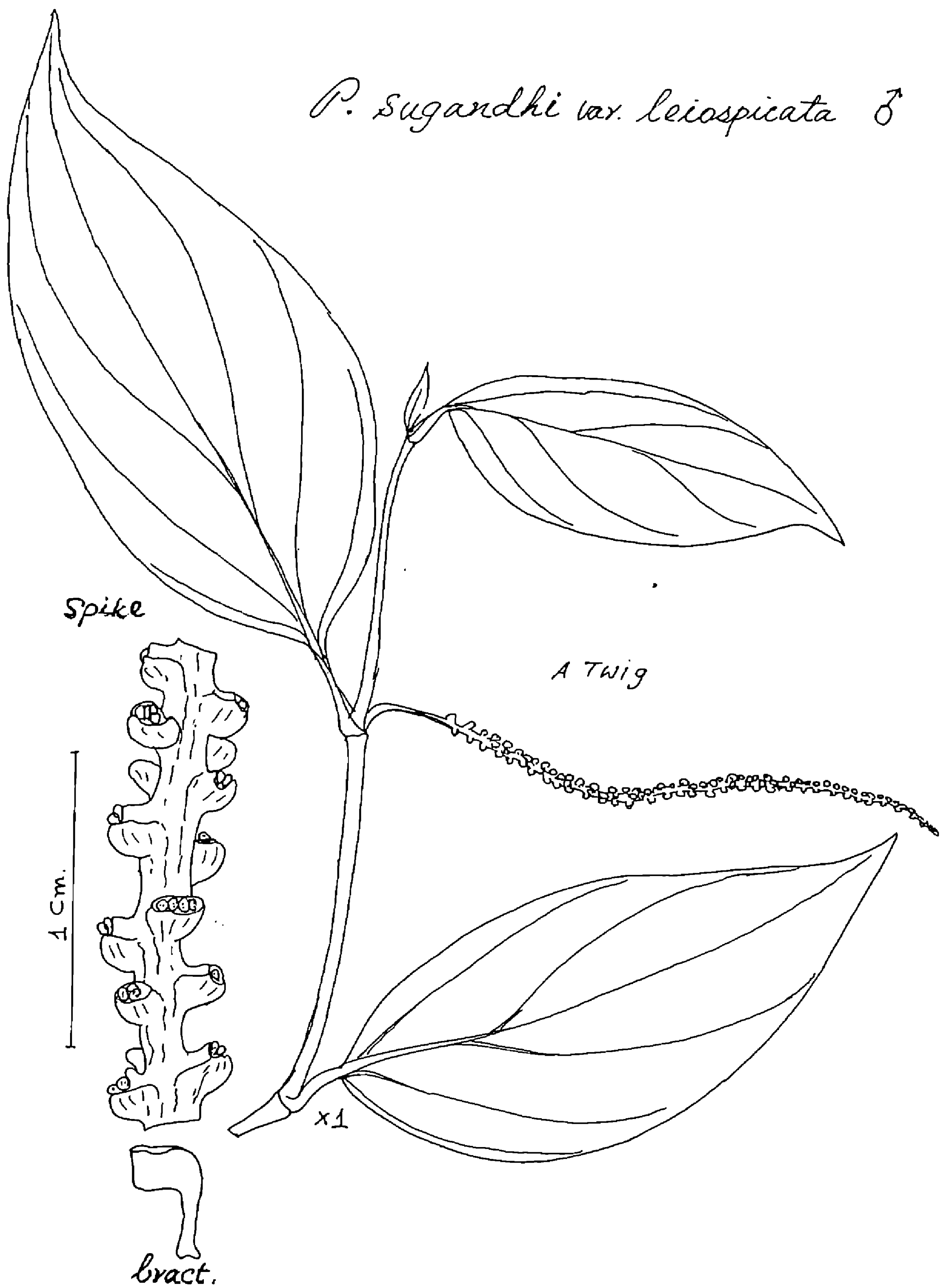
A stout woody perennial climber reaching a height of more than 10 m, climbing on trees. Branches terete, swollen at the nodes, glabrous. Orthotropic shoot tip purple, leaves glabrous, alternate, coriaceous ovate to ovate-elliptic in shape, tip accuminate, base round to acute, and often slightly asymmetrically placed, 7-13 cms long, 3-8 cms broad, prominently ribbed, 2-3 pairs of lateral ribs, the basal pair almost opposite, the upper pair unequally placed; margins slightly wavy, more prominent in the young leaves. Petiole about 2 cms, groved.

Dioecious, male spikes slender, filiform, pendulous; 10 - 14 cms long; female spikes thicker, 5-10 cms long, flowers held somewhat at right angles to the rachis, stipitate, bracts deeply cupular with free margins, minutely pubescent, stamens 2, filaments short and thick, embedded in the cupular bract, anthers projecting out at maturity, dithecous, dehiscing by apical longitudinal slits. Ovary ovoid, monocarpillary,


Piper Sugandhi Ravindran sp. nov.
♀
a twig
×1
Portion of a spike
Bract
Ovary
1 cm.


P. Sugandhi Ravindran sp. nov.
♂
×1
a twig - ♂
a portion of spike
1 cm


P. sugandhi var. leiospicata ♀
× 1
1 Cm.


P. sugandhi var. leiospicata ♂
Spike
A Twig
1 cm.
x1
bract.

embedded inside the cupular bract except for the top one quarter, style O, stigma 3-4 lobed, fleshy, white when young. Fruit bold, Ø.8 to 1.Ø cm dia., pungent, turns yellow and then to red on ripening.

Specimens examined: Holotype PNR - Sugandhagiri, Wynad, 678, 68Ø (NRCS Herbarium).

Flowering: April-May, fruit ripening December-January.

P.sugandhi var. leiospicata Ravindran Var. nova.

P.sugandhi var. sugandhi similie, sed differt bracteis perfecte glabris,

Holotypi lecti ed locum Sugandhagiri, Wynad et positi in Herbaria, NRCS, Calicut.

Very similar to P.sugandhi, but differs from it in having glabrous spikes (Fig. IV.2; Plate IV.5)

Specimens examined: Holotype PNR 637, 686 (Sugandhagiri, Wynad)

The specific epithets of both the taxa derived from the name of the locality from where these were collected. They were found to occur together in the above forest areas together with various other species.

P.wightii Miquel in Hook. Lon. J. Bot., 5:552, 1846

Wight Ic t. 1939 (named as P.wighitana in the plate), 1853; P.nigrum Wall., Cat. 6643 D (Upper right hand specimen), 1832.

Vigorous, large vine, rooting ivy like at first, later climbing up trees, often grow to about 10-12m high. Leaves small to medium approximately 9 x 6 cm, ovate, base round or acute, ribs prominent on the under side, 2 pairs of lateral ribs, 1st pair from the base and the 2nd pair about 1.0 cm above the base, unequally placed and running to the tip; leaf margin often curved outwards, under side with silvery scales.

Spikes filiform, pendulous, medium long, 4-8 cm, peduncle about 1-1.5 cm long, spikes sometimes reach about 15 cms. Flowers arranged spirally, bracts oblong, narrowed towards the base, overlapping with the successive bracts, adnate to the rachis, margins free; ovary conical, stigma 4-lobed, persistent; style 0, anthers 2-3, stalked, filament thick, dehisce by longitudinal slits. Fruits conical, but almost spherical when mature, with persistent stigma. (Plate IV.6)

Specimens examined:

Western Ghats - Barber, 6452, 7203, 7202, 7201, 7535, 7536; Deb, 30913, 30976, 30843, 31545, 31575; Ellis, 34612, 43295; Sharma, 35077, 40302; Vivekanandan, 40367 (MH)

PNR: Kodaikanal - 584, 585, 586, 594, 596

(NRCS Herbarium)

P.schmiditii Hooker f., Fl. Brit. India, 5:88, 1986;

P.arborescence in part, Miq., Syst. Pip. 220, 1843; Wight Ic. t. 1940, (right hand figure) 1853; C.DC in DC. Prodr. 16(1):359, 1869; Saldanha, Fl. Karnataka, 1:80, 1984; Manilal, Fl. Silent Valley, 231, 1988.

P.nigrum Wall. Cat. 6643 D (lower figure) 1832

P.arcuatum and P.quintuplinervum C.DC in DC. Prodr. 16(1): 359, 1869.

Dioecious, vigorous vine found at elevations above 2000 m. Leaves very thick and coriaceous, venation very prominent; leaves small, ovate to ovate-elliptic, base round or acute, tip acuminate, entirely glabrous. Ribs very prominent, lateral ribs 2 pairs, 1st from the base, 2nd about 1.0 cm above the base, placed unequally; leaves about 9 x 4 cm in size, larger in the young vines. (Plate IV.6; IV.7)

Spikes filiform, pendent, female spike thick, 6 - 16 cm, male spikes thinner, about 10 - 15 cm in length, bracts peltate, with raised free margins; stamens 2, filament thick, anthers opening by longitudinal slits. Ovary oblong, or conical, ovule single, style O, stigma 3-4 lobed, papillose; fruits oblong, bitter in taste, turning to yellow and finally to orange on ripening. Flowering in July-August, fruit maturity March-April.

Specimens examined:

Western Ghats (Nilgiris): Gamble, 43167; Sebastine, 5681, 3303, 2568, 3214, 2625, 2568, 2696; Shetty, 110914, 34086, 26482; Vajravelu, 35001, 36831, 34976, 39237; Subba Rao, 40491; Nair, 72026; Ellis, 38500, 34506; Radhakrishnan, 38054 (MH)

PNR: Ootacamund 414, 415, 592 (NRCS Herbarium)

P.barberi Gamble Kew Bull., 387, 1924

A poorly understood species. The species was erected by Gamble based on the male plants. An endangered species. During the present study the female plants were collected for the first time, but the male plants could not be located. Only a single specimen survives at the NRCS Germplasm conservatory. So detailed studies could not be carried out. A very distinct and remarkable species having pinnately reticulate venation and spikes borne on thin very long peduncles. Plant dioecious; leaves pinnately nerved, and not ribbed, glabrous, lanceolate, entire, base unequally acute, tip acuminate, about 10-15 cm long and5-8 cm broad, petiole short. Female spikes cylindrical, short, about 4-6 cm, borne on thin, long peduncle as long as or longer than the spike itself, pale purple when young. Fruit not known. (Plate IV.7)

Specimen examined: PNR 0614 (collected from the Brymore forest area and maintained at the NRCS Germplasm conservatory).

Cultivated *P.nigrum*

The cultivars of black pepper were originated from the wild ones through domestication and selection. Over seventy cultivars are known, though many of them during the recent past were replaced by a few better yielding ones. Fortyfour cultivars collected from various pepper growing tracts were used in the present study along with seven wild collections. Brief notes on the salient features of these cultivars are given here.

All of them are being maintained in the germplasm conservatory of National Research Centre for Spices Farm at Peruvannamuzhi, Calicut District, Kerala.

Aimpiriyan

This cultivar is originally from the Southern Kerala, but now grown mainly in the Pulpelly area of Wynad district. Vigorous vine, main stem round with longitudinal striations; leaves on the main stem (orthotropic shoot) are large with long petioles: lamina ovate or cordate, base round or cordate, ;tip accuminate. The stem of lateral shoots are round, leaves ovate with round base; approximately 14 x 7 cm in size, margin even; the young orthotropic shoot tip is purple in colour. Spikes medium long; 11-12 cm on an average, filiform, pendulous, often curved or twisted. Fruits (called commonly as berries, though botanically a drupe) bold, dark green, setting close, arranged in five longitudinal twisted rows. A high yielding, high quality pepper cultivar.

Arakkulammunda

A central Kerala cultivar. A vigorous vine, moderately good yielder and early maturing. Main stem with longitudinal striations, leaves on the main stem ovate with long petioles, base round. The emerging shoot tip purple. The lateral shoot stem angular to round, with longitudinal striations; leaves ovate, base round, margin wavy. Spike medium long, peduncle thin and short, setting moderately close, fruits medium, more or less oblong. A medium quality cultivar.

Arimulaku

A central Kerala cultivar not a very popular one. Main stem angular to round with very conspicuous, longitudinal striations; nodes swollen, internodes long; leaves cordate, base cordate, petiole long. Emerging shoot purple in colour. The lateral branches are angular to round with conspicuous longitudinal striations; leaves medium, mean size about 9.5 x 6.0 cm; lamina ovate, base round, margins even. The interveinal regions slightly raised in older leaves.
Spikes small to medium long, having a mean length of about 8.0 cm, spikes shorter than the leaf, straight, setting poor, fruits small, round.

Balancotta

A North Kerala cultivar, very popular earlier. It is a vigorous vine with more or less round stem with longitudinal striations and short internodes. Nodes not very conspicuous.

Leaves on the main stem cordate, or ovate in shape with long petiole, base round to cordate, ribs prominent, margins even. Main shoot purple on emergence. Lateral branches are more or less pendulous, internodes short, leaves large, approximately 19 x 9 cm, lanceolate to ovate or elliptic-lanceolate, base attenuate and often obliquely placed, margin even, sometimes somewhat wavy, thick and coriaceous. Colour lighter green than other cultivars. Spikes medium long to long, 11-13 cm on an average, peduncle 1.5 to 2.0 cm; straight; setting medium, fruits round, bold and dull green.

This cultivar has the largest leaves among all the black pepper cultivars studied. The leaves and especially berries are of a dull green colour and not dark green as in the case of other cultivars.

<u>Billimalligesara</u> (malligesara)

An Uttarakannada cultivar, grown mainly in the Sirsi taluk at an elevation of ca. 600 - 700 m. Vigorous vine, main stem with short internodes and inconspicuous longitudinal striations. Leaves on the main stem large, petiole long, ovate to cordate, margin wavy; emerging shoot tip purple. The lateral branches have angular stem and long internodes and large leaves - ca. 12 x 9 cms in size; petiole long (ca. 2 cm) and stout, lamina ovate to elliptical, base somewhat obliquely placed, margin wavy. Spikes medium long, ca. 9-11 cm; peduncle about one cm; setting compact, berries bold to medium bold, round. The berries are arranged in five rows, and when the setting is close the spikes assumes a twisted shape.

Cheppukulamundi

Vigorous vine, main stem thick, round with longitudinal striations. Internodes short, leaves on the main stem with long petiole, cordate, base cordate, tip accuminate and margins even. Main shoot tip colour light purple. Lateral stem angular when young, round on maturity with longitudinal striations. Leaf petioles are long, lamina medium, (ca.12.Ø x 6.5 cm) ovate, base obliquely placed, otherwise round, tip acuminate, margins even. Spikes medium long, (ca.9-11 cms) peduncle around 1 cm long, setting moderately close, straight, but become somewhat curved at maturity. Berries round and small. Not a common cultivar.

Cholamundi

Vigorous vine, main stem thick and round, internodes short with striations, leaves on the main stem medium large, cordate, petiole long, base cordate; emerging shoot tip purple. Runner shoots very rare. Lateral shoots highly branched, stem round with striations, leaves small to medium, lamina about 13 x 7 cm, elliptic to elliptic-lanceolate having an L/B value of 2.4Ø., base acute, margin even. Spikes medium long (ca. 11cm), setting poor to moderate, berries small to medium, round. Not a popular cultivar.

Jeerakamundi

A cultivar common in the Wynad areas, less vigorous vine, highly branched, main stem round with short internodes and small cordate leaves. Young orthotropic shoot purple. The lateral shoots are much branched with short internodes, stem angular to round, leaves small, approximately 11 x 6 cm; petiole short, lamina ovate to ovate-lanceolate (L/B value 1.9) base round to acute, margin wavy. Spike short, ca. 10 cm, curved, setting poor, berries small, round.
The bearing is often profuse, but yield is poor owing to poor setting and small size of fruits.

Cheriyakaniakkadan

A central Kerala cultivar. Vigorous vine. Main stem round with longitudinal striations. Leaves on the main stem long petioled, ovate to somewhat ovate-lanceolate, base round, and margin wavy. Lateral branches with round stem, medium large leaves (ca. 12 x 6 cm), base round margin wavy. Spikes small to medium long, ca. 10cm, peduncle about one cm; straight, setting poor berries medium sized.

A poor yielder, not popular with the farmers any more.
This was the pollen parent of the hybrid Panniyur 1.

Karimunda

A very popular cultivar, originally from the central Kerala, now grown widely in all pepper growing areas in Kerala.
A vigorous vine, main stem with longitudinal striations; leaves on the main stem ovate, base acute, tip accuminate, peduncle long; the young shoot tip dark purple. The lateral shoot round and smooth; leaves small to medium (approximately 11 x 9 cm) petiole short; lamina ovate to ovate-elliptic, flat, and margins even. Spikes short to medium long, ranging fron 4-9 cm; setting good, fruits round, small dark green. Quality medium. Regular bearer, adapted to varying elevations and agroclimatic conditions.

Kaniakkadan

A cultivar once popular in many parts of central Kerala, but replaced by more high yielding ones in recent years. Vigorous vine, stem with faint longitudinal striations, somewhat groved, but not prominent in older ones; leaves on the orthotropic stem ovate, petiole long, groved, leaf base round or cordate, tip acuminate and margin even; tip of runner shoot purple. The nodes on the lateral shoot are prominent, leaves medium, approximately 12 x 7 cm; ovate to elliptic, base round, sometimes acute, tip acuminate. Spikes medium long, 8-10 cm on an average, peduncle short to medium. (ca. 0.9 cm); setting medium, fruits medium, round. A poor to medium yielder of medium quality.

<u>Kalluvally (Pulpelly type)</u>

A medium vigorous vine. Main stem around swith striations. Leaves on the main stem medium sized, cordate, base cordate. Stem of lateral branches round with longitudinal striations, lamina about 14 x 8 cm, but smaller in older vines, cordate to ovate, base round to cordate, main shoot tip purple when young. Spikes short, ca. 6-8 cm, curved, peduncle 1-1.5 cm long; setting very close, berries round, small. This is a medium quality cultivar, moderately good yielder and gives high dry pepper recovery. Localised in cultivation, mainly in certain pockets in the Wynad district but gradually being replaced by other higher yielding types.

<u>Kalluvally (Malabar)</u>

Vigorous vine. Main stem round with longitudinal striations; internodes short, leaves, ovate, base round, petiole long, leaf margins often slightly curved downward. Lateral shoot stem angular to round with longitudinal striations; leaves medium (ca. 14 x 7 cm), ovate, sometimes ovate-lanceolate, base round, margin even and often curved downward. Spikes long (ca. 12 cm) peduncle about one cm, setting medium to more or less close; berries medium sized, round. A moderate yielder. Found only in certain isolated tracts in the North Kerala.

Kallubalancotta

A collection from the Kodagu district of Karnataka, but probably of Kerala origin. Vigorous vine, main stem more or less round with longitudinal striations; leaves ovate with round base, tip accuminate; petioles long. Stem of the lateral shoot round with prominent nodes, leaves ovate, approximately 14 x 6.5 cm; base attenuate to round, tip accuminate. The main shoot tip purplish when young. The leaves of the lateral shoots slightly folded dorsally along the mid rib; margins even. Spikes long, ca. 12-14 cm, peduncle ca. 1.0 cm, setting close, berries bold, somewhat ovate, dark green. A medium quality cultivar, not a common one.

Karimkotta

Very vigorous vine, main stem round having longitudinal striations and long internodes. Main shoot tip purple on emergence. Leaves on the main stem long petioled, small to medium, lamina cordate, tip accuminate, margins even, tip curved downwards in mature leaves. The lateral stem is angular when young, round in older ones, having longitudinal striations, nodes swollen internodes long. Leaves large, ca. 13.5 x 7.0 cm in size, ovate, base round, margins even. Spikes long, ca. 15-16 cm, peduncle ca. 2.0 cm; setting moderate, berries medium to bold, round, not a popular cultivar.

Karivilanchy

This is a south Kerala cultivar. Vigorous vine, stem round with longitudinal striations, nodes neither thick nor prominent; mature stem more or less ridged, young shoot tip purple. Leaves on the main stem medium, ovate with long petiole, base round. The lateral branches have smooth stems round with faint longitudinal striations when young, but not visible in older ones; leaves medium large (ca. 12.6 x 6.5 cm), base round or acute, margins wavy. Spike medium long, ca. 10.4 cm on an average; peduncle around 1.0 cm long; filling poor to medium, berries bold, prominently oblong.
A poor yielder, now not grown as it is replaced by better yielders.

Kottanadan

A very popular cultivar of the south Kerala especially of the Nedumangad taluk. Vigorous vine, stem more or less round with longitudinal striations, leaves on the main stem more or less cordate, base cordate, the margins even, curved gently outwards in older leaves. Main shoot tip purple when young.
Lateral shoots have smooth stem, leaves medium to large ca. 13 x 8 cm on an average; ovate, base round, rarely acute, margins even. Spike medium long, ca. 10.5 cm, peduncle around 1.0 cm, often gently curved, setting close, berries arranged in five distinct rows; medium bold, round.

Wax secretions are common on the growing shoot tips and young leaves. They appear like white, translucent pearl like globules, gradually turn black in a few days time. This is a high yielding, high quality cultivar.

<u>Kuching</u>

An introduction from SriLanka. This is the most important cultivar of Malaysia, and is also the most well known pepper cultivar in the world.

Vigorous vine, main stem round with longitudinal striations. Leaves on the main stem long petioled, ovate or cordate, base round or cordate. Main shoot tip purple when young. The leaves on the lateral shoot medium large, around 13.5 x 8.5 cm; lamina ovate, base round, tip accuminate, margins slightly wavy. Spike short to moderately long, ca. 9.Ø cm, peduncle about Ø.9 - 1 cm long; setting close. Berries medium, slightly oblong. Reported to be a profuse bearer.

<u>Kurimalai</u>

A cultivar collected from the Sagar taluk of Karnataka state. Vine medium vigorous, orthotropic stem with longitudinal striations, branches thin, nodes not prominent, runner shoot tip purple when young. The leaves on the main stem long petioled lamina ovate, flat, base round, tip accuminate. The stem of the lateral shoot groved, leaves small to medium (ca. 13 x 18 cm) ovate, sometimes ovate-lanceolate. Spikes medium long to long (ca. 12-13 cms) straight, peduncle ca. 1.4-1.5 cms. Setting good, berries round.

A good yielder under the conditions in the Sagar areas, but performance under lower elevations not tested. This cultivar is not collected from any other pepper growing area.

Kuthiravally

A south and central Kerala cultivar, now found in many pepper gardens all over Kerala, though not as popular as Karimunda. It is a vigorous vine, stem with longitudinal striations, leaves on the main stem long petioled, widely ovate, base round. The young orthotropic shoot tip is purple. Lateral shoots, round with longitudinal striations, leaves large, (ca. 11.5 x 10.5 cm) ovate to widely ovate, with even margins. Spikes long, ca. 15-17 cms, straight, filling good, berries round. High and consistent yielder, having good quality.

The name Kuthiravally (horse tail) denotes the long spikes of this cultivar.

Kuriyalmundi

A collection from the Idukki district of Kerala, not commonly cultivated. Vine vigorous, main stem round with longitudinal striations, leaves on the main stem small, ovate, base round to acute, margins wavy; long petioled.

The stem of the lateral branch round, leaves with shorter petioles, medium large (ca. 11.5 x 7.4 cm on an average), ovate, base round, margin wavy. The main shoot on emergence is purplish.

Spikes are very short (ca. 5-6 cm) curved or twisted, setting very close, fruits arranged in five distinct rows; peduncle about 1.Ø cm long, berries very small, round. Not a popular cultivar.

Malamundi

A collection from Wynad district, restricted in distribution to certain higher elevation areas. Vigorous vine, main stem round with longitudinal striations, leaves on the main stem long petioled, ovate to ovate-lanceolate, base round, margins even. Main shoot tip purple when young. Lateral branch stem round with longitudinal striations, leaves ovate, sometimes ovate-lanceolate, base round, size ca. 13 x 6.3 cm. Spikes short to medium; ca. 9-1Ø cm; peduncle Ø.8 cm; straight, close setting, berries medium, round.
Not a popular cultivar, found occassionally in certain old pepper gardens.

Mundi

A cultivar from the central Kerala area. Vigorous vine main stem round with longitudinal striations, leaves on the main stem long petioled, lamina ovate, base round, margins wavy.

Main shoot tip purple on emergence. Lateral branch stem round with longitudinal striations; leaves large (ca. 13 x 9 cm), ovate, base round, margins wavy. Spikes short (ca. 8.6 cm); peduncle about Ø.9 cm; medium bold, round; setting close.

Once a popular cultivar, but now replaced almost wholly by higher yielding ones.

Narayakkodi

Vigorous vine, main stem round with longitudinal striations. The leaves on the main stem small with short petioles; ovate, base round or acute, margins wavy. The main shoot tip purple when young; the lateral shoot stem slightly angular to round with longitudinal striations and short internodes. Leaves small (ca. 1Ø x 6.5 cm) with short petioles; ovate, base round, margins wavy. Spike short (ca. 8-9 cm), peduncle about Ø.8 cm; curved or twisted, setting very close, berries small, obovate.

A popular cultivar in the central Kerala region. Moderately good yielder, quality medium.

Neelamundi

A popular cultivar from the Idukki district. Main stem round with longitudinal striations, leaves on the main stem large with long petiole, ovate to ovate-lanceolate, base round, tip accuminate. Emerging shoot purple. Lateral branches round, leaves large ca. 15 x 9 cm; ovate to ovate-lanceolate, base round. Spike short to medium long, ca. 9-10 cm; peduncle 0.8 cm, straight, setting more or less average to good, berries bold, round.

A medium yielder, medium quality cultivar, common in the higher elevations of the Idukki district.

Nedumchola

A much less vigorous vine, small, scandent and highly branched. Main stem round with longitudinal striations, main shoot purple when young. Leaves on the main stem very small, lamina ovate to obovate, base round, tip accuminate. The lateral stem is round, leaves very small (ca. 8.5 x 4.5 cm) base round, shape ovate to obovate. Spikes very short, (ca. 5-6 cms), peduncle around 0.9-1.0 cm; setting poor, berries very small, obovate. A poor yielder, characteristically small in stature. Not a popular cultivar.

Neyyattinkaramundi

Vigorous vine, main stem round, with longitudinal striations. Leaves on the main stem long petioled, medium large, ovate, base round, the main shoot tip purple when young. The lateral shoots thin, round with prominent nodes, leaves medium sized (ca. 12.5 x 7.4 cm), ovate, base round, margin

wavy. Spikes short ca. 7.0 cm, peduncle about 0.7 cm; berries small, obovate, setting moderately close.
Not a high yielder and not a popular one.

Ottaplackal I

A vigorous vine. Main stem round with longitudinal striations, leaves on the main stem large, ovate with long petioles, base round, margin even. Lateral branches with round stem, leaves medium large, (ca. 11.5 x 7.0 on an average), ovate, base round, margin even. Spikes medium long (ca. 11 cm) peduncle about 1.2 cm. Berries medium sized, round.

Collection from Idukki district. A good yielder. Showed relative tolerance to the root knot nematode, (*Meloidogyne incognita*)

Panniyur I

A high yielding hybrid cultivar, main stem thick, round with prominent longitudinal striations. The shoot tip of the main stem and runner shoot characteristically whitish green in colour. Leaves on the orthotropic shoot cordate, petiole long, base cordate, margin even. Lateral branches have round stem, leaves large, margin even. Lateral branches have round stem, leaves large ca. 14 x 10 cm; cordate, sometimes ovate, base cordate or round. Spike long, ca. 14 cm; peduncle ca. 1.3-1.4 cm; straight; yellowish to whitish yellow in colour; berries bold, filling good.

An excellent yielder of medium quality. It was reported to be a hybrid from a cross involving Uthirancotta (38) and Cheriyankaniadakkan (6). The whitish green shoot tip and the whitish yellow spikes are characteristic feature of this cultivar. Wax secretions in the form of white translucent pearly globules are abundant on the growing shoot tips, and on young leaves.

Perambramunda

Vigorous vine. Main stem round with longitudinal striations. Leaves on the main stem medium large, lamina ovate, base round, margin even. The main shoot tip colour purple when young. Lateral shoots have angular to round stem, with longitudinal striations. Inter nodes short; leaves large (ca. 14.5 x 8.4 cm); ovate, sometimes ovate-lanceolate, base round, margins even. Spikes medium long to long (ca. 12 cm), peduncle 1.0 cm on an average; setting close, berries bold, oblong.

A moderately good yielder, but not common. Collected from the Pulpelly area of Wynad district.

Perumkodi

Vigorous vine, main stem round with longitudinal striations; leaves on the main stem long petioled, ovate lanceolate, base round. The stem of lateral branches round with short inter nodes and conspicuous nodes. Leaves large (ca. 15 x 7 cm) ovate to ovate-lanceolate, base round, margin even. Spikes medium long (ca. 11-12 cm) straight, setting low, berries bold and round. The shoot tip colour is purple when young. Once a popular cultivar of Central Kerala, but not commonly grown nowadays.

Poonjaranmunda

Vigorous vine, main stem round with conspicuous longitudinal striations. The leaves on the main stem long petioled, large, widely ovate with round bases. The lateral shoots are ridged, angular; leaves large (ca. 13 x 8 cm on an average) widely ovate, base round, margins even. Spike long (ca. 15-16 cm); peduncle about 1.2 cm long, straight, setting moderate, berries medium bold and round. The shoot tip colour is purple.

A central Kerala cultivar of medium quality, moderate yielder. Once popular, but now has gone out of popularity.

Sagar Local

A local cultivar collected from the Sagar taluk of Karnataka state. Vigorous vine, round, thick stem with longitudinal striations. The leaves on the orthotropic shoot are medium sized with long, stout petioles, cordate, base cordate or round, margin even. Main shoot tip colour light purple. Lateral branches long with angular or ridged stem with prominent longitudinal striations. Leaves large (ca. 15 x 9 cm), ovate, base acute with slightly oblique attachments, margins even. Spikes small to medium (ca. 9.0 cm); peduncle averages 1-1.1 cm; setting moderately good; berries small to medium; not a very good yielder.

Thevanmundi

A cultivar from the Kumali areas of Idukki district. Vigorous vine, main stem with longitudinal striations, leaves on the main stem long petioled, large, ovate with round base, main shoot tip colour purple when young. Lateral branches are angular to round, leaves large (ca. 14 x 9 cm), ovate, base round, margin even. Spikes small to medium (ca. 9-10 cm), peduncle about 0.9 cm; straight; setting good, berries medium sized, oblong.

A moderately good yielder under the Kumali conditions, Not common in the plains.

Thommankodi

A cultivar common in the eastern parts of Calicut district and also in some pockets in Wynad district. Vigorous vine, main stem round with longitudinal striations. Leaves with long petiole, ovate to widely ovate. Main shoot tip purple when young, base round; lateral branches with leaves medium large, ca. 10 x 6.5 cm round stem, lamina widely ovate to ovate, base round margins even. Spikes long (ca. 12-14 cm), straight, setting close. Berries medium sized and globose. Closely related to Kuthiravally, but the spikes are somewhat shorter.

Thulamundi

A south and central Kerala cultivar; vigorous vine; main stem round with longitudinal striations, leaves long petioled, ovate to widely ovate with round base and even margins. Main shoot tip is purple in colour. Lateral branches with round stem, leaves large (ca. 12 x 76 cm); ovate to ovate-lanceolate; base round. Spikes short, ca. 9-10 cm on an average, peduncle around 1 cm; straight, filling poor; berries medium sized, globose.

Uddakere

A popular cultivar from the Uttara Kannada district of Karnataka. Vigorous vine, main stem more or less round with longitudinal striations, nodes very prominent and swollen. Leaves on the main stem large with long petiole, lamina ovate, base round and margins even, emerging shoot tip purple. Leaves on the lateral branches are large, ca. 15 x 8 cm; ovate, sometimes widely ovate, base round, the interveinal regions slightly raised dorsally. Spikes long, ca. 12-13 cm; peduncle ca. 1.0 cm; setting moderately good, berries dull green, bold, round with a slight flattening at the top.

A moderately good yielder, especially in the Sirsi Taluk; where it is inter-cropped with arecanut.

Uthirancotta

A north Kerala cultivar, once popular in the areas and also in the Coorg district; but is no more in vogue. A vigorous vine, main stem round with longitudinal striations, leaves on the main stem large, cordate with even margin. Main shoot tip colour purple. Lateral branches have angular stem nodes very prominent and swollen, internodes long with longitudinal striations, leaves large, ca. 14 x 7 cm, lamina ovate-lanceolate to elliptic-lanceolate, base acute, often obliquely placed, margins even. Spikes medium long, ca. 10.5 cms; peduncle ca. 1.2 cm, setting poor, berries bold, round. This is the female parent of the hybrid Panniyur I. Poor yielder, not grown any more.

Vadakkan

A cultivar collected from the Coorg district of Karnataka. A very vigorous vine, main stem groved with longitudinal striatons, nodes very prominent. Leaves on the main stem more or less cordate, long petioled, base cordate, margins even, main shoot purple when young. Lateral branches have round stem, leaves large ca. 16 x 10 cm; more or less cordate, base round margins even. Spikes medium long ca. 11.5 - 12.0 cm, peduncle about 1.4 cm long; setting compact, berry bold and round. A good yielder having very bold berries.

Valiakaniakkadan

A central Kerala cultivar, now found occassionally in Wynad and Idukki districts. Vigorous vine, main stem round with longitudinal striations. The leaves on the main stem are large, ovate to widely ovate with even margin. Main shoot tip colour purple. Lateral branches with short inter nodes, and prominent nodes. Leaves medium large, ca. 11.4 x 5.4 cm; ovate, sometimes ovate-elliptical, base round, margins wavy. Spikes medium long, ca. 10 cm and peduncle around 1.4 cm on an average; setting good, berries medium large, oblong.
A moderately good yielder.

Vattamundi

A cultivar collected from the Idukki district. Vigorous vine, mature main stem ridged with longitudinal striations, leaves on the main stem long petioled, lamina large, cordate to widely ovate; base round to cordate, the regions between the ribs (veins) raised slightly. The main shoot tip purple when young. The stem of the lateral branch round, nodes very prominent, leaves medium large ca. 11.5 x 8 cm; widely ovate, base round, margins even. Spikes medium long, ca. 10 cm, peduncle ca. 1.05 cm; straight, setting moderately good; berries medium bold; round.

Vellanamban

A popular cultivar in the Idukki district of Kerala. Vigorous vine, main stem round with longitudinal striations. The leaves on the main stem ovate, with round base and long petiole. The regions between the ribs are slightly raised dorsally. The lateral shoot has angular to round stem, leaves medium large ca. 10 x 5 cm; ovate, base round, the lamina slightly folded dorsally along the mid rib; margins even. Spikes medium long to long ca. 12 cm; peduncle around 1.0 cm; setting moderately close; berries medium bold and round.

Velliyarenmunda

A cultivar from the Bison valley area of Idukki district, known to be originally from the central Kerala areas. Vigorous vine. The main stem thick round with longitudinal striations. Leaves on the main stem small to medium, ovate, with medium long peduncle and wavy margin. The lateral branches have angular stem, inter nodes short, leaves large, ca. 14.5 x 7.5 cm; ovate, base round, sometimes placed obliquely, interveinal regions raised dorsally. Spike medium long, ca. 10.0 cm, peduncle around 0.85 cm; berries medium, round.

A moderate yielder, but now not very popular.

Vokkalu

A north Kanara (Uttara Kannada) cultivar, a very poor yielder and only rarely found nowadays. Moderately vigorous vine, main stem round with prominent longitudinal striations. Leaves on the main stem small, cordate, petiole long, the intervein region raised slightly on the dorsal side. Main shoot tip purple. Lateral branches are relatively short, stem angular with longitudinal striations. Leaves small ca. 7 x 6 cm; ovate, base round, margins even and reflexed. Spikes very short ca. 3.4 cm on an average, the shortest among all the cultivars known. Berries very few (2-6 per spike) medium bold. A very poor yielder.

Piper nigrum wild

Seven collections of the wild *P.nigrum* from different areas were included in the study along with the 44 cultivars detailed above. Typical description of *P.nigrum* is given in the previous section (along with species descriptions). The seven collections included in the study differ mainly with regard to leaf size and shape, spike length and berry size. They are more or less uniform in most other characters including the main shoot tip colour which is purple in all the seven collections.

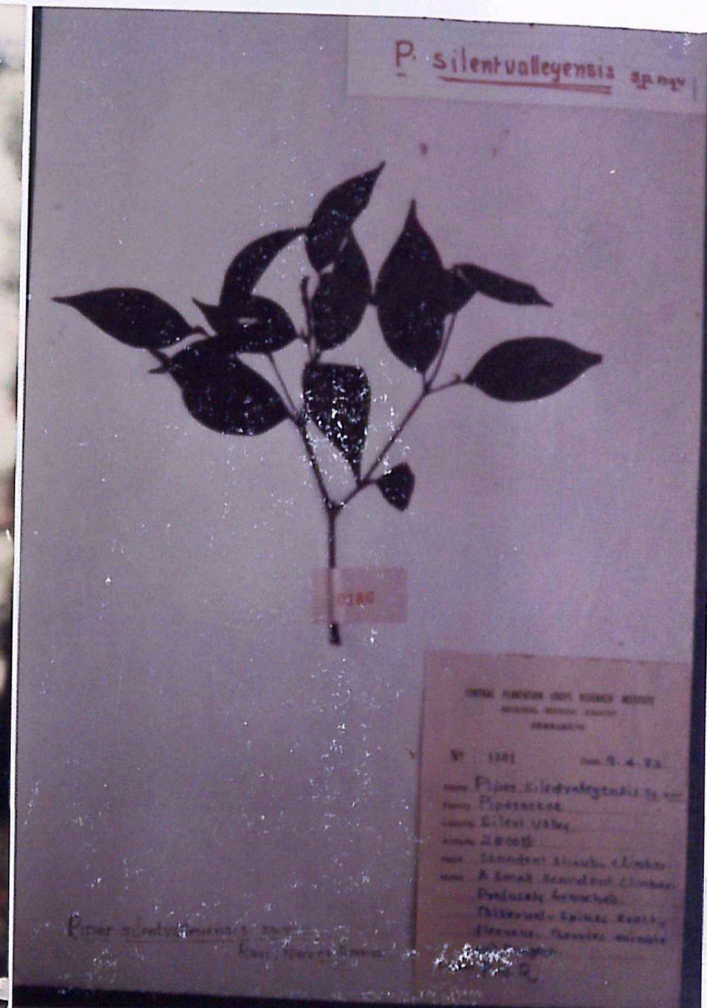
P L A T E IV. 1

P. longum

♀ plant

P. silentvalleyensis

P. mullesua


P. silentvalleyensis sp. nov.


Piper mullesua
Coll. 573

PLATE IV. 2

P. argyrophyllum

♀ plant growing in an earthern pot

P. argyrophyllum

a twig with fruiting spikes

P. hymenophyllum

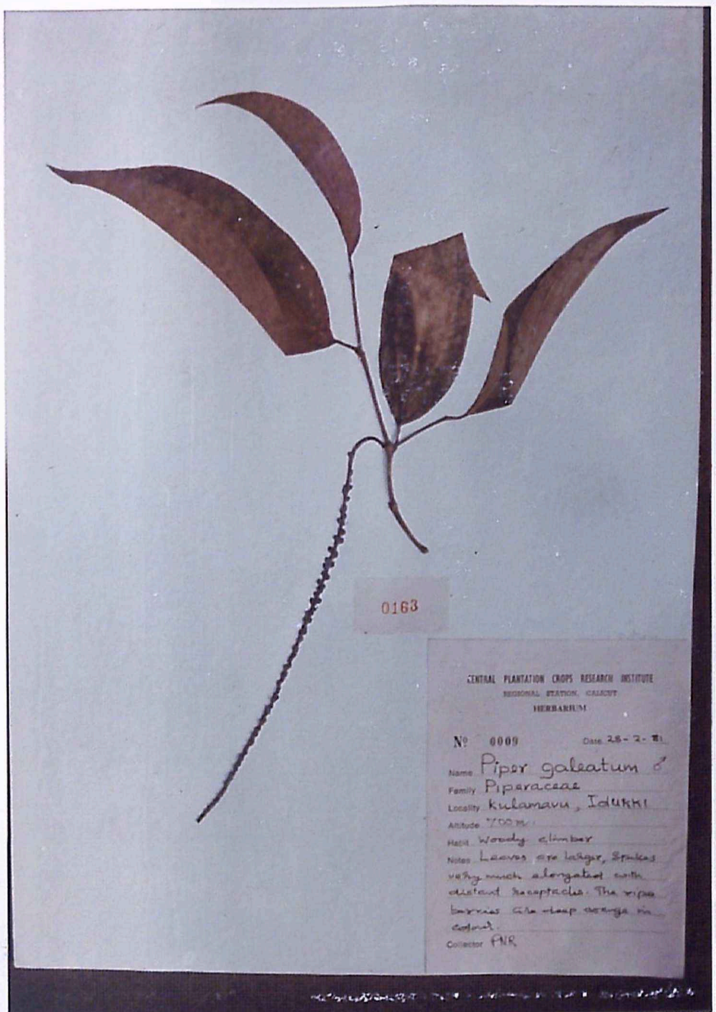
fruiting spikes

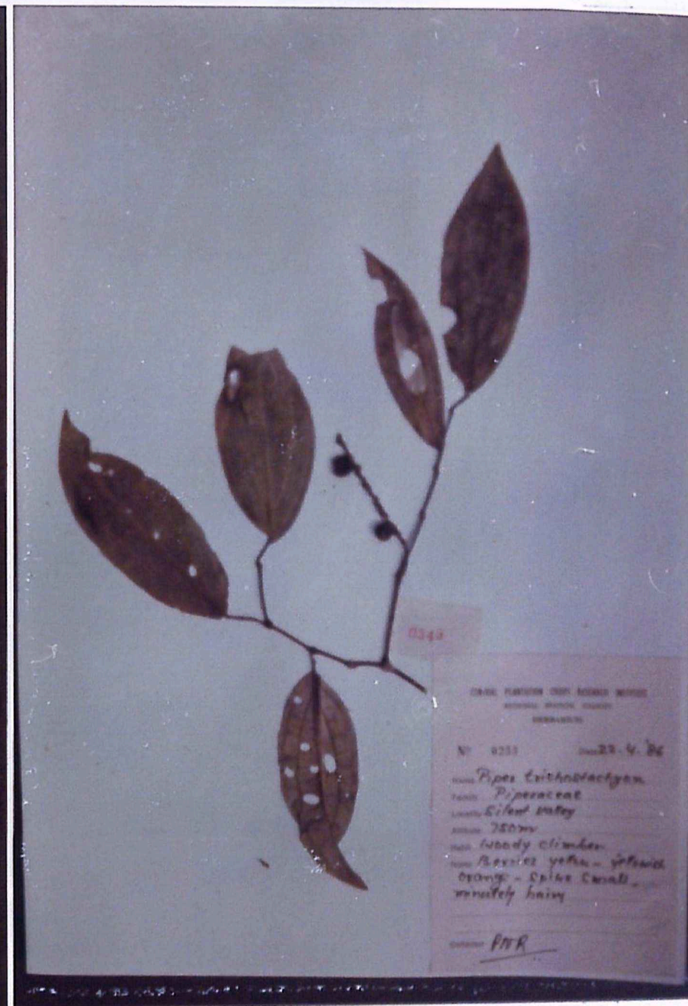
P L A T E IV. 4

<u>P. galeatum</u>

<u>P. trichostachyon</u>

<u>P. trichostachyon</u> (♂)


0163
CENTRAL PLANTATION CROPS RESEARCH INSTITUTE
REGIONAL STATION, CALICUT
HERBARIUM
№ 0009 Date 28-2-81
Name Piper galeatum ♂
Family Piperaceae
Locality kulamavu, Idukki
Altitude 700 m
Habit Woody climber
Notes Leaves are larger, Spikes very much elongated with distant receptacles. The ripe berries are deep orange in colour.
Collector PNR


0348
Piperaceae
Silent valley
750m
Woody climber
PNR

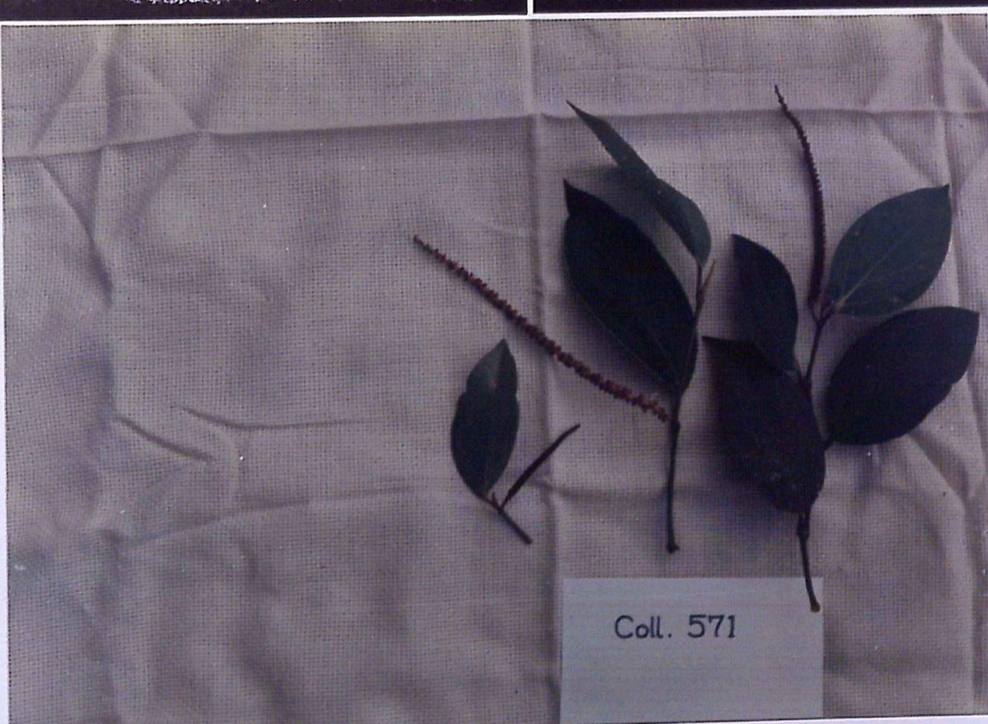

Coll. 571

PLATE IV. 5

P. sugandhi (♀)

P. sugandhi (♂)

P. sugandhi var. *leiospicata* (♂)

P. nigrum var. *hirtellosum* (♀)

0680
No. 0255 Date 21.7.89
Piper sugandhi ♀
Piperaceae
Woody climber
Fruit pungent
Bract- deeply cupular
0678
P. sugandhi ♂
Piperaceae
Woody climber
purple, pubescent
deeply cupular
17.2.89
NEW TAXA.
P. nigrum var. hirtellosum.
0315
No. 0232 Date 9.4.83
Piper nigrum var. hirtellosum
Piperaceae
Silent Valley
Vigorous climber.

P L A T E IV. 6

P. wightii

Twig with fruiting

spikes

P. wightii

Twig with ♂ spikes


Coll. 585

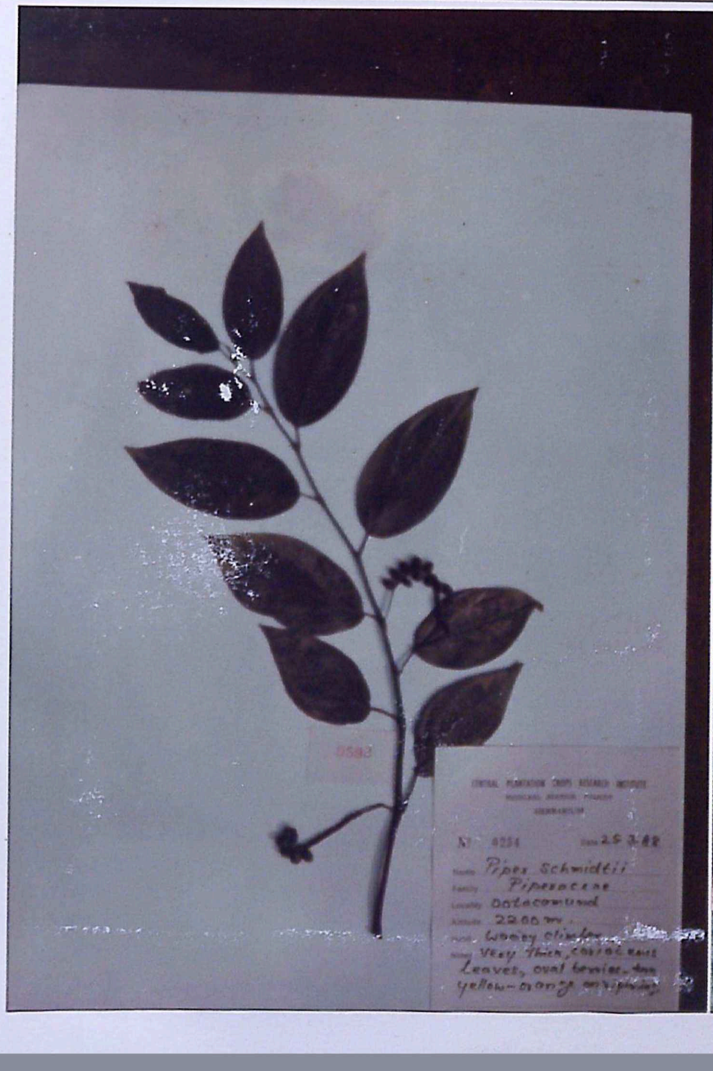
P L A T E XV. 7

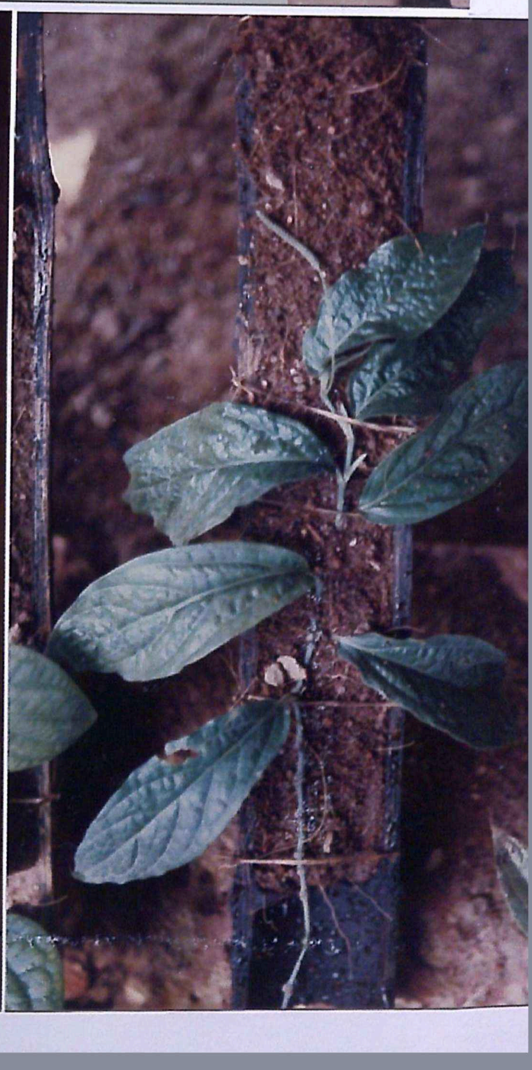
P. schmidtii
Twig with ripe fruits

P. schmidtii

P. barberi
Growing plant spike -
note the long peduncle


Piper schmidtii
Coll. 592


Piper Schmidtii
Piperaceae
Ootacamund
2200 m.
Woody climber



P L A T E S IV.8 - IV. 11

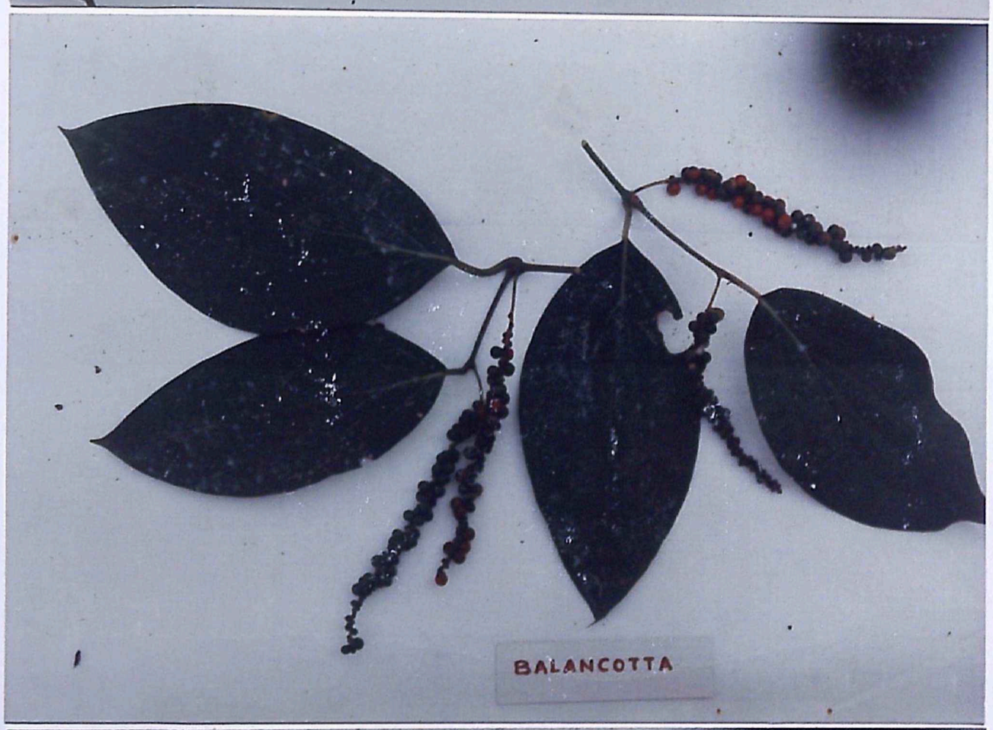
Some representative cultivars of black pepper (_P. nigrum_)

Aimpiriyan

Balancotta

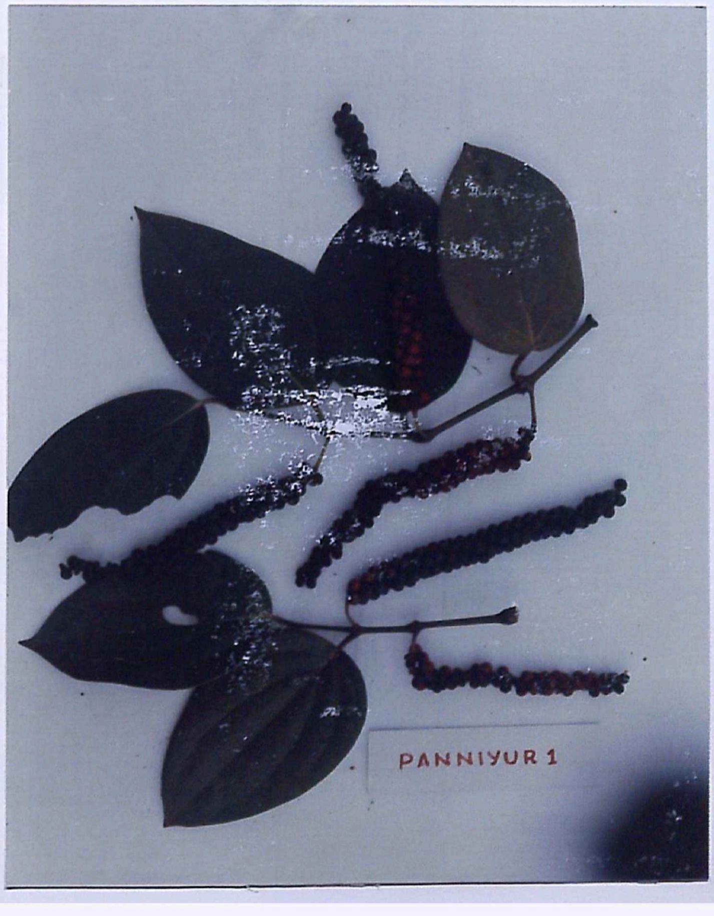
Kuching


AIMPIRIYAN


BALANCOTTA


KUCHING


KALLUVALLY [PULPELLY]

KURIYALMUNDI

PANNIYUR 1

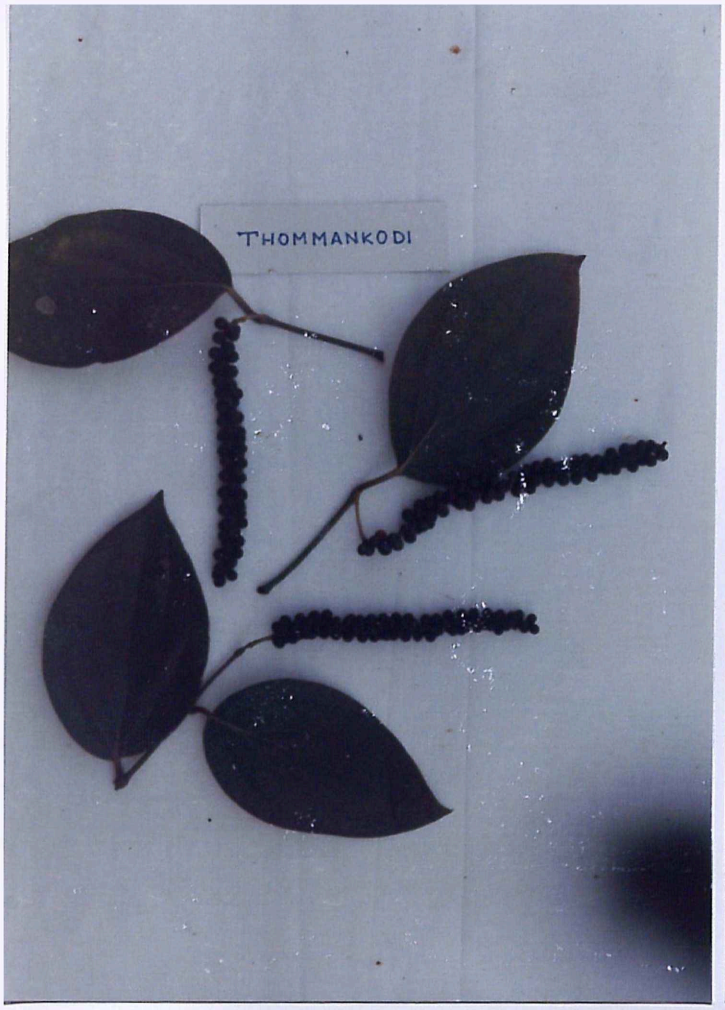
THULAMUNDI

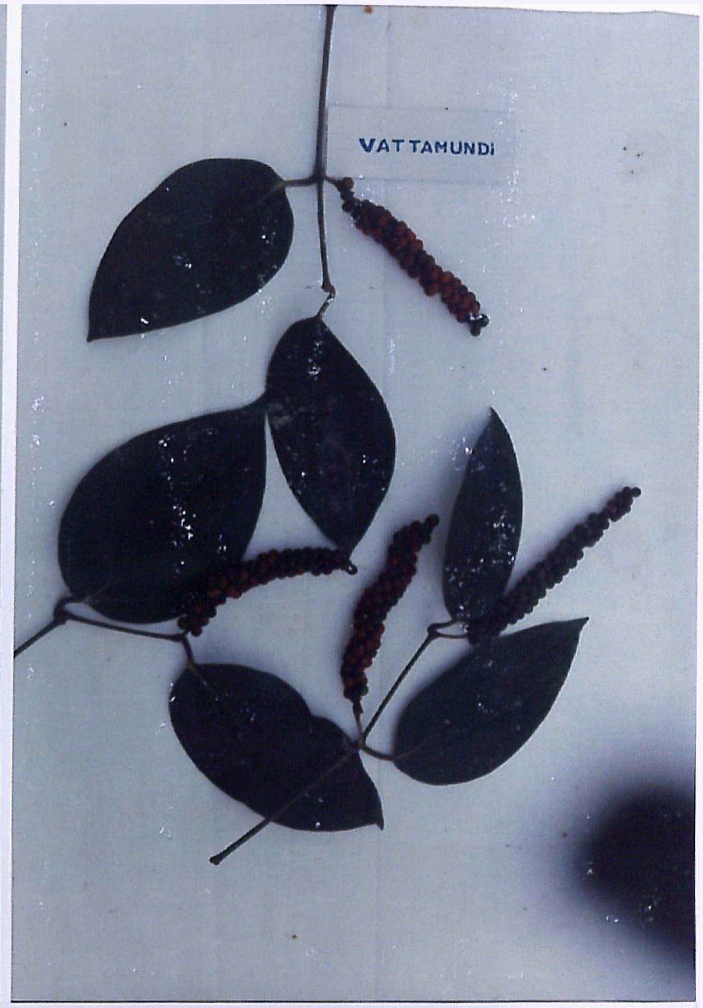
P L A T E IV. 10

Thommankodi

Vattamundi

N.T. line (Ottaplackal)


THOMMANKODI


VATTAMUNDI

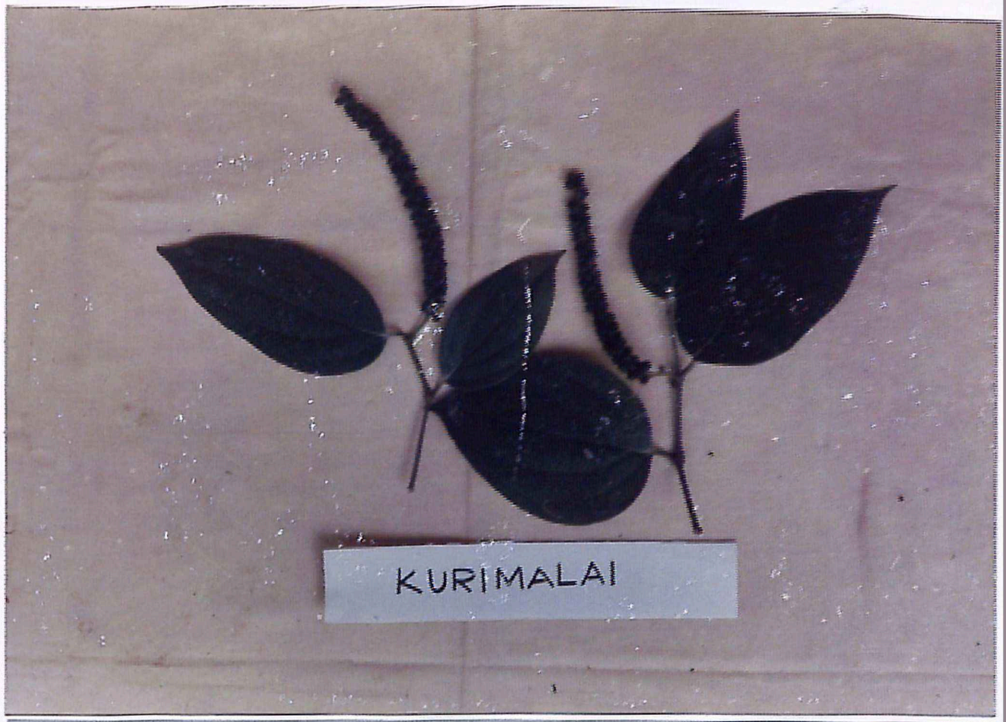
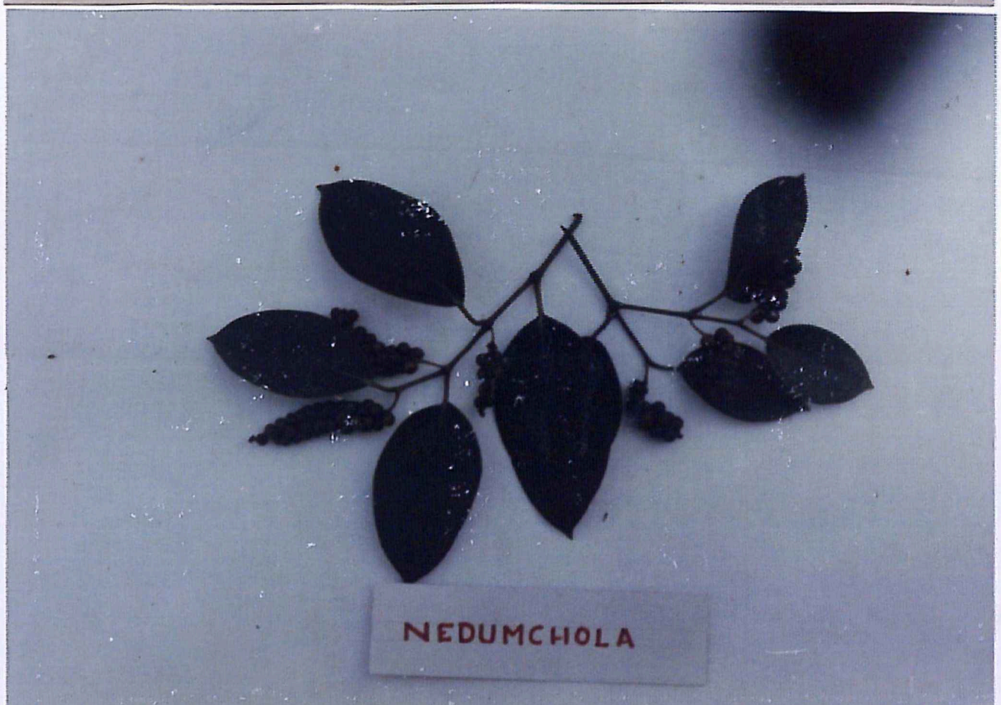
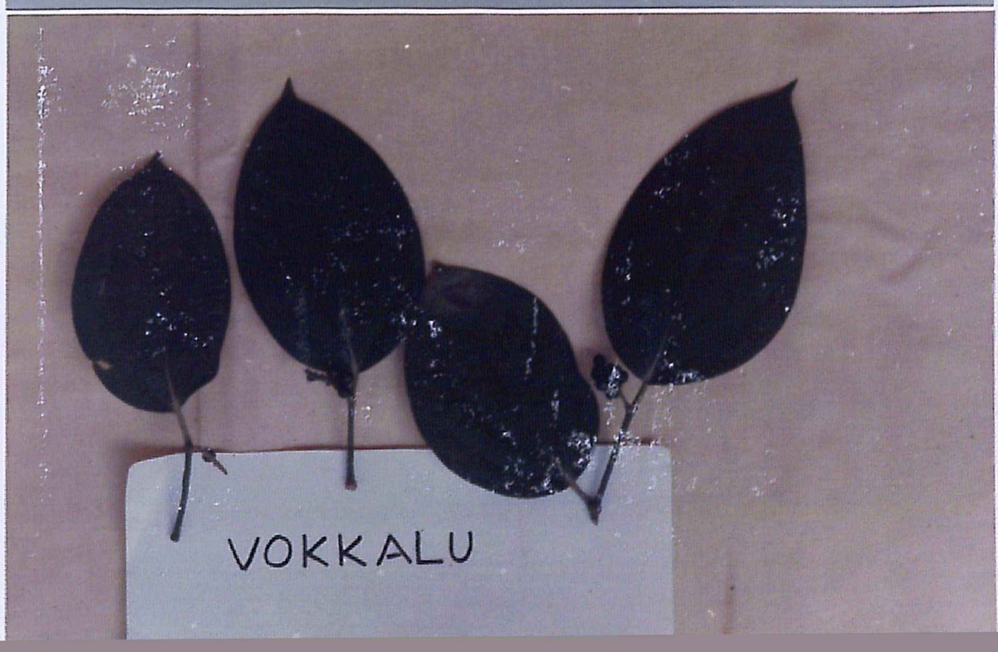

N.T.LINE (OTTAPLACKAL1)

P L A T E IV. 11

Kurimalai

Nedumachela

Vokkalu


KURIMALAI

NEDUMCHOLA

VOKKALU

CHAPTER V

GENERAL MORPHOLOGY OF PIPER

Type species *P. nigrum*

Black pepper is a perennial climber, climbing on support trees with the aid of aerial attachment roots. As the pepper plant grows on a support, it produces two different types of branches, i.e., pepper exhibits dimorphic branching. The main stem climbs up the support (orthotropic shoot), has indefinite growth. They grow in thickness, bear leaves alternately, and also produce during the course of growth runner shoots from the base.

As the pepper vine grows, flowering shoots are produced from the axils of leaves of main stem. These are the plagiotropic shoots, and they have sympodial growth habit. The runner shoots and lateral shoots differ in their origin and growth. The runner shoots developing at the base of the vine (from axillary buds) are the common planting material for the propagation of black pepper, and they climb up the support trees producing a normal pepper plant.

The lateral shoots grow sympodially where the terminal bud getS modified into the spike, and the growth is continued by the axillary bud. When these shoots are rooted and planted, they develop into dwarf and bushy plants. All *Piper* spp. present in Western Ghats have similar growth habit and all of them are climbers except in the case of P.longum which is a creeper. (Table V.1)

The Leaf

The leaves of black pepper are very variable, both in size and shape. Still, leaf size, shape and other characters are major features distinguishing the various cultivar, and hence much useful in cultivar delimitation.

In all the species studied, the juvenile leaves (on the emerging orthotropic/runner shoots) differ from the normal leaves, found on the lateral shoots. The juvenile leaves are small, and ivy like in P.mullesua and to some extent in P.schmidtii and P.wightii. In P.longum the leaves on the orthotropic shoot are large, having typical cordate shape and borne on long petioles, while in fruiting branches the leaves are smaller, elliptic-lanceolate and practically sessile, or with very short petioles. Such variations in leaf size and shape were noted in many cultivars also.

Black pepper leaf is dorsiventral. The morphological variability among the cultivars and species are given in Tables V.2 and V.3. The venation is comptodromous or acrodromous type, where all the main veins (often called ribs) start from the base or near the base and ascend to the apex.

Among the *Piper* spp., the largest leaves are those of *P.nigrum* (14.0-17.2 cm in length, and 6.8-9.7 cm in width). The smallest leaves are those of *P.silentvalleyensis*, having a mean length of 6.0 cm and breadth of 2.2 cm. *P.mullesua* also has small leaves about 8.0 x 3.0 cm . The length/breadth values indicate the shape of the leaves, and these values ranged from 1.37 in *P.longum* to 2.92 in *P.silentvalleyensis* indicating that in the former the leaves are widely ovate while in the latter the leaves are elliptic in shape. The L/B values of all other species were above 1.5 indicating ovate shapes. In fact except in *P.mullesua* and *P.silentvalleyensis* which have elliptic leaves, all other species have ovate to ovate-lanceolate leaves.

Among the pepper cultivars there are considerable variation in leaf length and breadth. Leaf lengths vary from 8.8 cm in the cv. Nedumchola to 19.0 in cv. Balancotta; leaf breadth from 4.7 cm in cv.Nedumchola to 10.2 cm in cv. Panniyur I. The L/B values range from 1.09 to 2.4. Leaf size index (LSI) is highest in Balancotta (81.45). The smallest leaves were those of Nedumchola (LSI=40.00).

The variations in leaf with regard to margin, base and shape are given in Table V.2. The most basic leaf shape is found to be ovate, variations from this shape include widely ovate, ovate-lanceolate and cordate. Both even and wavy margins are met with among the cultivars. Leaf bases are either round, attenuate, acute or cordate.

Tables: V.1: GROWTH HABITS OF PIPER Spp.

Species	Plant Type	Growth habit	Distri-bution	Presence of thrips
P.attenuatum	Dioecious	shrubby clinmber	Low to high elevations	Absent
P.argyrophyllum	do	do	do	do
P.hymenophyllum	do	do	do	do
P.galeatum	do	woody climber	do	do
P.longum	do	creeper	plains and low elevat-ions	do
P.mullesua	do	shrubby	high elevations	do
P.schmidtii	do	woody climber	do	do
P.silentvalley-ensis	Monoecious	shrubby climber	do	
P.sugandhi	Dioecious	woody climber	medium elevation	do
P.sugandhi var. leiospicata	do	do	do	
P.trichostachyon	dioecious	woody climber	low to high elevations	do
P.wightii	do	do	high eleva-tions	do
P. nigrum (1)	partially monoecious	do	plains to high elev-vations	present
P. nigrum var. hirtellosum	do	do	do	do

Leaves are glabrous in most of the species studied including the cultivars, the exception being *P.hymenophyllum* where the leaf is hairy, and *P.argyrophyllum* in which the underside of the leaves are sometimes sparsely hairy along the ribs. In *P.mullesua* and *P.longum* the juvenile leaves sometimes possess minute hairs. In *P.wightii* and in *P.argyrophyllum* there are silvery scales on the under surface of the leaves. Microscopic hairs are present on the young orthotropic shoots of *P.trichostachyon*.

Leaves are thick, and coriaceous in *P.nigrum*, (including all the cultivars), *P.galeatum*, *P.schmidtii*, and *P.sugandhi*; thin and papery in *P.attenuatum*, *P.hymenophyllum* and *P.mullesua* and *P.silentvalleyensis*, and fleshy and sarcous in *P.longum*.

The leaf sheath and prophyll

The runner shoots and in vegetative shoots (like the erect climbing orthotropic shoots) the young shoot tips are protected by the sheathing petiole of the leaf. In the case of flowering lateral shoots (plagiotropic shoots) the shoot tip emerges from within a cap like structure (similar to the stipule in *Ficus*). These cap like structures are the prophylls which are the modified first leaf of the axillary branch. Generally dicots have two prophylls but *Piper* has only one (Plate V.1). The prophyll subtends the axillary branch and the emerging spike. In other words prophyll is

TABLE V.2: LEAF CHARACTERS OF BLACK PEPPER CULTIVARS

No.	Cultivar	Leaf length	Leaf breadth	L/B	Leaf shape lateral	Leaf base	Leaf margin	Leaf shape orthotrope
1.	Aimpiriyan	138.4	71.2	1.9	ovate	round	even	cordate
2.	Arakkulamunda	153.3.	78.3	2.1	ovate	round	wavy	ovate
3.	Arimulaku	96.1	61.2	1.6	ovate	round	even	ovate
4.	Balancotta	191.Ø	95.Ø	2.Ø	ovate lance-olate	acute	even	ovate
5.	Bilimallige-sara	119.4	9Ø.2	1.4	ovate	round	even	ovate
6.	Cheriyakani-akkadan	119.4	6Ø.6	1.9	ovate	round	even	ovate
7.	Cheppukula-mundi	145.8	8Ø.4	1.8	ovate	round	even	ovate
8.	Cholamundi	138.2	57.6	2.4	ovate-lanceolate	acute	even	ovate
9.	Jeerakamundi	116.Ø	59.3	1.9	-do-	-do-	-do-	-do-
1Ø.	Karimunda	117.8	9Ø.7	1.3	-do-	-do-	-do-	-do-
11.	Kaniakkadan	127.9	69.2	1.8	-do-	round	-do-	-do-
12.	Karuvilanchy	126.3	6Ø.5	2.1	ovate	acute	wavy	-do-
13.	Karimkotta	137.7	71.8	1.9	-do-	round	even	-do-
14.	Kalluvally 1	142.4	78.5	1.8	-do-	-do-	-do-	cordate
15.	Kalluvally 2	14Ø.3	73.7	1.9	-do-	round	-do-	-do-
16.	Kallubala-ancotta	14Ø.3	65.Ø	2.2	-do-	acute	-do-	-do-
17.	Kottanadan	129.2	82.7	1.6	-do-	round	-do-	-do-
18.	Kuching	138.Ø	85.2	1.6	-do-	-do-	wavy	-do-

19.	Kuriyalmundi	118.Ø	74.9	1.6	-do-	-do-	-do-	-do-
2Ø.	Kuthiravally	115.4	1Ø5.6	1.1	-do-	-do-	even	cordate
21.	Kurimalai	129.7	77.9	1.7	-do-	-do-	-do-	ovate
22.	Malamundi	129.8	63.1	2.1	-do-	-do-	-do-	-do-
23.	Mundi	128.4	87.8	1.5	-do-	-do-	wavy	-do-
24.	Narayakkodi	1Ø2.8	66.7	1.5	-do-	cordate	-do-	-do-
25.	Neelamundi	153.5	88.5	1.7	-do-	round	even	-do-
26.	Nedumchola	88.4	47.5	1.9	-do-	-do-	-do-	-do-
27.	Neyyattin-karamundi	125.Ø	74.8	1.7	-do-	-do-	wavy	-do-
28.	Ottaplackal 1	117.2	7Ø.Ø	1.7	ovate	round	even	ovate
29.	Panniyur 1	143.5	1Ø2.3	1.4	cordate	cordate	-do-	cordate
3Ø.	Perambra-munda	148.3	84.1	1.8	ovate	round	-do-	ovate
31.	Perumkodi	152.3	73.5	2.1	-do-	-do-	-do-	-do-
32.	Poonjaran-munda	132.1	87.2	1.5	-do-	-do-	-do-	cordate
33.	Sagar Local	153.3	92.3	1.5	-do-	-do-	-do-	-do-
34.	Thevanmundi	141.6	93.1	1.5	-do-	-do-	-do-	-do-
35.	Thommankodi	1Ø2.1	64.4	1.6	-do-	-do-	-do-	-do-
36.	Thulamundi	123.6	66.5	1.9	-do-	-do-	-do-	cordate
37.	Uddakere	15Ø.3	82.4	1.8	-do-	-do-	-do-	ovate
38.	Uthirancotta	143.Ø	67.Ø	2.1	-do-	-do-	-do-	-do-
39.	Vadakkan	164.9	99.1	1.7	-do-	-do-	-do-	-do-
4Ø.	Valiakani-akkadan	114.Ø	54.Ø	2.1	-do-	-do-	wavy	-do-
41.	Vattamundi	114.1	78.8	1.5	-do-	-do-	even	cordate
42.	Vellanamban	1Ø2.3	52.1	1.9	-do-	-do-	-do-	ovate

43.	Velliyaren-munda	145.1	75.5	1.9	-do-	-do-	-do-	-do-
44.	Vokkalu	71.4	61.3	1.7	-do-	-do-	-do-	-do-
45.	p.nigrum (wild) 2079	155.4	75.8	2.1	-do-	-do-	wavy	cordate
46.	-do- 2071	141.5	77.1	1.8	-do-	-do-	-do-	ovate
47.	-do- 2009	144.9	67.9	2.1	elli-laneo.	cordate	even	-do-
48.	-do- 2059	165.3	86.9	1.9	-do-	-do-	-do-	-do-
49.	-do- 2060	151.1	96.5	1.6	cordate	-do-	-do-	cordate
50.	-do- 2015	149.0	77.0	1.9	ovate	round	wavy	ovate
51.	-do- 2062	171.8	80.9	2.1	elli-lanceo-late	cordate	even	-do-

Table V.3A: Leaf Morphological characters of Piper spp. (Contd.)

Specimen	Leaf shape	Leaf base	Leaf texture	Leaf nature	Distance from base to 2nd pair of ribs (mm)	No. of ribs
P.attenuatum	ovate to ovate elliptic	round to attenuate	glabrous	membraneous	3.8	7
P.argyrophyllum	-do-	round	sparsely hairy on ribs	-do-	5.1	5
P.galeatum	ovate-lanceolate	-do-	glabrous	coriaceous	8.2	5
P.hymenophyllum	ovate-to.-elliptic	round	hirsute	membraneous	3.7	5
P.longum	cordate	cordate	glabrous	-do-	Ø.Ø	7
P.mullesua	elliptical-elli- lan.	acute	glabrous	-do-	16.2	5
P.schmidtii	ovate-to. elliptic	round	-do-	coriaceous	12.4	5
P.silent-valleyensis	elliptic-ell-lan.	acute	-do-	membraneous	4.3	5
P.sugandhi	ovate	round	-do-	coriaceous	16.Ø	5-7
P.sugandhi var. leiospicatum	-do-	-do-	-do-	-do-	15.9	do
P.trichstachyon	ovate-lan.	acute	-do-	coriaceous	7.3	5
P.wightii	ovate	round	-do-	-do-		

Table V.3A: Leaf Morphological characters of *Piper* spp. (Contd.)

Specimen	Leaf shape	Leaf base	Leaf texture	Leaf nature	Distance from base to 2nd pair of ribs (mm)	No. of ribs
P.attenuatum	ovate to ovate elliptic	round to attenuate	glabrous	membraneous	3.8	7
P.argyrophyllum	-do-	round	sparsely hairy on ribs	-do-	5.1	5
P.galeatum	ovate-lanceolate	-do-	glabrous	coriaceous	8.2	5
P.hymenophyllum	ovate-to.-elliptic	round	hirsute	membraneous	3.7	5
P.longum	cordate	cordate	glabrous	-do-	Ø.Ø	7
P.mullesua	elliptical-elli-lan.	acute	glabrous	-do-	16.2	5
P.schmidtii	ovate-to. elliptic	round	-do-	coriaceous	12.4	5
P.silentvalleyensis	elliptic-ell-lan.	acute	-do-	membraneous	4.3	5
P.sugandhi	ovate	round	-do-	coriaceous	16.Ø	5-7
P.sugandhi var. leiospicatum	-do-	-do-	-do-	-do-	15.9	do
P.trichstachyon	ovate-lan.	acute	-do-	coriaceous	7.3	5
P.wightii	ovate	round	-do-	-do-		

P.nigrum	(1)	-do-	-do-	-do-	-do-	15.8	5-7
-do-	(2)	ovate-lan.	acute	-do-	-do-	28.Ø	do
-do-	(3)	ovate	round	-do-	-do-	16.2	do
-do-	(4)	-do-	-do-	-do-	-do-	21.7	do
-do-	(5)	-do-	-do-	-do-	-do-	26.Ø	do
-do-	(6)	-do-	-do-	-do-	-do-	31.3	do
-do-	(7)	-do-	-do-	-do-	-do-	22.1	do
P.nigrum var. hirtellosum		-do-	-do-	-do-	-do-	18.7	do

Table V.3B: Leaf Morphological Characters of Piper Spp.

Species	Leaf length (mm)	Leaf breadth (mm)	L/B	Petiole length (mm)
P. attenuatum	111.5	55.3	2.0	8.6
P. argyrophyllum	120.4	70.5	1.7	12.4
P. galeatum	106.0	40.0	2.7	10.8
P. hymenophyllum	89.1	36.0	2.1	8.4
P. longum	70.0	51.0	1.4	2.1
P. mullesua	83.6	30.0	2.8	6.7
P. schmidtii	92.0	38.0	2.4	8.9
P. silentvalleyensis	60.3	22.4	2.7	4.5
P. trichostachyon	108.1	36.5	2.9	11.5
P. wightii	87.8	57.0	1.5	10.4
P. nigrum (1)	149.0	77.0	1.9	11.9
-do- (2)	171.8	80.9	2.1	17.9
-do- (3)	155.4	75.8	2.1	16.0
-do- (4)	141.5	77.1	1.8	21.0
-do- (5)	144.9	67.9	2.1	15.0
-do- (6)	165.3	86.9	1.9	18.0
-do- (7)	151.1	96.5	1.6	18.6
P. nigrum var. hirtellosum	150.8	71.7	2.1	16.5
P. sugandhi	128.0	77.0	1.7	24.0
P. sugandhi var. leiospicata	131.7	78.5	1.7	23.8

associated with the sympodially growing flowering node, while the leaf sheaths are characteristic of the vegetative nodes. The vegetative and flowering nodes have similar external morphology in all the species occurring in the Western Ghats. The prophyll falls off with the emergence of the bud and spike; the leaf sheaths which are extensions of the petiole are also cauducous and they get dried up and fall off in due course.

Leaf anatomical features

The leaf anatomical features are given in Table V.4. Among the Pepper cvs. the leaf thickness varies from 0.313 mm in Karimunda to 0.412 mm in Poonjaranmunda; the majority of the cultivars have leaf thickness between 0.340 and 0.380 mm. The upper epidermal thickness ranges from 0.08 mm in Thevanmundi to 0.144 mm in Cheppukulamundi. The lower epidermal thickness ranges between 0.106 mm in Kaniakkadan to 0.165 mm in Uthirancotta. The mesophyll thickness varies from 0.105 mm in a wild collection (No.2009) to 0.152 mm in Nedumchola. The stomatal frequency varies from 61.2/mm in Karimunda to 130.4 /mm in Vadakkan (Table V.5). The cultivars with high stomatal frequency are Vadakkan(130.4) Bilimalligeswara (125.0), Kaniakkadan (128.9), Uthirancotta (127.0), Vattamundi (127.2), Vokkalu (126.4), Nedumchola (122.3), Perambramunda (124.8) and Sagar local (123.7). The low frequency group includes Arrakkulammunda (79), Balancotta (81.8), Karimunda (61.2), Karimkotta (85.8), Malamundi

(84.6), Neelamundi (84.6), Ottaplackal (80.2), Thulamudi (80.7), Valiakaniakkadan (81.4) and one collection of wild nigrum (85.5).

Among the related taxa, the lowest stomatal density is in P. attenuatum ($68.4/mm^2$), followed by P. trichostachyon $80.0/mm^2$). The highest stomatal frequencies are in P. longum (113.3) and in P. schmidtii (103.7).

The length of guard cells varies from 0.022 mm (in Kottanadan, Kuriyalmundi and Kuthiravally) to 0.28mm (in Thulamundi and Acc. No. 2059); and the breadth of guard cell from 0.015 mm (in Velliyaranmunda) to 0.025 mm in Vadakkan. In the related taxa the length varies from 0.023 mm in P. longum to 0.033 in P. hymenophyllum and guard cell breadth from 0.016 mm in P. schmidtii and P. trichostachyon to 0.002 in P. hymenophyllum.

The leaf epidermis is made of small rectangular cells, beneath which there is a hypodermis on both sides, composed of 2-3 layers of large, more or less rectangular cells. The cuticle over the epidermis gives a corrugated appearance in T.S. The palisade is relatively narrow, composed of just one row of cells in most of the area. The spongy tissue is composed of 3-4 layers of round to irregularly shaped cells. Both palisade and spongy cells contain discoid chloroplasts, 5-10 in the former, 2-5 in the latter (Plate V.2).

TABLE V.4 LEAF ANATOMICAL CHARACTERS OF PEPPER CULTIVARS

Cultivar	Leaf thickness	Lower epidermis	Upper epidermis	Mesophyll Thickness
	(Measurement in mm)			
Aimpiriyan	0.340	0.133	0.106	0.132
Arakkulam munda	0.340	0.120	0.090	0.121
Arimulaku	0.343	0.110	0.092	0.145
Balancotta	0.378	0.139	0.106	0.129
Bilimalligesara	0.317	0.115	0.100	0.112
Cheriyarakaniakkadan	0.368	0.120	0.090	0.138
Cheppukulamundi	0.387	0.138	0.144	0.135
Cholamundi	0.367	0.132	0.090	0.126
Jeerakamundi	0.360	0.129	0.093	0.137
Karimunda	0.313	0.118	0.096	0.124
Kaniakkadan	0.351	0.106	0.096	0.144
Karivilanchy	0.373	0.123	0.098	0.143
Karimkottta	0.325	0.122	0.094	0.110
Kalluvally (1)	0.377	0.130	0.104	0.134
Kalluvally (2)	0.382	0.135	0.101	0.144
Kallubalancotta	0.362	0.138	0.108	0.139
Kottanadan	0.378	0.134	0.103	0.135
Kuching	0.400	0.142	0.116	0.144
Kuriyalmundi	0.374	0.136	0.112	0.124
Kuthiravally	0.328	0.109	0.097	0.141
Kurimalai	0.389	0.137	0.115	0.141
Malamundi	0.369	0.129	0.101	0.115
Mundi	0.398	0.134	0.119	0.139

Narayakkodi	0.369	0.129	0.101	0.134
Neelamundi	0.319	0.128	0.094	0.115
Nedumchola	0.388	0.132	0.097	0.152
Neyyatinkaramundi	0.356	0.122	0.090	0.136
Ottaplackal	0.365	0.138	0.121	0.123
Panniyur I	0.341	0.118	0.086	0.135
Perambramunda	0.348	0.123	0.089	0.137
Perumkodi	0.373	0.130	0.101	0.141
Poonjaranmunda	0.412	0.141	0.120	0.144
Sagar Local	0.362	0.142	0.101	0.127
Thevanmundi	0.338	0.126	0.080	0.133
Thommankodi	0.360	0.129	0.093	0.137
Thulamundi	0.409	0.154	0.122	0.139
Uddakere	0.417	0.160	0.113	0.140
Uthirancottta	0.404	0.165	0.101	0.137
Vadakkan	0.390	0.139	0.108	0.142
Valiakaniakkadan	0.405	0.150	0.120	0.138
Vattamundi	0.344	0.120	0.093	0.120
Vellanamban	0.397	0.150	0.155	0.135
Velliyaranmunda	0.408	0.118	0.111	0.151
Vokkalu	0.346	0.121	0.100	0.130
P.nigrum (2077)	0.330	0.123	0.101	0.118
-do- (2071)	0.348	0.119	0.107	0.124
-do- (2009)	0.355	0.136	0.114	0.105
-do- (2059)	0.343	0.124	0.095	0.125
-do- (2060)	0.352	0.141	0.110	0.140
-do- (2015)	0.349	0.129	0.110	0.105
-do- (2062)	0.345	0.125	0.110	0.110

Mucilage canals are seen inside the mesophyll, often close to the vascular supplies. These cavities are filled with a dark substance, probably mucilage.

Wax glands or pearl glands are present on the upper and lower surface of the leaf. These glands consist of a stalk and globose head, located inside a depression in the epidermis (Plate V.2). The glands contain a dark substance. When the leaves are young the glands are active and secrete white, shiny, wax globules which on continuous exposure to air turns black. The wax secretions are found to be profuse in certain cultivars as in Panniyur I, but very scarce in many others.

The T.S through a vein shows the vasuclar cylinder, consisting of an indistinct bundle sheath and 5-7 groups of xylem elements. Below the xylem a small group of phloem cells are present. a small group of phloem cells are present.

Stomata and stomatal ontogeny

The stoma of P.nigrum is tetracytic surrounded by a ring of four subsidiary cells, but five or six cells are also encountered (Plate V.3). Stomatogenesis begins when one of the protoderm cells enlarges and gets differentiated into a meristemoid having an isodiametric shape. This undergoes an anticlinal division giving rise to two cells one of which becomes a subsidiary cell and the other undergoes a periclinal division. One of the daughter cells becomes the

TABLE V.5 : STOMATAL CHARACTERS OF BLACK PEPPER CULTIVARS

Cultivar	Stomatal frequency	Guardcell length	Guardcell breadth
		(Measurements in mm)	
Aimpiriyan	101.8	0.024	0.019
Arakkulam munda	78.8	0.024	0.018
Arimulaku	113.8	0.025	0.020
Balancotta	81.8	0.026	0.020
Bilimalligesara	125.0	0.026	0.019
Cheriyakaniakkadan	101.5	0.026	0.019
Cheppukulamundi	98.7	0.025	0.019
Cholamundi	101.5	0.026	0.019
Jeerakamundi	105.9	0.025	0.020
Karimunda	61.2	0.023	0.019
Kaniakkadan	128.9	0.024	0.020
Karivilanchy	100.2	0.027	0.020
Karimkotta	85.8	0.026	0.019
Kalluvally (1)	97.4	0.027	0.020
Kalluvally (2)	116.5	0.025	0.021
Kallubalancotta	108.9	0.026	0.019
Kottanadan	102.1	0.022	0.017
Kuching	108.6	0.026	0.019
Kuriyalmundi	101.1	0.022	0.017
Kuthiravally	95.6	0.022	0.017
Kurimalai	118.8	0.024	0.017
Malamundi	84.6	0.025	0.019
Mundi	113.3	0.025	0.018
Narayakkodi	107.8	0.026	0.019

Neelamundi	84.6	0.025	0.019
Nedumchola	122.3	0.024	0.018
Neyyattinkaramundi	108.9	0.026	0.019
Ottaplackal 1	80.2	0.026	0.021
Panniyur 1	118.9	0.026	0.019
Perambramunda	124.8	0.025	0.021
Perumkodi	98.5	0.026	0.019
Poonjaranmunda	104.0	0.027	0.020
Sagar Local	123.7	0.025	0.017
Thevanmundi	91.9	0.026	0.019
Thommankodi	105.9	0.025	0.019
Thulamundi	80.7	0.028	0.022
Udakkere	92.6	0.026	0.017
Uthirancotta	127.0	0.024	0.017
Vadakkan	130.4	0.027	0.025
Valiakaniaddakan	81.4	0.026	0.020
Vatttamundi	127.2	0.025	0.019
Vellanamban	110.6	0.025	0.015
Velliyaranmunda	118.2	0.025	0.015
Vokkalu	126.4	0.025	0.018
P.nigrum (wild: Coll 2077)	94.1	0.025	0.018
-do- coll. 2017	85.5	0.025	0.019
-do- coll. 2009	114.5	0.027	0.020
-do- coll. 2059	108.1	0.028	0.020
-do- coll. 2060	97.5	0.025	0.019
-do- coll. 2015	106.0	0.026	0.021
-do- coll. 2062	96.1	0.026	0.020

Table : V.6: Stomatal Characters of Piper Spp.

Species	Stomatal density	Guardcell length	Guardcell breadth
P.attenuatum	68.41	0.025	0.018
P.argyrophyllum	83.18	0.027	0.017
P.galeatum	82.10	0.029	0.022
P.hymenophyllum	85.65	0.033	0.022
P.longum	113.30	0.023	0.018
P.mullesua	97.82	0.027	0.020
P.schmidtii	103.70	0.024	0.016
P.silentvallyensis	97.14	0.024	0.018
P.sugandhi	90.0	0.026	0.017
P.sugandhi var. leiospicatum	83.4	0.024	0.017
P.trichostachyon	80.40	0.028	0.016
P.wightii	109.50	0.022	0.018
P.nigrum (1)	106.00	0.026	0.021
-do- (2)	96.11	0.026	0.021
-do- (3)	94.06	0.025	0.018
-do- (4)	85.85	0.026	0.019
-do- (5)	114.47	0.027	0.020
-do- (6)	108.08	0.028	0.020
-do- (7)	97.48	0.025	0.019
-do- var. hirtellosum	86.19	0.027	0.018

second subsidiary cell and the other cell then divides anticlinally. The daughter cell formed towards the outside becomes the third subsidiary cell. The inner cell divides transversely producing an outer cell which becomes the fourth subsidiary cell and an inner cell which becomes the guard cell mother cell. This then divides periclinally producing the guard cells. The enlargement of the guard cell pushes apart the subsidiary cells which then become a whorl surrounding the guard cells.

The guard cells and the subsidiary cells are formed from the same merstemoid. Hence the stomatal development is mesogenous.

Variations in the above general petters do exist, such as the presence of 3, 5 or 6 subsidiary cells instead of the normal four. Such variations were more common in _P. longum_. Here the stomata are either tetracytic, anisocytic, anomocytic or their modified forms, though the most frequent being the tetracytic type. The developmental sequences of some of these types are given in Plate V.3. In certain instances mesoperigenous type of development was found in which one subsidiary cell was contributed by the Perigene cells.

The Petiole

The petiole is groved on the upper surface. The epidermis is made of hexagonal cells, the cuticle is thick and corrugated in appearance (in T.S.). Below the epidermis there is a sclerenchymatous outer cortex, which forms a band all around.Below this there are 10-12 rows of parenchymatous cells. There is a mucilage cavity which occupies central position.

The vascular bundles are distributed in a semicircular fashion. The bundles just below the grove are very small (usually three in number) and each of these bundles consists of 4-5 elements only. On the two corners adjacent to the middle grove there are two bundles larger than the other bundles in the outer whorl. Here the protoxylem elements are oriented towards the central mucilage cavity. The bundle opposite the grove is the largest, which along with the adjacent two bundles are located slightly interior compared to the rest of the bundles. These may be the bundles derived from the medullary bundles.

Pearl glands are seen on the petioles also. The sides of the petiole develop into sheaths and these sheaths are deciduous and they get dry up and shed as the leaf grows. (Plate V.4).

<u>The Stem</u>

As mentioned earlier <u>Piper</u> exhibits dimorphism in branching. The main stem and the runner shoots belong to one class, and they grow monopodially. The fruiting lateral shoots belong to the other class, where the growth is sympodial. The two are developmentally different and hence show variations in their behaviour. The monopodial shoot (orthotropic shoot) when cut and planted produces a normal climbing pepper vine, while the lateral shoots of finite growth produce bushy spreading plants. (Plate V.5). The two types of branches differ to some extent in their anatomical features also.

The orthotropic stem

The structure of the orthotropic shoot is typical of that of Piperaceae and is the one studied by all the previous workers. The epidermis is made of rectangular cells over which there is a corrugated layer of cuticle. Below the epidermis there are 2-3 rows of collenchymatous cells, with many sclerides distributed in it. Below this there is a discontinuous band of sclerenchyma consisting of 4-6 rows of cells. Inner to this band there are 7-8 rows of parenchyma cells. The peripheral ring of vascular bundles or cortical bundles are situated below the parenchymatous region. This ring is composed of 30-40 vascular bundles, consisting of both small and large which often alternate. Each bundle is characterised by a sclerenchymatous cap at the phloem end, below which lies phloem, cambium and xylem. Just below the ring of peripheral bundles there is a continuous wavy band of sclerenchyma. The inner parenchymatous region lies inside this band, and is made of closely arranged parenchyma cells. The central bundles (or medullay bundles) are arranged inside this parenchyma region. There are 8-10 central bundles, they are larger than the cortical bundles. Each bundle has sclerenchymatous cap towards the outside, below which lies phloem, cambium and xylem. The medullary rays consist of hexagonal cells. The pith is small and at the centre of the pith there is a mucilage canal which in fact forms a continuous canal traversing the entire plant body (Plate V.6).

Secondary thickness is initiated by the formation of a cambial ring in the area of peripheral bundles.

The plagiotropic (lateral) shoot

The anatomy of the plagiotropic shoot (lateral branch) differs from that of the orthotropic shoot in the following details (Plate V.7).

1. Continuous band of sclerenchyma in the outer region of the cortex where as in the orthotropic shoot this band is discontinuous.
2. There are no sclerenchymatous caps over the peripheral vascular bundles.
3. Less number of peripheral bundles (18-24) as compared to 30-40 in the orthotropic shoot.
4. Less number of central bundles (4-6) compared to 8-10 in the orthotropic shoot.
5. Fewer number of xylem elements both in peripheral and central bundles than that of orthotropic shoot.

The aerial root and the normal root

The normal underground root is more or less similar to a typical dicot root (Plate V.8). There are 5-8 groups of xylem and phloem and a relatively large pith which is not very common in dicot roots. There is no central mucilage canal in the root. The metaxylem elements vary from 1-3 and the protoxylem 5-8.

The aerial root differs from the normal root in having more number of xylem and phloem groups (12-15). The cortex is made of irregularly shaped, closely packed cells. The xylem elements are arranged as flattened discs. The number of xylem elements are more but are smaller than that of the normal root. (Plate V.8).

The Peduncle

In Piper the inflorescence is a catkin or spike which is formed opposite a leaf and is the transformed apical bud. The T.S. of the peduncle show the following structure (Plate V.4.). An epidermis made of rectangular cells, below which there is a band of sclerenchyma, 3-4 rows in width. Inner to this there are 7-8 rows of closely arranged parenchyma. The cortical ring of bundles lies below this which is associated with a band of sclerenchyma. This is a continuous band and is formed in such a way as to encircle the vascular bundles. There are two medullary (central) bundles which are larger than the cortical bundles. Each of these consists of sclerenchyma caps on either side, phloem, cambium and xylem. Pith is practically absent or very small.

Anatomical features of other Piper spp.

The anatomical features of *P. attenuatum*, *P. hymenophyllum* *P. trichostachyon*, *P. sugandhi* and *P. longum* were studied in order to see whether these differ substantially form *P. nigrum*. Basically the anatomical features were found to be very similar in all these species except for minor variations.

In *P. hymenophyllum* the stem (plagiotropic shoot) epidermis has large number of multicellular uniseriate hairs. There is a broken ring of sclerenchyma all around the stem which is followed by 1-2 layers of chloroplast containing parenchymatous cells. The cortical bundles are 16-18 in number, arranged in a ring and immersed in a wavy band of sclerenchyma. These bundles differ in size, some very small, others larger. The larger bundles consist of 7-10 tracheary elements while in the smaller bundles there are only 2-3 elements.

The medullary bundles are six in number, larger than the cortical bundles. Each bundle consists of 6-10 xylem elements. A mucilage canal is present at the centre of the stem. Pearl glands (wax glands) are absent.

The stem structure of P.attenuatum is more or less the same as that of P.hymenophyllum. In the plagiotropic shoot, the epidermis is followed by 2-3 layers of chloroplast containing parenchyma cells. There is a broken ring of sclerenchyma all round. Such a ring of sclerenchyma was absent in the orthotropic shoot, where large number of sclerides are found distributed in the outer cortex.

There are 22-26 cortical bundles arranged in a ring just below which is a wavy band of sclerenchyma. These bundles vary in size. There are six medullary bundles which are larger than the peripheral bundles. Bast fibres are found inside the phloem of the medullary bundles. There is a central mucilage canal. Wax glands absent.

The stem structure of P.sugandhi and P.trichostachyon are more or less similar. Both have microscopic hairs on the young orthotropic shoot, and these hairs are uniseriate, muticellular. The sclerenchymatous bands below the epidermis are discontinuous at a few places. The cortical bundles are located over wavy bands of sclerenchyma in both species. The number of cortical bundles are 23-24 in P.trichostacyon and 26 to 28 in P.sugandhi.

The medullary bundles are 7-8 in P.sugandhi and 6-7 in P.trichostachyon. One major difference between the two species is the presence of central mucilage canal in

P.sugandhi and its absence in P.trichostachyon. The medullary bundles have sclerenchymatous caps at the protoxylem ends in both species. A few bast fibres are found in the phloem tissues.

The structure of the plagiotropic shoot is more or less similar. These are totally glabrous with a thick layer of cuticle over the epidermis. The sclerenchyma are arranged in the form of short patches. There are 22-24 cortical bundles arranged over a wavy band of sclerenchyma. In P.sugandhi the cortical bundles are 26-28. The medullary bundles are 7-8 in P.sugandhi and 7 in P.trichostachyon. In this case also there is no central mucilage canal in P.trichostachyon.

In P.longum the epidermis has minute hairs, which are either unicellular or multicellular, uniserate. Below the epidermis there are patches of sclerenchyma forming a broken ring. Peripheral bundles numbering 18-20 are arranged over a wavy band of sclerenchyma. These bundles vary in size. The inner medullary bundles are six in number, each one possessing a sclerenchymatous cap at the protoxylem end. Two to four bast fibres are seen in phloem. In the middle there is a prominent mucilage canal. The runner shoot has very similar structure, but the medullary bundles do not have a sclerenchymatous cap at the protoxylem end.

Petiole

In *P.hymenophyllum* the petiole is groved, epidermis has many hairs which are multicellular, uniserite. Below the epidermis there is an unbroken band of sclerenchyma and below this there are 1-2 rows of chloroplast containing parenchyma cells. About 8-10 peripheral bundles are arranged in an incomplete ring. The inner bundles (medullary bundles) are three in number and are larger than the cortical or peripheral bundles. There are 5-6 or even more mucilage canals. There is no central mucilage canal as in *P.nigrum*.

In *P. attenuatum* the main point of difference from *P.nigrum* is the absence of central mucilage canal, though as in *P.hymenophyllum* 4-6 mucilage canals are seen in the T.S. of the petiole. The petiole structure is very similar to that of *P.hymenophyllum*.

In *P.longum* the upper grove is deeper than in other species. Unicellular or multicellular (uniseriate) hairs arise from the epidermis. The sclerenchyma band is discontinuous unlike in other species. About ten bundles are arranged in a semicircular fashion. There is no distinction between peripheral and central bundles, except for one large bundle situated opposite the grove. There are no mucilage canals in petiole, which is a major difference between *P.longum* and of other species.

The roots

Both the aerial roots and normal underground roots are developmentally identical and are adventitious. The roots originating from the root initials of nodes develop into aerial roots and help the plant to attach to support trees. The same initials in contact with soil and moisture develop into normal absorbing roots. The roots in general have an epidermis, a closely packed parenclymatous cortex, and endodermis and stele.

In *P.hymenophyllum* and *P.attenuatum* the stele is composed of radiating plates of xylem consisting of about 16 protoxylem groups radiating from a circular plate of xylem. The phloem groups are arranged alternating with the projecting protoxylem. There is a central mucilage canal.

In *P.trichostachyon* and *P.sugandhi* the steles consist of radiating plates of xylem having 11-12 protoxylem groups and phloem alternating with them. There are no central mucilage canals.

In *P.longum* the cortex contains many sclerides. The endodermis is prominent. The stele consists of a radiating plate of xylem from which 11-12 protoxylem groups are projecting and which alternate with the phloem groups. There is no central mucilage canal in *P.longum*.

Spike, Flower and Fruit characters of Piper Spp.

The spike characters of Piper Spp. are given in Table 5.7. The spikes of Piper spp. can be either pendulous or erect. Erect spikes are seen only in three species namely, P.longum, P.silentvalleyensis and P.mullesua

Based on shape the spikes can be either filiform, cylindrical or globose. Globose spikes is found only in P.mullesua, cyindrical spike only in P.longum. In all the other species the spikes are filiform. P.longum is also exceptional because here the flowers are laterally fused while in all the other species, the flowers are free.

Spike length in various Piper Spp. ranges from about 1 cm in P.mullesua (mean 9.Ø mm) to 18.Ø cm in P.attenuatum and P.galeatum. In P.nigrum (wild) the seven – collections studied range in spike length from 5.7 cm to 13.5 cm. Lengths of the spike stalk (peduncle) also vary among the species from Ø.2 cm in P.mullesua to 2.5 cm in P.argyrophyllum.

Spikes are glabrous in most of the species studied except in P.trichostachyon, in a collection of P.nigrum,P.nigrum var. hirtellosum) and in P.sugandhi.

Bract type is important in species delimitation of South Indian Piper. In P.attenuatum,P.argyrophyllum andP.hymenophyllum the bracts are sessile and adnate to the rachis. In P.longum, P.mullesua and P.silentvalleyensis bracts are peltate, stalked and orbicular. In P.galeatum and P.trichostachyon the bracts are connate, transformed into fleshy cup like structures. In P.nigrum the bracts are cupular with decurrent base. In P.sugandhi and in P.sugandhi var.leiospicata the bracts are deeply cupular with adnate base.

In P.schmidtii the bracts are circular with raised, free margins. In P.wightii the bracts are oblong, narrowed towards the base and adnate with free margins. Stamens are two in P.nigrum, P.mullesua, P.trichostachyon, P.galeatum,P.schmidtii and P.silentvalleyensis, 2 or rarely 3 in P.wightii; 3 in P.attenuatum and P.hymenophyllum, 3-4 in P.argyrophyllum and P.longum.

In P.argyrophyllum and P.hymenophyllum the male spikes posses a gentle lemon or lime-like fragrance. The colour of the inflorescence is purple in certain collections of P.nigrum, in other species the spikes are white or lighter yellow or green.

Spike variations among cultivars

The spike characters of the cultivars are given in Table 5.11. The smallest spike (3.4 cm) is found in the cv.Vokkalu, a collection from the Sagar taluk of Karnataka state.

The longest spike is in the cv.Kuthiravally (17.0 cm) a central Kerala cultivar. The other long spiked cultivars are Poonjaranmunda (16.4 cm), Karimkottta (15.6 cm) and Panniyur 1 (14.0 cm). The peduncle length ranged from 0.5 cm in Vokkalu to 2.1 cm in Karimkotta.

Leaf-spike relationship has shown that in the majority of cultivar the spike length is more or less equal to the leaf length (x + S.D = 0.99 - 1.8). In a few cultivars the L.L/Sp.L is less than one, and here the mean spike length is greater than the mean leaf length. These include Karimkotta, Kuthiravally, Poonjaranmunda, Thommankodi and Vellanamban (x + S.D = <0.99). In six cultivars spike length is much shorter than leaf length (x + S.D = >1.8). They include Kalluvally (Pulpelly) Kuriyalmundi, Vokkalu and wild collections 46 (2071) 47 (2009) and 49 (2060).

The spikes of majority of cultivars are straight, while some cultivars have characteristic curve or twisting of the spike. These include Aimpiriyan, Kalluvally (Pulpelly), Kuriyalmundi Narayakkodi and Kottanadan. The main reason for such twisting is the closeness of the flower arrangement and the high setting as a result of which the spikes become twisted or curved.

The pepper fruit is botanically a drupe, but often referred as a berry. The fruit is single seeded, having a fleshy pericarp and hard endocarp. The seed has litle endosperm but copious perisperm. The pepper fruit differs in size and to some extent in shape also. Some cultivars have bold fruits (berries) (Panniyur 1, Balancotta, Vadakkan, Udakkere etc.), while in other cases the fruits are either medium or small. Jeerakamundi and Kuriyalmundi have the smallest fruits, and the largest are those of Vadakkan. The fruits are spherical in shape in most cases, obovate in a few and oblong in others. (PLATE V.9)

Fruit (berry) character of the Piper Spp. are given in Table 5.12.

The fruits can be either free as in most species, or fused laterally as in P.longum. Fruit shape is obovate-oblong in P.attenuatum, P.argyrophyllum, P.hymenophyllum, P.galeatm, P.wightii, P.sugandhi and P.schmidtii; elliptical in P.longum and P.mullesua; obovate in P.silentvalleyensis and spherical or rarely oblong in P.nigrum and P.trichostachyon. The fruits are minute in P.longum, P.mullesua and P.silentvalleyensis, bold in P.galeatum, P.trichostachyon, P.sugandhi and in certain P.nigrum collections; and medium in other species. The various species of Piper can also be subdivided on the basis of the colour change of fruits on ripening. The two basic types are green turning black directly on ripening; and green turning to yellow, orange or red on ripening. P.attenuatum, P.argyrophyllum, P.hymenophyllum, P.longum, P.mullesua, and P.silentvalleyensis belong to the first group. P.galeatum, P.trichostachyon, P.sugandhi, P.wightii and P.nigrum belong to the second group.

Fruits taste bitter in P.attenautum, P.argyrophyllum, P.hymenophyllum, P.schmidtti, and P.wightii, in P.galeatum and P.trichostachyon fruits taste bitter first and somewhat pungent later. The fruits of P.longum, P.mullesua and P.silentvalleyensis taste spicy and aromatic, while the fruits are pungent in P.nigrum and P.sugandhi.

Table : V.7 Spike Characters of Piper Spp.

Species	Spike length	Peduncle length	Spike shape	Spike orient-tation	Spike texture	Bract type
P.attenuatum	120.0	20.0	filiform	pendu-lous	glabr-ous	adnate
P.argyrophyllum	83.0	25.2	do	do	do	do
P.hymenophyllum	73.0	22.0	do	do	do	do
P.galeatum	105.0	17.4	do	do	do	connate fleshy cup
P.longum	38.0	14.0	cylin-drical	erect	do	stalked, peltate, orbicular
P.mullesua	9.0	2.3	globose	erect	do	do
P.schmidtii	125.0	20.0	filiform	pendu-lous	do	obconical angular free margins
P.silentvalley-ensis	40.0	1.3	filiform	ascend-ing	do	stalked, peltate, orbicular
P.sugandhi	69.0	14.0	do	pendu-lous	hirt-ellous	deeply cupular
P.sugandhi var. leiospicata	71.0	14.6	do	do	glabr-ous	do
P.trichostachyon	76.0	15.3	do	pendu-lous	hirt-ellous	fleshy cup
P.wightii	65.0	12.0	do	do	glab-rous	
P.nigrum (1)	105.0	10.7	do	do	do	shallow cup under the ovary
do (2)	135.6	17.4	do	do	do	do

do	(3)	57.5	1Ø.1	do	do	do	do
do	(4)	65.5	5.3	do	do	do	do
do	(5)	65.5	5.3	do	do	do	do
do	(6)	1Ø1.4	16.1	do	do	do	do
do	(7)	6Ø.6	11.8	do	do	do	do
P.nigrum var. hirtellosum		93.6	21.6	do	do	do	do

TABLE V.8 : SPIKE AND BERRY (FRUIT) CHARACTERS OF BLACK PEPPER CULTIVARS

No.	Cultivars	Spike length (mm)	Peduncle length (mm)	L.L. / Sp. 1	Spike shape	Berry shape	Berry size
1.	Aimpiriyan	115.60	12.20	1.20	curved	round	bold
2.	Arakkulammunda	114.00	13.10	1.34	straight	-do-	medium
3.	Arimulaku	80.35	13.23	1.20	-do-	-do-	small
4.	Balancotta	127.40	17.20	1.55	-do-	-do-	bold
5.	Billimalligesara	105.60	8.60	1.13	-do-	-do-	medium
6.	Cheriyakkania-kkadan	105.40	9.20	1.13	-do-	obovate	small
7.	Cheppukulamundi	120.30	19.00	1.21	-do-	round	medium
8.	Cholamundi	111.30	6.40	1.24	-do-	-do-	small
9.	Jeerakamundi	103.60	6.00	1.16	-do-	-do-	-do-
10.	Karimunda	78.00	10.00	1.51	-do-	-do-	medium
11.	Kaniakkadan	92.50	9.00	1.38	-do-	-do-	-do-
12.	Karivilanchy	104.30	10.00	1.21	-do-	oblong	bold
13.	Karimkotta	156.30	21.00	0.88	-do-	round	-do-
14.	Kalluvally 1	69.17	12.00	2.05	curved	-do-	small
15.	Kalluvally 2	124.90	10.60	1.90	straight	-do-	medium
16.	Kallubalancotta	136.36	10.50	1.02	-do-	-do-	medium
17.	Kottanadan	106.90	11.10	1.20	-do-	-do-	-do-
18.	Kuching	91.00	9.70	1.51	-do-	oblong	-do-
19.	Kuriyalmundi	53.20	10.10	2.22	curved	round	small
20.	Kuthiravally	171.60	10.50	0.67	straight	-do-	medium

21.	Kurimalai	126.13	14.73	1.03	-do-	-do-	-do-
22.	Malamundi	96.70	7.90	1.34	-do-	-do-	-do-
23.	Mundi	86.30	9.10	1.56	-do-	-do-	bold
24.	Narayakkodi	82.30	7.90	1.25	curved	obovate	small
25.	Neelamundi	96.97	7.90	1.60	straight	round	bold
26.	Nedumchola	51.70	9.60	1.71	-do-	obovate	small
27.	Neyyatinkara-mundi	71.00	7.00	1.26	-do-	round	-do-
28.	Ottaplackal 1	113.80	12.40	1.03	-do-	-do-	medium
29.	Panniyur 1	140.00	13.70	1.02	-do-	-do-	bold
30.	Perambramunda	119.00	10.00	1.25	-do-	oblong	medium
31.	Perumkodi	117.60	13.10	1.30	straight	round	bold
32.	Poonjaranmunda	163.90	12.20	0.81	-do-	-do-	-do-
33.	Sagar Local	90.00	10.80	1.70	-do-	-do-	-do-
34.	Thevanmundi	96.50	8.71	1.46	-do-	oblong	medium
35.	Thommankodi	127.60	15.50	0.80	-do-	round	-do-
36.	Thulamundi	95.00	10.60	1.30	-do-	-do-	-do-
37.	Udakkere	128.80	11.65	1.17	-do-	-do-	bold
38.	Uthirancotta	105.60	12.60	1.35	-do-	-do-	-do-
39.	Vadakkan	117.30	14.60	1.41	straight	round	-do-
40.	Valiakanikkadan	97.50	13.80	1.77	-do-	oblong	-do-
41.	Vattamundi	99.70	12.45	1.14	-do-	round	-do-
42.	Vellanamban	122.40	9.60	0.84	-do-	-do-	-do-
43.	Velliyaranmunda	100.06	8.46	1.45	-do-	-do-	medium
44.	Vokkalu	33.70	5.30	2.12	-do-	-do-	-do-

45.	P.nigrum No.	2079	113.80	12.40	1.36	-do-	oblong	medium
46.	-do-	2071	57.50	10.10	2.46	-do-	-do-	-do-
47.	-do-	2009	65.50	5.33	2.21	-do-	-do-	-do-
48.	-do-	2059	101.40	16.10	1.63	-do-	round	bold
49.	-do-	2060	60.60	11.86	2.49	-do-	-do-	-do-
50.	-do-	2015	105.10	10.70	1.42	-do-	-do-	-do-
51.	-do-	2062	135.60	17.00	1.27	-do-	-do-	-do-

TABLE V.9 : Fruit (berry) characters of *Piper* spp.

Species	Berry nature	Berry shape	Berry colour change	Berry taste
P. attenuatum	free	ovate-oblong	G --> Bl	bitter
P. argyrophyllum	do	do	do	do
P. hymenophyllum	do	do	do	do
P. galeatum	do	do	G --> OR	do
P. longum	fused	elliptical	G --> Bl	Spicy
P. mullesua	free	do	do	do
P. schmidtii	free	ovate-oblong	G --> OR	bitter
P. silentvalleyensis	do	obovate	G --> Bl	Spicy
P. trichostachyon	do	spherical	G --> OR	bitter
P. sugandhi	do	ovate-oblong	G --> OR	pungent
P. sugandhi var. hirtellosum	do	do	do	do
P. wightii	do	conical	G --> OR	bitter
P. nigrum (1)	do	spherical	G --> R	pungent
do (2)	do	do	do	do
do (3)	do	do	do	do
do (4)	do	do	do	do
do (5)	do	do	do	do
do (6)	do	do	do	do
do (7)	do	do	do	do
do var. hirtellosum	do	do	do	do

G --> Bl : Green to Black
G --> OR : Green to Orange Red
G --> R : Green to Red

P L A T E V. 1

A young vine showing orthotropio and plagio-tropic shoots.

Shoot tip showing leaf sheaths

A node of the lateral branoh showing leaf-opposed branoh, prophyll and spike.

A node showing leaf -opposed spike

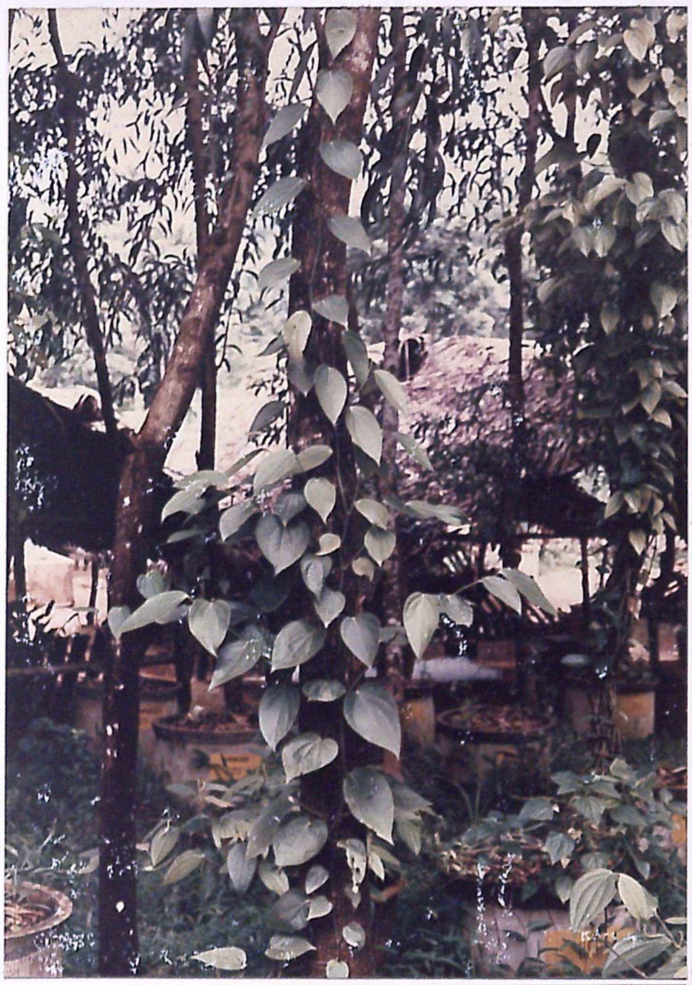


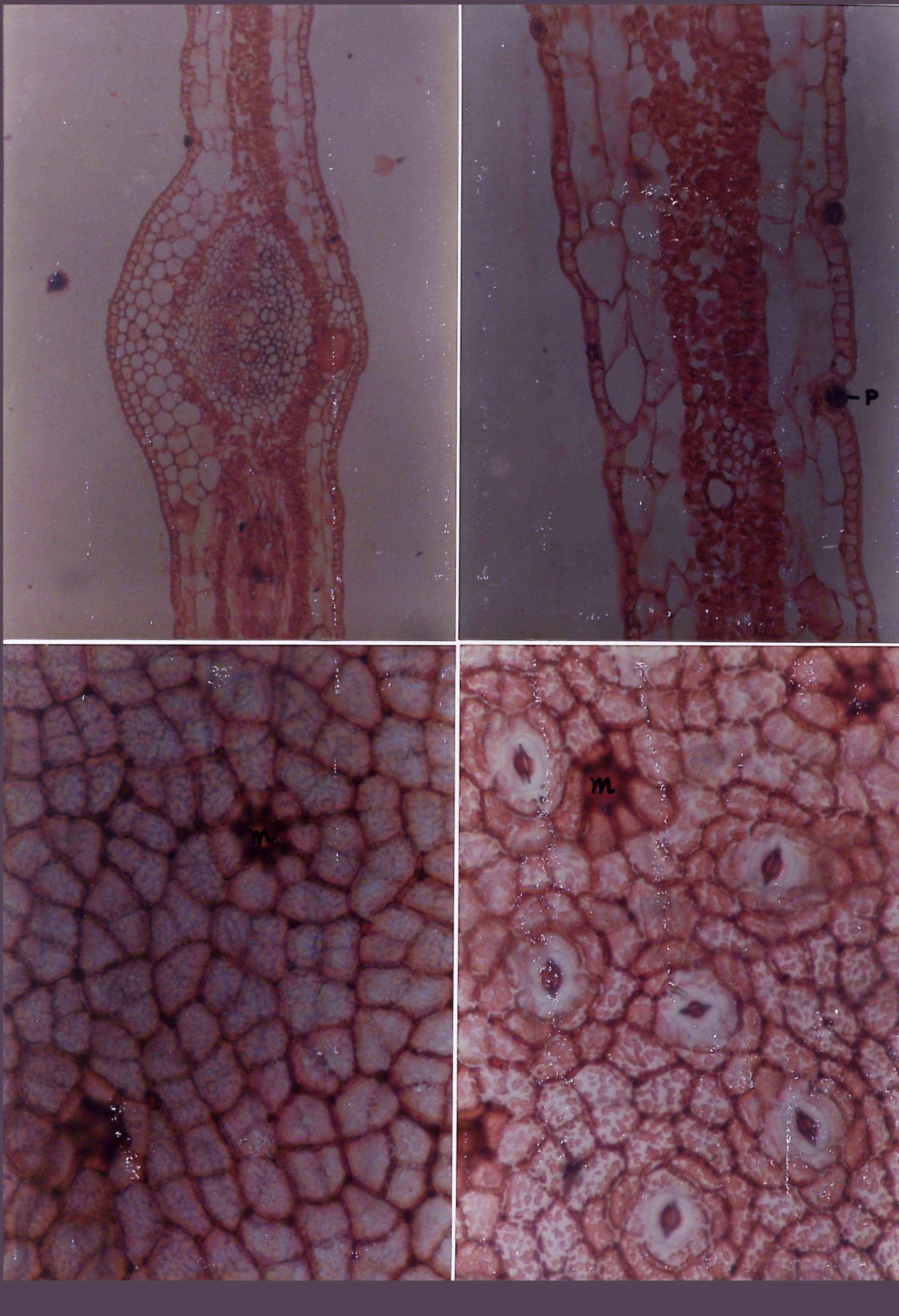

PLATE V. 2

T. S. of leaf

T.S of leaf showing the internal struoture . Note pearl glands (p)

Upper epidermis of leaf
m – mucilage canal

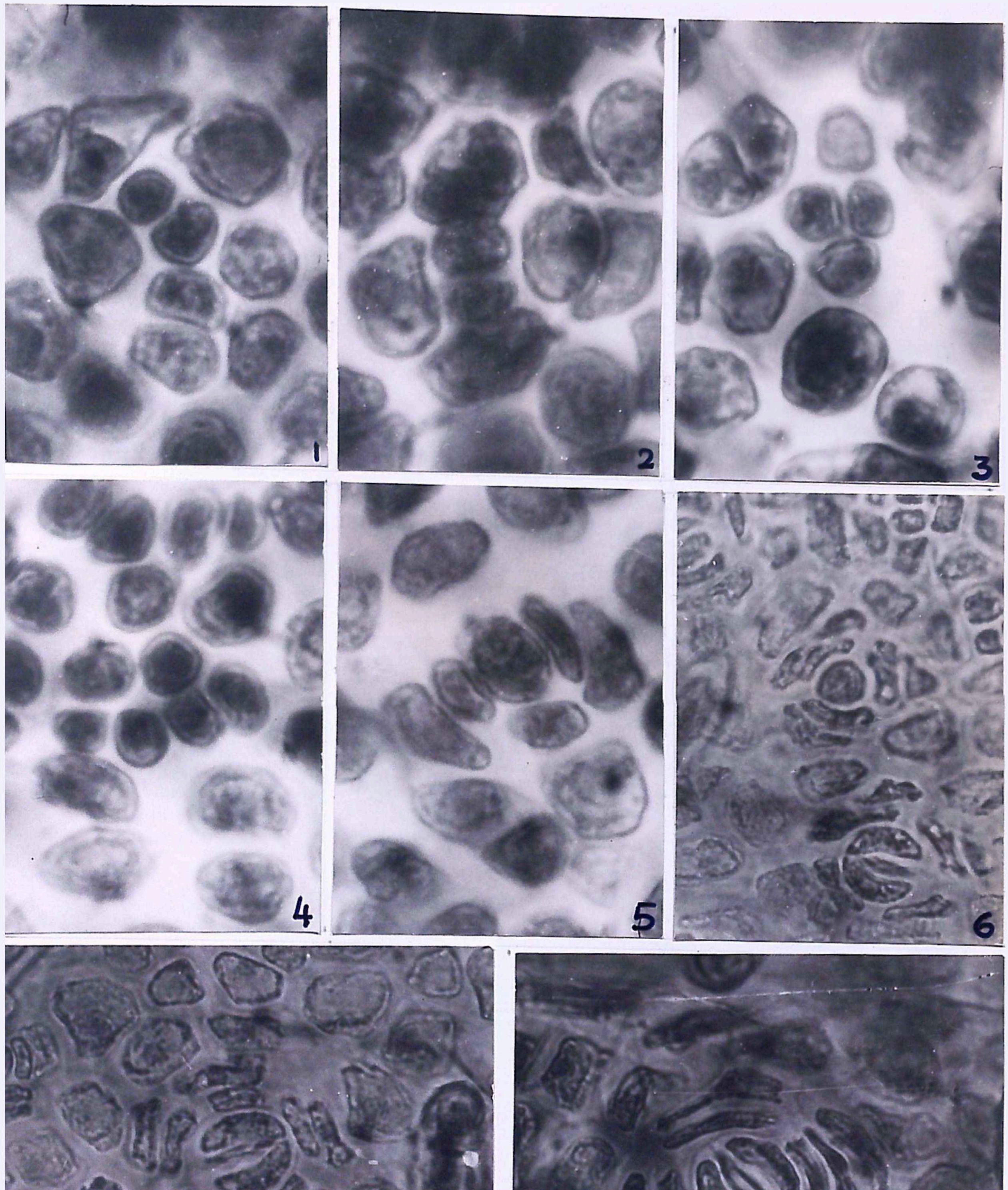
Lower epidermis showing stomata and mucilage cavity (m)


P
m
m

P L A T E V. 3

Some stages in stomatogenesis (x 2790)

1. Stomatal initial
2. Division of the stomatal initial giving rise to two cells
3. Three cells formed as a result of dividions
4. A tetrad of cells formed by two longitudinal and one transverse division.
5. A tetrad of cells (linear) formed by longitudinal divisions.
6. A guard cell mother initial
7. Division of the guard cell mother cell
8. A stomata with two whorls of subsidiary cells.


1
2
3
4
5
6
7
8

P L A T E V. 4

T. S of leaf petiole showing
the ring of vascular bundles
and the central mucilage canal

T.S of the peduncle showing
the cortical and medullary
bundles.

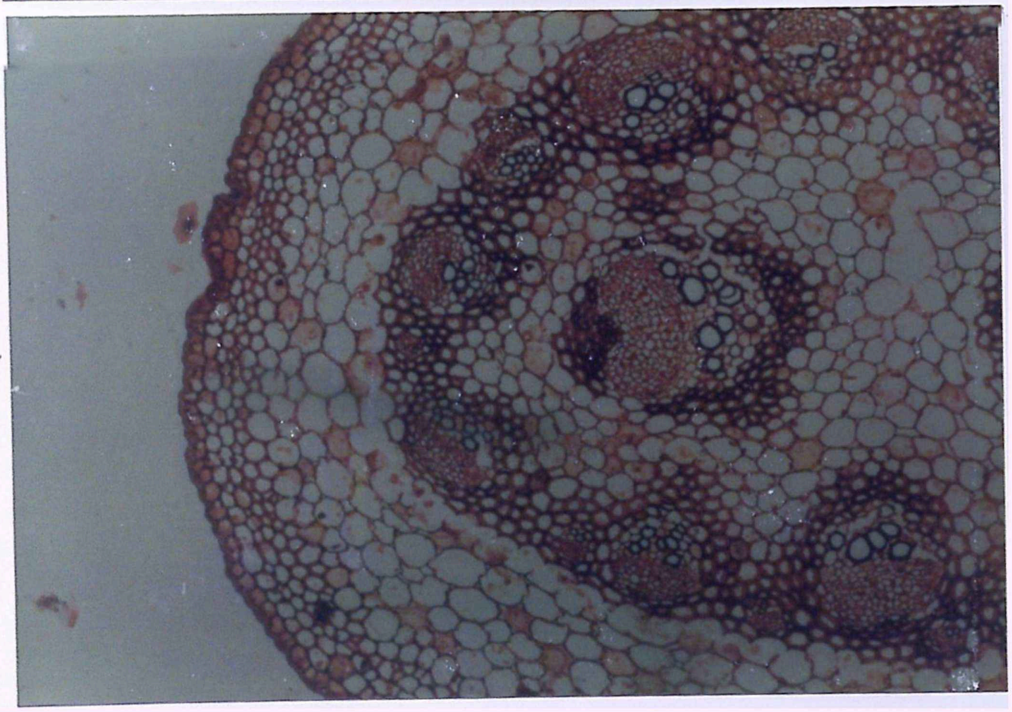



PLATE V. 5

A normal black pepper plant
climbing on a support tree.

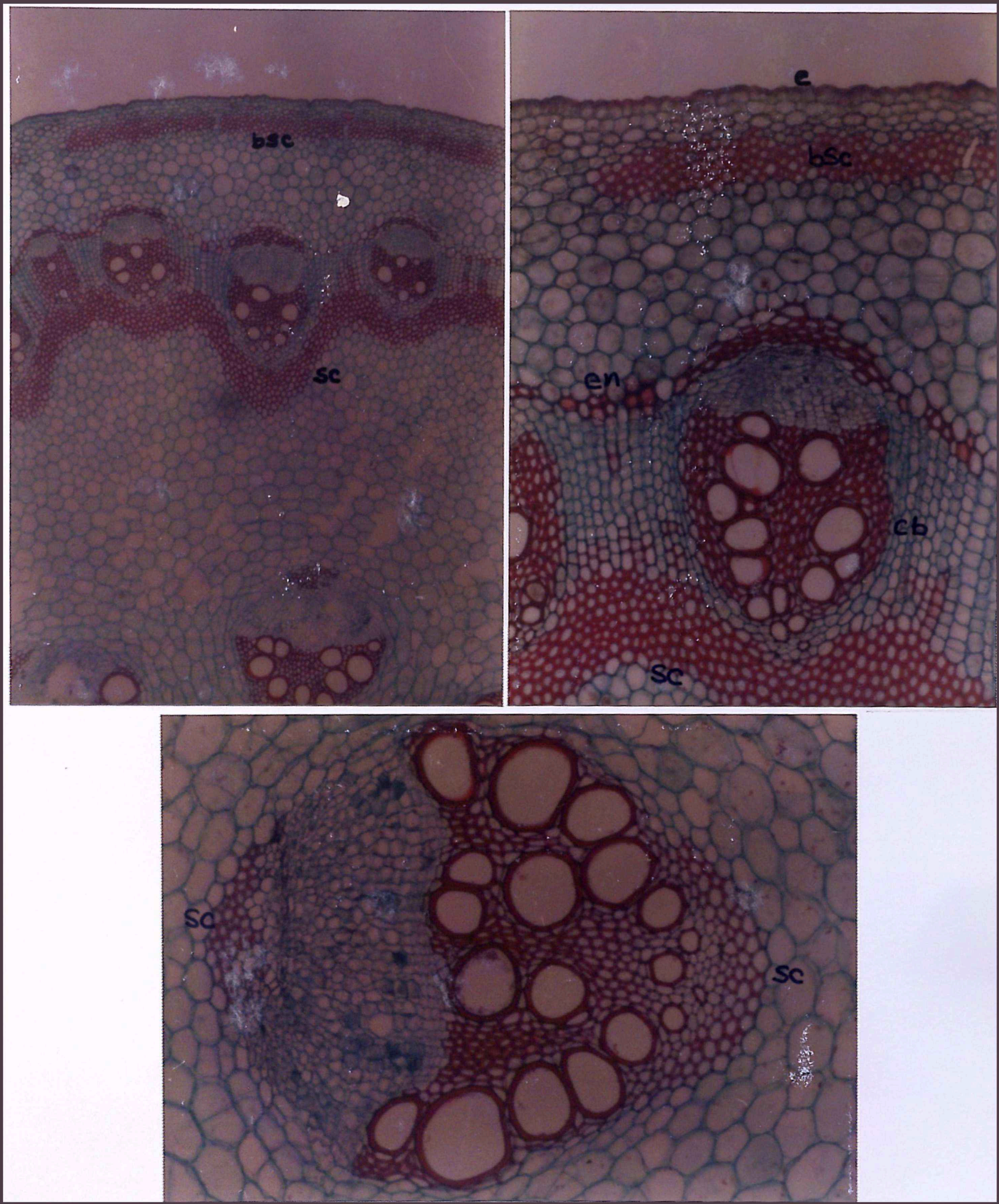
A bush pepper growing in a pot-
developed from the sympodial
plagiotropic shoot.

P L A T E V. 6

T.S of orthotropic shoot showing portions of outer cortex, and ring of cortical ring of bundles.
bsc. broken band of sclerenchyma
sc: wavy band of sclerenchyma
(x 60)

An enlarged view showing the epidermis (e), band of sclerenchyma (bsc), endodermis (en), cortical bundles (cb) and the wavy inner band of sclerenchyma (sc).
(x 120)

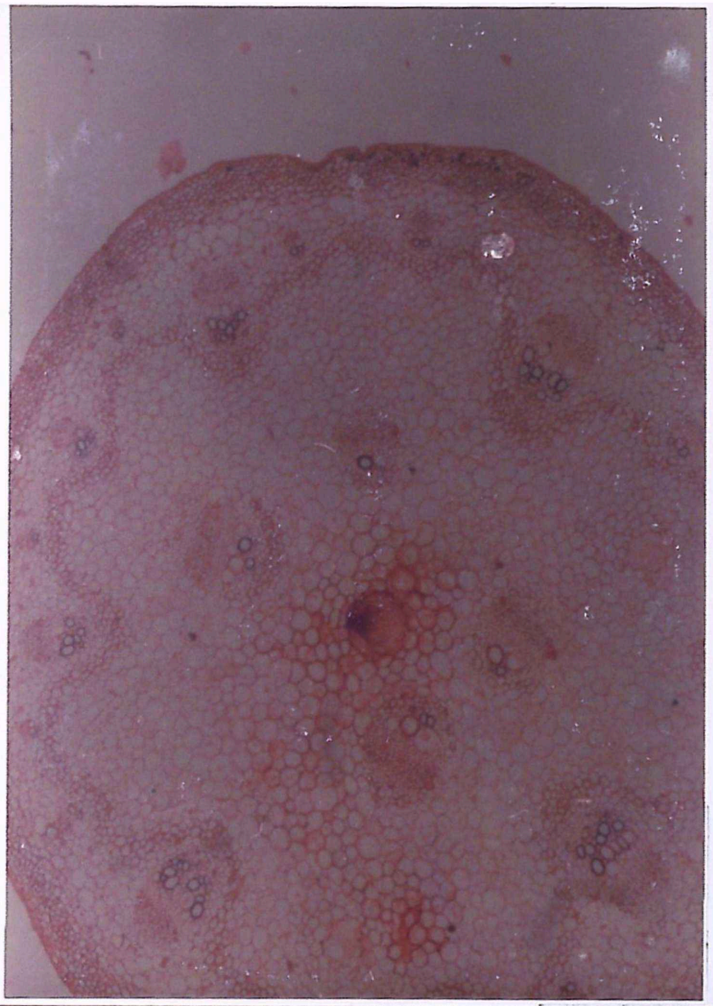
A medullary bundle- enlarged. Note the sclerenchymatous caps on either side of the bundle.
(x 220)


bsc
sc
e
bsc
en
cb
sc
sc
sc

P L A T E V. 7

T. S of the stem of the fruiting lateral- general view. (x 50)

A portion enlarged showing the cortical ring of bundles, the medullary bundles, and the central mucilage oanal (m).
sc- wavy band of sclerenchyma (x90)



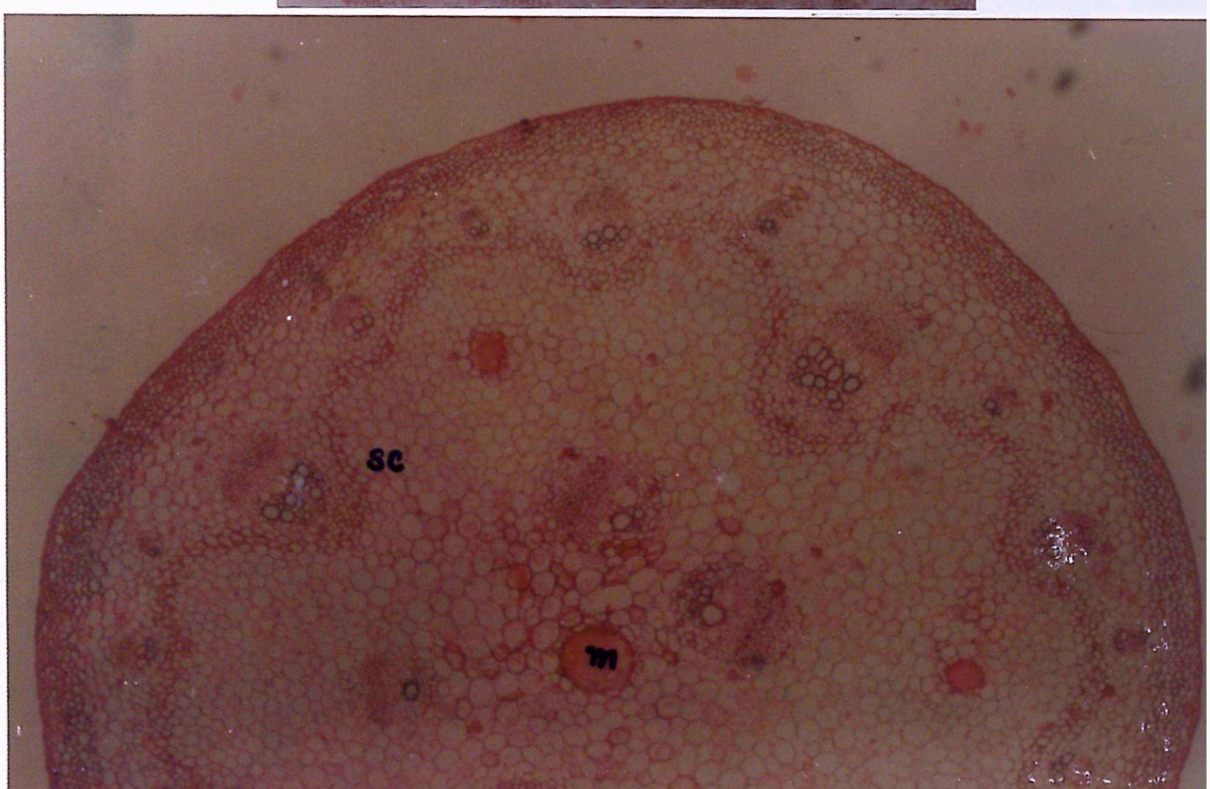
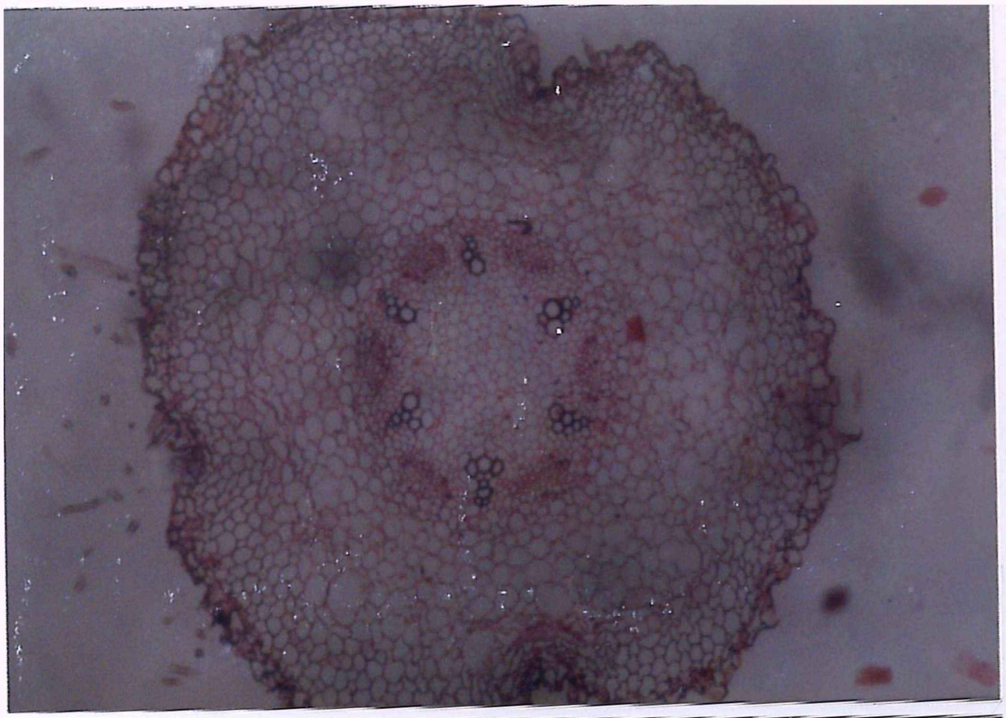

SC
m

PLATE V. 8

T. S of a normal underground root showing six xylem andphloem groups.

T.S of the aerial root showing 13 groups of xylem and phloem and the large pith (p). Note the flattened nature of the xylem .



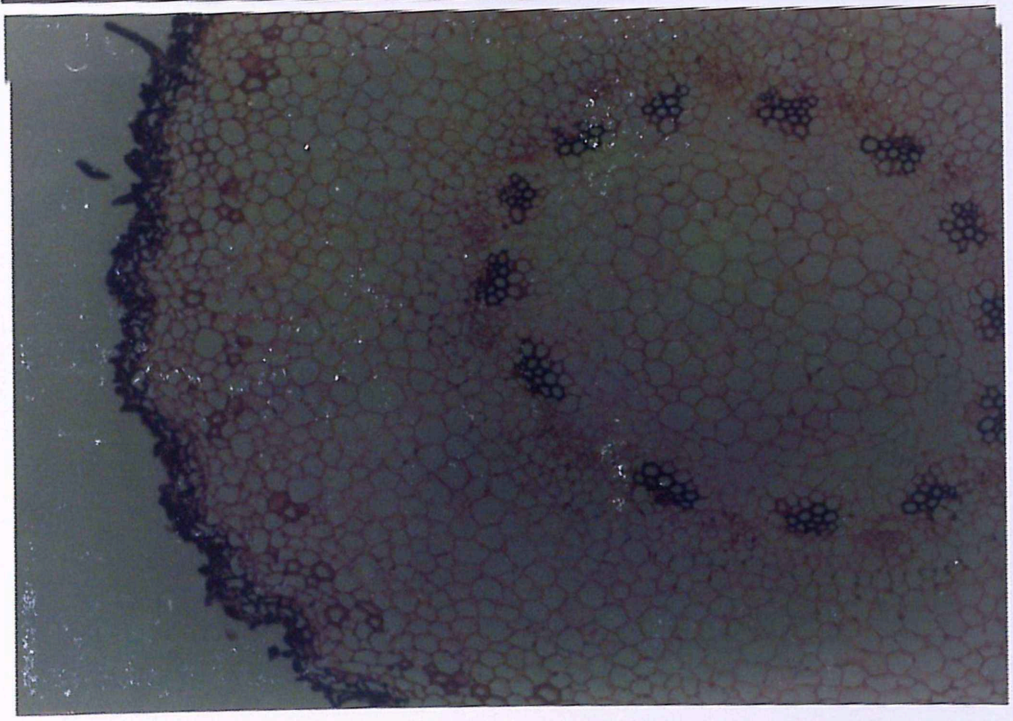
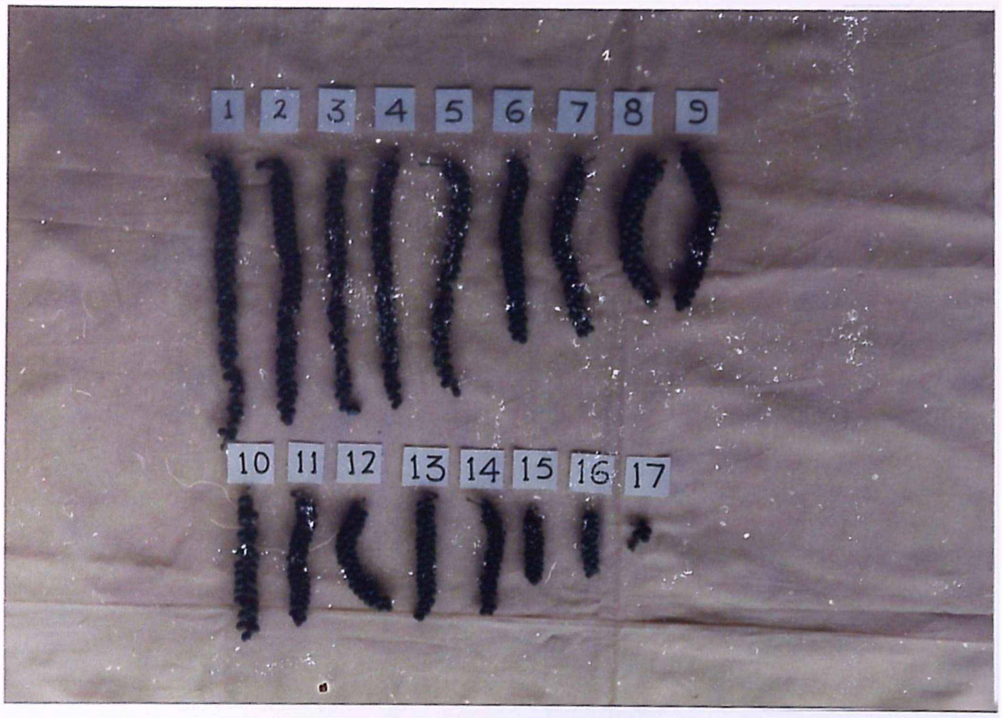


PLATE V. 9

Variability in spike length among cultivars of black pepper

Ripe (red) and mature (green) fruits of black pepper


1 2 3 4 5 6 7 8 9
10 11 12 13 14 15 16 17

CHAPTER VI

NUMERICAL TAXONOMY

INTRODUCTION

Numerical taxonomy is defined as the grouping of taxonomical units into taxa by numerical methods on the basis of their character states. It also encompasses the drawing of phylogenetic inferences from the data by statistical or mathematical methods. The principles and philosophy behind the numerical taxonomy are elegantly outlined by Sneath and Sokal (1973) in their classical book on numerical taxonomy. Numerical taxonomy has the versatility of integrating data from diverse sources (such as from cytology, chemistry etc.). The advocates of this system argue that numerical taxonomic methods being quantitative provide greater discrimination along the spectrum of taxonomic differences and are more sensitive in delimiting the taxa; and thereby they should give better taxonomic keys and classification. The methods of numerical taxonomy have become powerful tools in the hands of the taxonomists, not only for the identification of taxa and their interrelationships, but also in answering and interpreting a number of concepts basic to biology and evolution.

The basic unit used in numerical taxonomy is the Operational Taxonomic Unit (OTU), a term given to the lowest taxon being studied in a particular investigation (Sneath and Sokal, 1973). OTU s can be families, genera, species or individuals, or any other taxonomic entity. Each OTU has to be scored for the possession of one or more "character states" or attributes for each character which results in a data matrix of attributes. This data matrix is then analysed using one or more of the many methods available.

Many numerical taxonomic studies have been reported during the past three decades of its existence (Prance, Rogers and White 1969; Bisby, 1973; Challice, 1973; Sneath and Sokal, 1973; Barrett and Rhodes, 1976; Small, Jui and Lefkovitch, 1976; Small 1978, 1980, 1981; Hilu and Right, 1982 etc.). These studies also have shown the adaptability of the numerical taxonomic methods to any level of taxonomic organisation, subspecific, specific, generic, familial and super familial levels. In one such study Young and Watson (1970) even attempted a reclassification of dicotyledons using 543 representative genera. The results of the present study on black pepper culivars and related taxa are given below.

The cluster analysis of characters

The cluster analysis was carried out using 22 character variables recorded from 51 OTUs (cultivars). Table VI.1 gives the list of black pepper cultivars (OTUs) used in the present study. Table VII.2 gives the list of characters and their states considered for the analysis. Table VI.3 gives

TABLE: VI.1: BLACK PEPPER CULTIVARS (OTU's) USED IN THE PRESENT STUDY

1. Aimpiriyan
2. Arakkulam munda
3. Arimulaku
4. Balancotta
5. Bilimalligesara
6. Cheriyakaniakkadan
7. Cheppukulamundi
8. Cholamundi
9. Jeerakamundi
10. Karimunda
11. Kaniakkadan
12. Karivilanchy
13. Karimkotta
14. Kalluvally (Pulpally)
15. Kalluvally (2)
16. Kallubalancotta
17. Kottanadan
18. Kuching
19. Kuriyalmundi
20. Kuthiravally
21. Kurimalai
22. Malamundi
23. Mundi
24. Narayakkodi
25. Neelamundi
26. Nedumchola
27. Neyyattinkaramundi
28. Ottaplackal(No.812)
29. Panniyur 1
30. Perambramunda
31. Perumkodi
32. Poonjaranmunda
33. Sagar Local
34. Thevanmundi
35. Thommankudi
36. Thulamundi
37. Udakkere
38. Uthirancotta
39. Vadakkan
40. Valikaniakkadan
41. Vattamundi
42. Vellanamban
43. Velliyaranmunda
44. Vokkalu
45. P.nigrum wild Acc.2077
46. do Acc.2071
47. do Acc.2009
48. do Acc.2059
49. do Acc.2060
50. do Acc.2015
51. do Acc.2062

Table: VI.2 CHARACTERS AND THEIR STATES USED IN THE STUDY OF BLACK PEPPER cvs.
(all measurements in mm)

1. Leaf length
2. Leaf breadth
3. Leaf length / leaf breadth
4. Leaf size index (L.L x L.B / 100)
5. Leaf thickness
6. Epidermal thickness (lower)
7. Epidermal thickness (upper)
8. Mesophyll thickness
9. Stomatal frequency per mm^2
10. Guard cell length
11. Guard cell breadth
12. Spike length
13. Peduncle length
14. Leaf length - spike length ratio
15. Leaf shape : (1) ovate(2) cordate (3) ovate-elliptic (4) ovate-lanceolate
16. Leaf base : (1) round (2) cordate (3) acute
17. Leaf margin : (1) even (2) wavy
18. Leaf shape of orthotropic shoot: (1) ovate (2) cordate
19. Fruit shape: (1) round (2) oblong (3) obovate
20. Fruit size : (1) small (2) medium (3) bold
21. Colour of the new shoot: (1) Purple (2) Whitish green
22. Spike shape: (1) Straight (2) curved or twisted

TABLE VI.3 STATISTICS FOR THE VARIABLES (CHARACTERS)

	VAR NO.	MEAN	STANDARD DEVIATION	SMALLEST VALUE	SMALLEST CASE	LARGEST VALUE	LARGEST CASE
cv	1	133.4573	21.8560	71.4000	44	191.0000	4
cv	2	76.0710	13.4020	47.5000	26	205.6000	20
	3	1.7957	0.3036	1.0900	20	2.7000	39
cv	4	103.0976	29.8856	40.0000	26	181.4500	4
	5	0.3644	0.0266	0.3130	10	0.4170	37
	6	0.1304	0.0123	0.1060	11	0.1650	38
	7	0.1034	0.0117	0.0800	34	0.1440	7
	8	0.1318	0.0116	0.1050	47	0.1520	26
	9	103.9070	15.7790	61.2000	10	130.4000	39
l	10	0.0253	0.0013	0.0220	17	0.0280	36
b	11	0.0912	0.0015	0.0150	43	0.0250	39
cv	12	103.3676	28.0055	33.7000	44	171.6000	20
cv	13	11.0347	3.1258	5.3000	44	21.0000	13
	14	1.3925	0.4098	0.6700	20	2.4900	49
	15	1.4118	0.8984	1.0000	1	4.0000	47
	16	1.3529	0.6877	1.0000	1	3.0000	4
	17	1.2157	0.4154	1.0000	1	2.0000	2
	18	1.2157	0.4154	1.0000	2	2.0000	1
	19	1.3725	0.5621	1.0000	1	3.0000	6
	20	1.7451	0.7705	1.0000	1	3.0000	3
	21	1.0196	0.1400	1.0000	1	2.0000	29
	22	1.0784	0.2715	1.0000	2	2.0000	1

the statistics of each variable (character) recorded from 51 OTUs. Table VI.4 gives the inter-character correlations among the 22 variables. The process of average linkage clustering of character is depicted diagrammatically in fig. 6.1.

The process of clustering starts with the combining of character leaf breadth and leaf size index (2&4) and to this cluster the character leaf length (1) is combined. Characters fruit shape and fruit size (19 & 20) are combined seperately and this group is clubbed with the group formed earlier consisting of leaf length, leaf breadth and leaf size index.

Characters peduncle length and leaf length-spike length ratio (13 & 14) are combined separately and character spike length (12) is combined with this group. The cluster so formed is then combined with the group formed in the previous step consisting of five characters. Characters leaf shape and colour of the new shoot (15 & 21) are combined into an independent cluster, and this is then clubbed with the cluster formed earlier. This process continues and the process is given in fig. 6.1 Table VI.5.

One important out come of this clustering process is that certain clear sub groups of characters have emerged. The group containing the 12 characters from 1-22 in the fig. 6.1 is independent of the group containing 10 characters

TABLE VI.4 INTER CHARACTERS CORRELATIONS AMONG 22 CHARACTERS

	X(1) 1	X(2) 2	X(3) 3	X(4) 4	X(5) 5	X(6) 6	X(7) 7	X(8) 8	X(9) 9	X(10) 10	X(11) 11	X(12) 12	X(13) 13
1	1.000												
2	0.542	1.000											
3	0.487	-0.344	1.000										
4	0.868	0.879	0.078	1.000									
5	-0.016	-0.257	0.286	-0.143	1.000								
6	0.168	-0.143	0.331	0.029	0.701	1.000							
7	0.092	-0.019	0.105	0.038	0.586	0.538	1.000						
8	-0.249	-0.096	-0.068	-0.172	0.567	0.149	0.063	1.000					
9	-0.178	-0.037	-0.033	-0.104	0.145	-0.076	-0.120	0.293	1.000				
10	0.277	-0.055	0.375	0.141	0.192	0.191	0.114	-0.083	-0.004	1.000			
11	0.170	0.018	0.383	0.135	-0.006	0.008	0.357	-0.089	0.007	0.571	1.000		
12	0.330	0.260	0.140	0.308	0.027	0.061	0.201	0.030	-0.096	0.076	0.073	1.000	
13	0.384	0.238	0.172	0.370	-0.024	0.098	0.028	-0.071	-0.186	0.117	0.148	0.509	1.000
14	0.141	0.080	0.002	0.149	-0.060	0.009	0.029	-0.128	-0.025	-0.202	-0.007	-0.787	0.295
15	0.326	0.086	0.195	0.241	-0.245	0.139	-0.103	-0.295	-0.073	0.176	0.171	-0.029	0.045
16	0.181	-0.026	0.196	0.095	-0.163	-0.039	-0.156	-0.071	-0.201	0.184	0.118	0.048	-0.061
17	-0.036	-0.103	0.027	-0.096	0.060	-0.069	0.108	-0.101	-0.175	-0.016	-0.086	-0.277	-0.115
18	0.038	0.263	-0.218	0.156	-0.065	0.025	0.050	0.111	-0.045	-0.053	0.054	0.233	0.126
19	-0.222	-0.278	0.024	-0.275	0.078	-0.061	-0.208	0.161	0.022	0.115	-0.019	-0.280	-0.274
20	-0.319	-0.281	-0.071	-0.360	-0.208	-0.249	-0.099	0.136	-0.034	-0.195	-0.118	-0.364	-0.454
21	0.066	0.280	-0.186	0.209	-0.126	-0.144	-0.213	0.039	0.136	0.074	-0.015	0.187	0.122
22	-0.109	-0.071	-0.078	-0.111	0.006	0.038	0.058	-0.021	-0.035	-0.126	-0.078	-0.245	-0.045

	X (14) 14	X(15) 15	X(16) 16	X(17) 17	X(18) 18	X(19) 19	X(20) 20	X(21) 21	X(22) 22
14	1.000								
15	0.178	1.000							
16	0.013	0.634	1.000						
17	0.226	-0.243	-0.062	1.000					
18	-0.124	-0.136	0.008	-0.159	1.000				
19	0.069	-0.162	-0.075	0.356	-0.225	1.000			
20	0.144	-0.019	-0.016	0.113	-0.137	0.464	1.000		
21	-0.130	0.094	0.134	-0.074	0.270	-0.080	-0.138	1.000	
22	0.203	-0.135	-0.044	0.202	0.202	0.057	0.289	-0.041	1.000

TABLE VI.5 AVERAGE LINKAGE CLUSTERING OF CHARACTERS

VARIABLE NO.	OTHER BOUNDARY OF CLUSTER	NUMBER OF ITEMS IN CLUSTER	DISTANCE OR SIMILARITY WITH CLUSTER FORMED
1	9	22	9.63
2	4	2	87.85
4	1	3	70.49
19	20	2	45.43
20	1	5	23.92
12	13	3	40.18
14	12	2	78.70
13	1	8	25.63
18	21	2	26.97
21	1	10	15.71
17	22	2	29.17
22	1	12	14.64
3	9	10	12.63
10	11	2	57.05
11	3	3	37.93
15	16	2	63.41
16	3	5	17.32
5	9	5	18.69
6	5	2	70.09
7	5	3	56.17
8	9	2	29.28
9	1	22	9.63

FIG.VI. 1 CLUSTERING OF CHARACTERS BY AVERAGE DISTANCE METHOD

(Number of cultivars of Piper nigrum L. = 51)

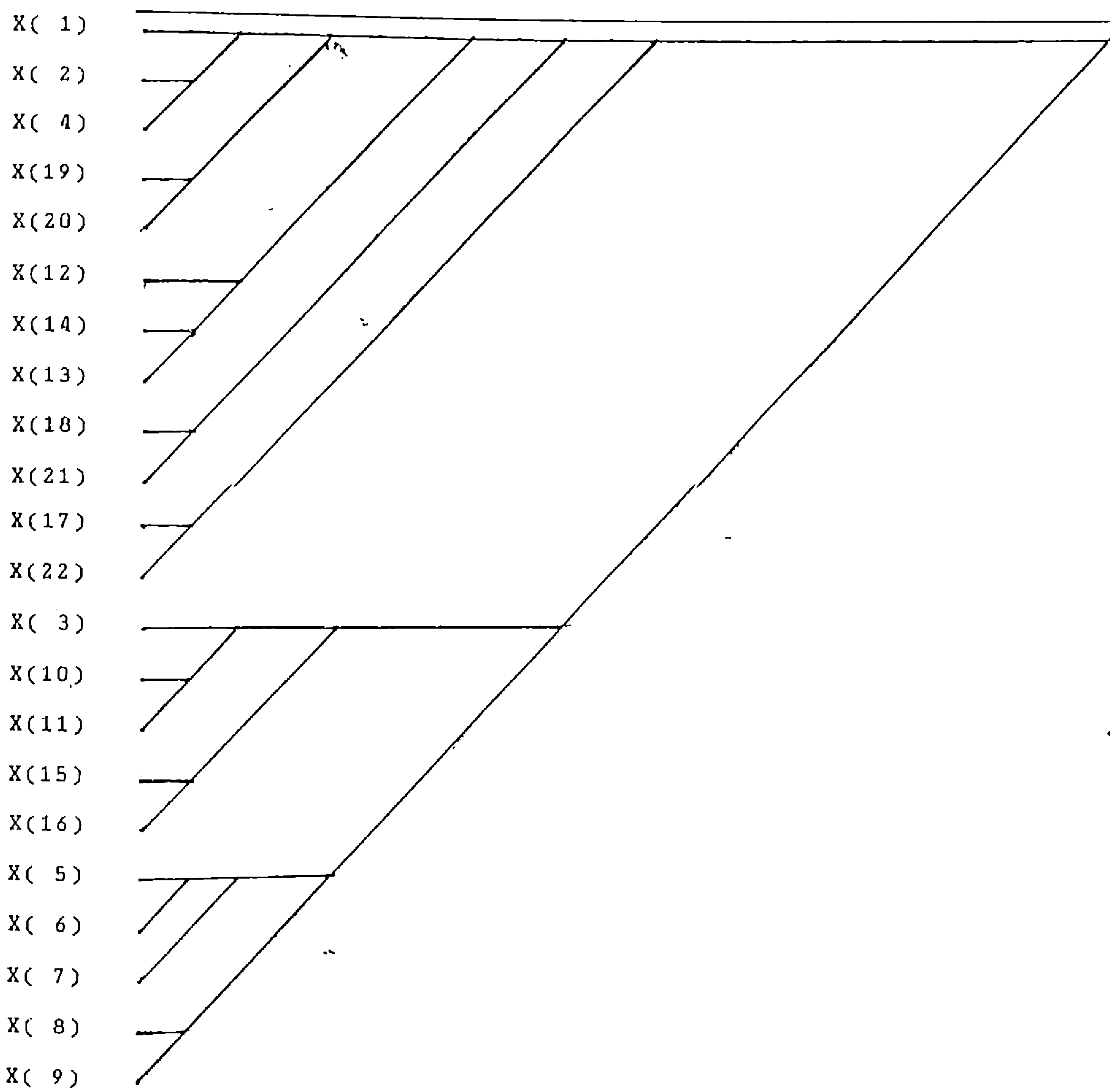
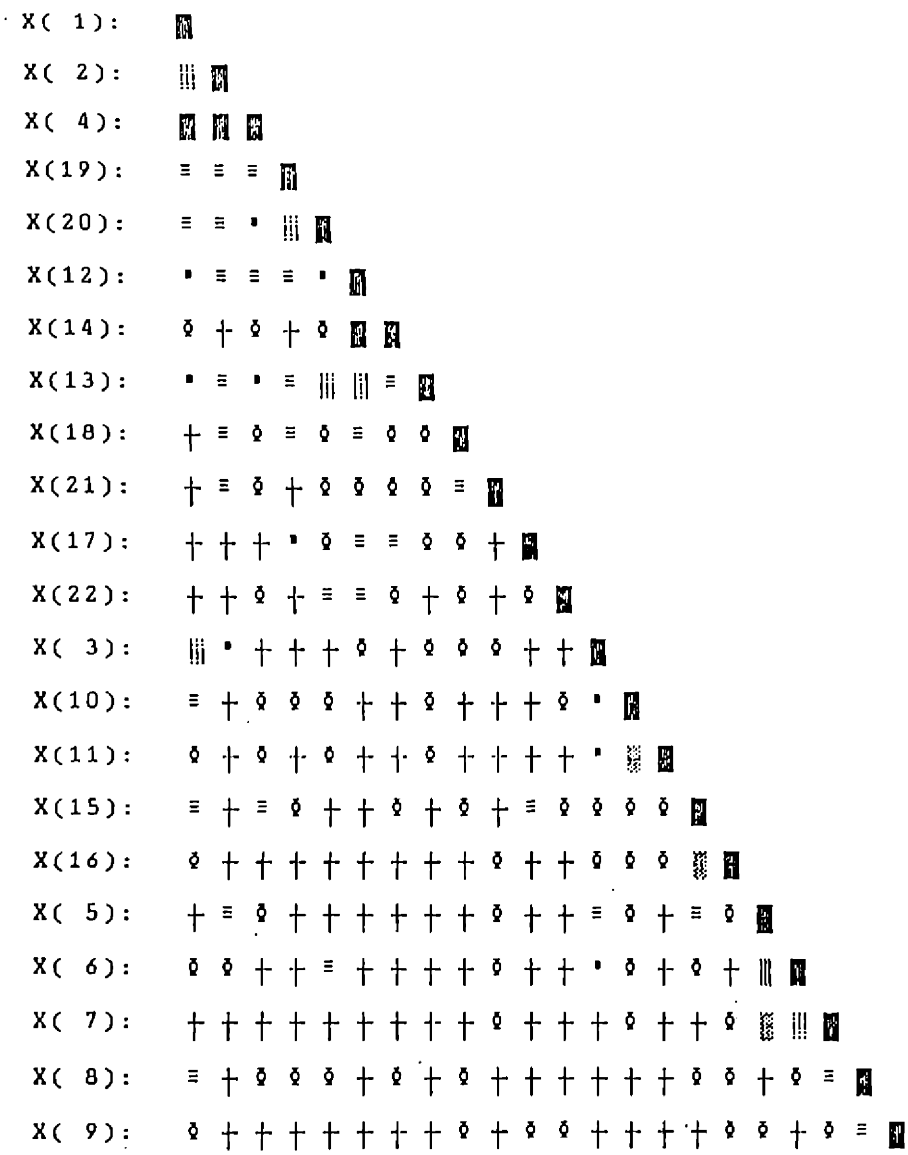


FIG. VI. 2 AVERAGE LINKAGE OF CHARACTERS : ABSOLUTE VALUES OF CORRELATION IN SORTED AND SHADED FORM.



EXPLANATION :

▓ : Correlation Coeff.> 0.769

‖ : Correlation Coeff.between 0.659 - 0.769

▒ : Correlation Coeff.between 0.550 - 0.659

⁞ : Correlation Coeff.between 0.440 - 0.550

▪ : Correlation Coeff.between 0.330 - 0.440

≡ : Correlation Coeff.between 0.220 - 0.330

ǒ : Correlation Coeff.between 0.111 - 0.220

† : Correlation Coeff. < 0.111

starting from character 3 down to 9. These two sets of characters do not overlap as is seen from the tree diagram.

The character groupings are further brought out in the shaded diagram in fig. 6.2. The following character groupings are distinguishable:

1. Leaf length, leaf breadth and leaf size index.
2. Fruit shape and fruit size
3. Spike length, L.L/Sp.L and peduncle length
4. L.L/L.B, guard cell length, guard cell breadth
5. Leaf shape, leaf base
6. Leaf thickness, upper epidermal thickness and lower epidermal thickness

However, characters such as leaf shape of orthotropic shoot, colour of the new shoot, leaf margin, spike shape , mesophyll thickness and stomatal frequency show lesser degree of relationship with the other characters.

Principal Component Analysis

Principal component analysis was carried out using the 22 characters from the 51 OTU s (cultivars). Table VI.6 gives the factors or principal components along with the variance explained by each factor, the cumulative proportion of variance explained by each factor in data space and factor space. Table VI.7 gives the factor loadings for the eight major principal components or factors. Table VI.8 gives the factor loadings after orthogonal rotation of the factors after rearranging the columns in decreasing order of variance, and simultaneoulsy rearranging the rows so that for

TABLE VI.6 VARIANCE EXPLAINED AND THE CUMULATIVE PROPORTION OF VARIANCE

FACTOR	VARIANCE EXPLAINED	CUMULATIVE PROPORTION OF VARIANCE IN DATA SPACE	IN FACTOR SPACE
1	4.0102	0.1823	0.2437
2	2.8760	0.3130	0.4184
3	2.4823	0.4258	0.5692
4	1.9442	0.5142	0.6874
5	1.4796	0.5815	0.7773
6	1.3124	0.6411	0.8570
7	1.2496	0.6979	0.9329
8	1.1038	0.7481	1.0000
9	0.9272	0.7902	
10	0.8559	0.8292	
11	0.6409	0.8583	
12	0.6075	0.8859	
13	0.5707	0.9118	
14	0.4830	0.9338	
15	0.4576	0.9546	
16	0.3768	0.9717	
17	0.2353	0.9824	
18	0.1875	0.9909	
19	0.0874	0.9949	
20	0.0657	0.9979	
21	0.0422	0.9999	
22	0.0031	1.0000	

THE VARIANCE EXPLAINED BY EACH FACTOR IS THE EIGEN VALUE FOR THAT FACTOR. TOTAL VARIANCE IS DEFINED AS THE SUM OF THE POSITIVE EIGEN VALUES OF THE CORRELATION MATRIX.

Fig. VI. 3. CUMULATIVE PROPORTION OF VARIATION EXPLAINED BY THE FACTORS OF BIOMETRICAL CHARACTERS IN CULTIVARS OF *Piper nigrum* L.

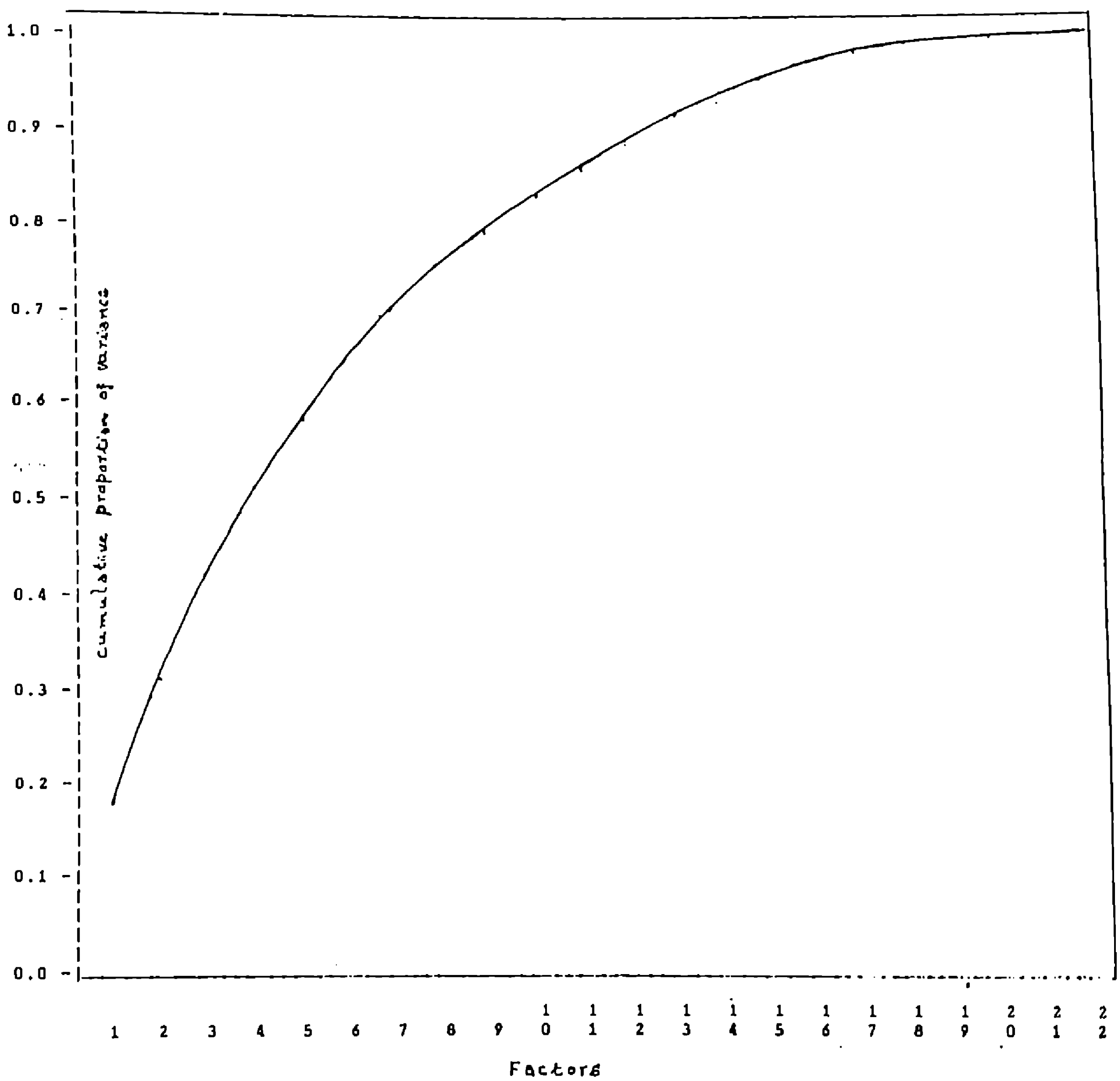


TABLE VI.7 UNROTATED FACTOR LOADINGS FOR EIGHT PRINCIPAL COMPONENTS

VAR. NO.	FACTOR 1	FACTOR 2	FACTOR 3	FACTOR 4	FACTOR 5	FACTOR 6	FACTOR 7	FACTOR 8
1	0.791	0.126	0.306	0.295	-0.001	0.098	-0.013	-0.244
2	0.643	-0.363	-0.172	0.483	0.193	0.169	-0.008	-0.136
3	0.239	0.573	0.464	-0.237	-0.090	0.057	-0.000	-0.063
4	0.817	-0.123	0.086	0.441	0.146	0.161	-0.021	-0.202
5	-0.166	0.854	-0.192	0.151	0.236	-0.092	0.037	-0.194
6	0.095	0.789	-0.052	0.223	0.040	-0.282	-0.006	0.033
7	0.010	0.638	-0.054	0.400	-0.079	-0.214	0.012	0.012
8	-0.272	0.330	-0.435	-0.050	0.485	0.042	0.154	-0.324
9	-0.174	0.020	-0.206	-0.126	0.663	0.252	-0.275	0.155
10	0.302	0.418	0.389	-0.225	0.178	0.336	0.234	0.270
11	0.299	0.296	0.365	-0.259	0.120	0.315	0.141	0.452
12	0.617	0.137	-0.488	-0.367	-0.249	0.061	0.119	-0.197
13	0.613	0.139	-0.228	-0.050	-0.323	0.105	0.047	0.084
14	-0.194	-0.135	0.577	0.590	0.302	-0.066	-0.155	0.148
15	0.370	-0.208	0.581	-0.263	0.222	-0.386	-0.005	-0.142
16	0.252	-0.123	0.460	-0.346	0.155	-0.439	0.343	-0.254
17	-0.302	0.039	0.243	0.375	-0.360	0.361	0.232	-0.135
18	0.233	-0.128	-0.441	0.177	0.123	-0.229	0.516	0.281
19	-0.507	0.092	0.226	-0.022	-0.027	0.483	0.291	-0.336
20	-0.615	-0.167	0.214	-0.013	0.034	0.007	0.289	-0.276
21	0.283	-0.286	-0.228	-0.098	0.377	0.152	0.406	-0.005
22	0.265	-0.069	0.039	0.384	-0.094	-0.184	0.512	0.310

TABLE VI.8 SORTED, ROTATED FACTOR LOADINGS FOR THE EIGHT PRINCIPAL COMPONENTS

VAR. NO.	FACTOR 1	FACTOR 2	FACTOR 3	FACTOR 4	FACTOR 5	FACTOR 6	FACTOR 7	FACTOR 8
1	0.970	0.000	0.000	0.000	0.000	0.000	0.000	0.000
2	0.876	0.000	0.000	0.000	0.000	0.000	0.000	0.000
1	0.823	0.000	0.000	0.000	0.000	0.000	0.000	0.000
5	0.000	0.875	0.000	0.000	0.000	0.000	0.000	0.000
6	0.000	0.851	0.000	0.000	0.000	0.000	0.000	0.000
7	0.000	0.757	0.000	0.000	0.000	0.000	0.000	0.000
14	0.000	0.000	-0.906	0.000	0.000	0.000	0.000	0.000
12	0.000	0.000	0.891	0.000	0.000	0.000	0.000	0.000
13	0.341	0.000	0.528	0.000	0.000	0.000	-0.255	0.000
11	0.000	0.000	0.000	0.840	0.000	0.000	0.000	0.000
10	0.000	0.000	0.000	0.833	0.000	0.000	0.000	0.000
3	0.000	0.368	0.000	0.545	0.000	0.273	0.000	-0.343
19	0.000	0.000	0.000	0.000	0.816	0.000	0.000	0.000
17	0.000	0.000	0.000	0.000	0.641	-0.256	-0.332	0.000
20	-0.344	0.000	-0.253	0.000	0.577	0.000	0.000	0.000
16	0.000	0.000	0.000	0.000	0.000	0.885	0.000	0.000
15	0.000	0.000	0.000	0.000	0.000	0.795	0.000	0.000
9	0.000	0.000	0.000	0.000	0.000	0.000	0.727	0.000
8	0.000	0.358	0.000	0.000	0.000	0.000	0.700	0.000
18	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.779
22	0.000	0.000	-0.290	0.000	0.000	0.000	0.000	0.643
21	0.267	-0.297	0.000	0.000	0.000	0.000	0.388	0.416

each successive factor loadings greater than 0.5 appear first, loadings less than 0.25 have been replaced by zero. The advantage of presenting the factor loadings in this way is that the factors which have higher loadings on any set of characters can be interpreted as representing the corresponding set of character.

Table VI.9 gives the estimated factor scores for each of the 51 cultivars. Fig. 6.3 shows the increase in the cumulative proportion of variance explained by successive factors by means of a curve. It is seen from this figure that there is a steady increase in variance explained upto first eight factors and afterwards the further increase is tapering off. Table VI.8 also shows that the first eight factors explain the whole of variance in factor space and hence the first eight factors are taken into consideration for further studies.

As regards Factor 1 in Table VI.8, the loadings are high for the set of characters leaf size index, leaf breadth and leaf length (4,2,1). Comparing this with the process of linkage or clustering of characters (Fig. 6.2) we see that the above set of characters are in one group thus confirming the results of cluster analysis.

Factor 2 shows high loadings on characters leaf thickness, lower epidermal thickness and upper epidermal thickness (5,6,7). From the results of the average linkage analysis

TABLE VI.9 ESTIMATED FACTOR SCORRES FOR 51 CULTIVARS

OTU NO.	FACTOR 1	FACTOR 2	FACTOR 3	FACTOR 4	FACTOR 5	FACTOR 6	FACTOR 7	FACTOR 8
1	-Ø.521	Ø.278	Ø.142	Ø.Ø26	-Ø.846	-Ø.415	-1.118	2.476
2	Ø.548	-Ø.7Ø9	Ø.686	-Ø.669	Ø.935	-Ø.411	-1.875	-Ø.781
3	-1.593	-1.34Ø	Ø.122	Ø.Ø8Ø	-Ø.2Ø6	-Ø.49Ø	Ø.693	-Ø.145
4	2.225	Ø.887	Ø.513	Ø.142	-Ø.1Ø9	2.Ø84	-Ø.8Ø8	-Ø.458
5	-Ø.Ø15	-1.8Ø4	-Ø.367	Ø.Ø89	-Ø.851	-1.Ø4Ø	Ø.Ø93	-Ø.337
6	-Ø.985	-Ø.695	Ø.727	Ø.341	1.832	Ø.Ø67	Ø.664	-Ø.677
7	Ø.578	1.494	Ø.263	-Ø.576	1.739	-Ø.Ø2Ø	Ø.229	-Ø.426
8	-1.161	-Ø.Ø13	Ø.142	Ø.22Ø	Ø.176	2.943	-Ø.Ø45	-Ø.677
9	-1.549	-Ø.3Ø4	Ø.ØØ9	-Ø.183	-Ø.Ø52	2.667	Ø.542	-Ø.281
1Ø	-Ø.Ø31	-1.199	-Ø.374	-1.798	-Ø.387	2.159	-1.473	Ø.144
11	-Ø.5Ø3	-1.Ø7Ø	-Ø.542	-Ø.129	-Ø.652	Ø.472	1.241	-Ø.912
12	-Ø.7Ø5	-Ø.Ø46	Ø.714	1.Ø91	1.484	Ø.838	Ø.Ø54	-Ø.226
13	-Ø.224	-1.173	2.Ø68	Ø.643	-Ø.775	-Ø.929	-2.1Ø1	-Ø.538
14	-Ø.ØØ9	Ø.521	-1.513	1.Ø16	Ø.126	-Ø.124	-Ø.424	3.Ø18
15	Ø.12Ø	Ø.383	-Ø.372	Ø.445	-Ø.395	-Ø.346	Ø.964	-Ø.513
16	-Ø.648	Ø.722	1.141	Ø.337	-Ø.594	1.374	Ø.224	Ø.912
17	Ø.135	Ø.478	Ø.383	-2.182	-Ø.595	-Ø.Ø85	Ø.139	Ø.654
18	Ø.912	1.Ø88	-Ø.387	-Ø.122	1.519	-Ø.683	Ø.672	-Ø.276
19	-Ø.237	Ø.778	-2.134	-1.773	Ø.573	-Ø.471	-1.474	1.456
2Ø	Ø.66Ø	-1.266	1.844	-2.8Ø7	-Ø.171	-Ø.361	Ø.243	Ø.927
21	Ø.Ø84	Ø.898	Ø.843	-1.393	-Ø.4Ø2	-Ø.378	Ø.6Ø7	-Ø.598
22	-Ø.889	-Ø.Ø42	-Ø.Ø59	-Ø.Ø63	-Ø.421	-Ø.Ø5Ø	-1.Ø95	-Ø.599
23	Ø.8Ø1	Ø.639	-Ø.722	-Ø.821	Ø.222	-1.Ø42	Ø.459	-Ø.353
24	-1.155	-Ø.167	-Ø.434	Ø.36Ø	2.634	Ø.176	-Ø.265	1.775

25	Ø.872	-Ø.936	-Ø.573	-Ø.257	-Ø.711	-Ø.514	-1.116	-Ø.598
26	-1.876	Ø.2Ø7	-Ø.7Ø4	-Ø.521	1.152	Ø.ØØ6	1.647	-Ø.654
27	Ø.13Ø	-Ø.921	-Ø.829	Ø.25Ø	2.552	-Ø.523	Ø.6Ø2	-Ø.478
28	-Ø.9Ø1	Ø.419	Ø.63Ø	Ø.525	-Ø.542	-Ø.5Ø4	-1.154	Ø.131
29	1.869	-2.Ø82	1.448	Ø.628	Ø.151	Ø.955	2.717	2.915
3Ø	Ø.6Ø9	-1.Ø37	Ø.19Ø	Ø.567	Ø.476	-Ø.6Ø8	1.145	-Ø.741
31	Ø.326	Ø.355	Ø.6Ø8	Ø.289	-Ø.33Ø	-Ø.33Ø	Ø.Ø69	-Ø.7Ø9
32	Ø.32Ø	1.3Ø8	1.5Ø9	Ø.342	-Ø.579	-Ø.559	Ø.829	1.234
33	1.226	Ø.115	-Ø.98Ø	-Ø.126	-1.Ø31	-Ø.829	Ø.573	-Ø.676
34	Ø.886	-1.211	-Ø.15Ø	-Ø.151	Ø.758	-Ø.349	Ø.322	-Ø.446
35	-1.187	-Ø.617	1.534	Ø.Ø26	-Ø.174	-Ø.82Ø	Ø.125	-Ø.433
36	-Ø.925	1.774	Ø.127	1.568	-Ø.468	-Ø.123	-Ø.Ø96	1.6Ø8
37	Ø.746	2.Ø98	Ø.721	-Ø.858	-Ø.346	-Ø.Ø72	Ø.199	-Ø.538
38	-Ø.1Ø2	1.719	Ø.Ø8Ø	-Ø.744	-1.Ø66	-Ø.238	Ø.7Ø8	-1.Ø62
39	1.588	Ø.673	-Ø.Ø43	3.Ø32	-Ø.486	-Ø.946	1.252	-Ø.7Ø3
4Ø	-1.Ø53	1.626	Ø.81Ø	Ø.8Ø4	Ø.948	-Ø.664	-1.Ø28	-Ø.217
41	-Ø.538	-1.235	Ø.Ø6Ø	Ø.158	-1.518	-1.1Ø6	Ø.276	Ø.814
42	-1.883	1.166	Ø.773	Ø.3Ø4	-1.19Ø	-Ø.457	Ø.2Ø5	-Ø.383
43	Ø.48Ø	Ø.877	-Ø.137	-1.72Ø	Ø.2Ø4	Ø.171	1.411	-1.Ø12
44	-1.86Ø	-1.ØØ8	-2.387	-Ø.434	-1.847	-1.Ø37	-Ø.891	-Ø.143
45	Ø.7Ø5	-Ø.59Ø	Ø.569	-Ø.Ø24	1.321	-Ø.542	-1.418	Ø.49Ø
46	Ø.771	-Ø.361	-1.639	-Ø.Ø14	1.298	-Ø.7Ø8	-1.134	-Ø.446
47	-Ø.185	Ø.Ø38	-2.281	1.242	-Ø.433	1.761	-Ø.293	-Ø.741
48	1.186	-Ø.717	-Ø.387	1.328	-Ø.811	1.285	-Ø.154	-Ø.6Ø1
49	1.558	Ø.671	-1.867	-Ø.5Ø9	-1.Ø36	Ø.686	Ø.255	1.126
5Ø	Ø.434	-Ø.441	-Ø.357	1.29Ø	-Ø.175	-1.296	-1.494	-Ø.494
51	Ø.967	-Ø.228	-Ø.584	Ø.725	-Ø.896	1.425	-1.484	-Ø.811

presented in Figs. 6.1 & 6.2, we find that both the results agree closely. Thus the above three characters form a distinct group and can be jointly represented by Factor 2.

Factor 3 shows high loadings for the set of characters 14, 12 and 13 (Leaf length-spike length relation, spike length and peduncle length), though for character 14 the loading is negative. Thus these three characters can be represented by Factor 3. Again looking into Fig. 6.2 and the clustering process, we find that in the correlation tree these three characters are inter-related and in the tree diagram of cluster analysis they are grouped together.

Factor 4 has high loadings on guard cell length, guard cell breadth, and leaf length/leaf breadth, though the loadings on L.L/L.B is somewhat less. The three characters are grouped together in the cluster tree diagram (Fig. 6.2). However, in the correlation tree also, the correlation between L.L/L.B; guard cell length and guard cell breadth are in the range of Ø.33 to Ø.44 only. Hence it will be better to consider guard cell length and guard cell breadth as separate group for all practical purposes and thus Factor 4 can be taken as representing guard cell length and guard cell breadth.

Factor 5 shows high loadings on characters 19 (fruit shape), 2Ø (fruit size) and 17 (leaf margin). However, taking the clustering process in Fig. 6.1 we see that the character fruit shape is grouped with fruit size and the linkage of these two characters with leaf margin is rather distant. From the correlation tree in Fig. 6.2 it is seen that the correlation between leaf margin and fruit shape is less than Ø.111 and that between leaf margin and fruit size is in the range Ø.33 - Ø.44. Thus it is better to take Factor 5 as representing the fruit characteristics, fruit size and fruit shape.

Factor 6 shows high loadings on characters 15 and 16 (leaf shape of lateral branch and leaf base). The grouping is the same in cluster tree (Fig. 6.1) as well as in the correlation tree (Fig. 6.2). Thus Factor 6 represents leaf shape and leaf base.

Factor 7 shows high loading on characters 9 and 8 (stomatal frequency and mesophyll thickness). In the cluster analysis also these two characters were grouped together (Fig. 6.1); however, in the correlation tree (Fig. 6.2) we find that the correlation between these two characters is only in the range of Ø.22 - Ø.33.

Factor 8 shows high loading on characters 18 (leaf shape of orthotropic shoot), 22 (spike shape) and 21 (colour of the new shoot). However, in the clustering process there is a close link between character 18 and 21 obviously due to the fact that both representing orthotropic shoot characters and the linkage of these two characters with 22 (spike shape) is rather distant. In the correlation tree also (Fig. 6.2) spike shape has very low correlation with the other two characters (leaf shape and colour of the new shoot). Thus Factor 8 may be taken as representing characters 18 and 21.

The factors emerging out from the analysis are given below:

Factor 1. Leaf size index, leaf length, leaf breadth.

Factor 2. Leaf thickness, lower epidermal thickness, upper epidermal thickness.

Factor 3. Leaf length-spike length ratio, spike length and peduncle length.

Factor 4. Guard cell length and guard cell breadth.

Factor 5. Fruit size and fruit shape.

Factor 6. Leaf shape and leaf base.

Factor 7. Stomatal frequency and mesophyll thickness.

Factor 8. Leaf shape (orthotropic shoot) and colour of the shoot tip.

The above analysis shows that principal component itself is a good tool for grouping characters into meaningful factors, it is also useful to compare it with cluster analysis to resolve the issue in a much better way.

Grouping of cultivars by centroid linkage

Table VI.10 gives the details of centroid linkage of 51 cultivars. This table gives the order of successive amalgamation of cultivars (OTUs), the OTUs involved in each amalgamation step, the number of OTUs at each step and the distance.

1. OTUs 9 & 8 (Jeerakamundi and Cholamundi) were combined at a distance of 2.446.

2. OTUs 23 & 18 (Mundi and Kuching) were combined at a distance of 2.843

3. OTUs 31 & 15 (Perumkodi and Kalluvally 2) were combined at a distance of 3.028.

4. To the group formed at step 3 OTU 30 (Perambramunda) was clubbed at an overall distance of 3.059.

5. OTUs 51 & 48 (wild collections 2062 and 2059) were combined at a distance of 3.101.

6. OTUs 34 (Thevanmundi) was clubbed with the cluster formed at step (4) at an overall distance of 3.109. OTU 33 (Sagar Local) was clubbed to the above formed group at a distance of 3.266.

7. OTUs 45 and 2 (wild coll. 2077 and Arakkulam munda) were combined at a distance of 3.291.

8. OTUs 28 & 22 (Ottaplackal 1 and Malamundi) were clustered at a distance of 3.392.

9. To the cluster formed at step 6, OTU 25 (Neelamundi) was added at an overall distance of 3.397.

10. The OTUs Vattamundi and Bilimalligesara were combined at a distance of 3.591.

11. The cluster formed at step 10 was clubbed with the cluster formed at step 9 at an overal distance of 3.479. This cluster was then clubbed with the cluster formed at step 8 at an overall distance of 3.571.

12. The OTU's 38 & 37 (Uthirancotta and Uddakere) were

TABLE VI.10 : CENTROID LINKAGE OF PEPPER CULTIVARS:-

No.	Cases	No. of Cases	Distance
1.	9, 8	2	2.446
2.	23, 18	2	2.843
3.	31, 15	2	3.028
4.	51, 48	2	3.101
5.	34, 30	2	3.139
6.	33, 15	3	3.286
7.	30, 15	5	3.059
8.	45, 2	2	3.291
9.	28, 22	2	3.392
10.	25, 15	6	3.397
11.	22, 15	8	3.571
12.	41, 5	2	3.591
13.	15, 5	10	3.479
14.	38, 37	2	3.592
15.	21, 17	2	3.610
16.	17, 5	12	3.571
17.	27, 6	2	3.640
18.	48, 4	3	3.671
19.	5, 2	14	3.173
20.	50, 2	15	3.627
21.	18, 2	17	3.699
22.	11, 3	2	3.878
23.	35, 2	18	3.947
24.	3, 2	20	3.887
25.	6, 2	22	3.913

26.	42, 40	2	4.059
27.	46, 2	23	4.182
28.	43, 2	24	4.204
29.	40, 37	4	4.218
30.	37, 2	28	3.857
31.	16, 12	2	4.477
32.	12, 2	30	3.946
33.	36, 32	2	4.509
34.	32, 2	32	4.512
35.	14, 1	2	4.715
36.	2, 1	34	4.467
37.	8, 1	36	4.817
38.	7, 1	37	4.963
39.	49, 1	38	5.210
40.	13, 1	39	5.267
41.	4, 1	42	5.224
42.	47, 1	43	5.630
43.	24, 19	2	5.707
44.	19, 1	45	5.343
45.	10, 1	46	5.728
46.	44, 26	2	5.811
47.	26, 1	48	5.286
48.	20, 1	49	6.445
49.	39, 1	50	6.727
50.	29, 1	51	8.650

combined at a distance measure of 3.592.

13. The OTU s 21 & 17 (Kurimalai and Kottanadan) were clustered at a distance of 3.610 and this cluster was then amalgamated with the cluster formed at step 11 at an overall distance measure of 3.571.

14. OTUs 27 & 6 (Neyyattinkaramundi and Cheriyakanikkadan) were clustered at a distance of 3.640.

15. OTU 4 (Balancotta) was clubbed with the cluster formed at step 5 at an overall distance of 3.671.

16. The cluster formed at step 11 was combined with the cluster formed at step 13 at an overall distance of 3.730.

To this cluster OTU (wild coll. 2015) was added. This cluster is then clubbed with the cluster formed at step 2 at an overall distance of 3.70. OTU 3 (Arimulaku) was combined to the above cluster at a distance of 3.867. OTU 11 (Kaniakkadan) was then joined to the above cluster, the distance being 3.878. The cluster formed at step 14 was then combined to the above cluster at an overall distance of 3.913. OTU 35 (Thommankodi) was combined with the above cluster at an overall distance of 3.947.

17. OTU 42 & 40 (Vellanamban and Valiakaniakkadan) were combined at a distance of 4.059.

18. Coll. 2071 (OTU 46) was combined to the cluster formed at step 17 atadistance of 4.182. OTU 43 was then added to this cluster at a distance of 4.204.

19. The cluster formed at step 12 was added to the cluster

formed at step 18 and to this group was added OTU 12 (Karivilanchy), and OTU 16 (Kallubalancotta) with an overall distance of 4.477.

20. OTUs 36 & 32 (Poonjaranmunda and Thulamundi) were clubbed and the cluster so formed was then combined with the cluster formed at step 19 at an overall distance of 4.512. To this cluster OTUs 1 & 14 (Aimpiriyan and Kalluvally 1) were clubbed and the cluster so formed was combined with the cluster formed at step 1 at an overall distance of 4.842. To this cluster the OTU's 7 (Cheppukulamundi), 49 (wild coll.2060), 13 (Karimkotta), 4 (Balancotta) and 47 (Coll. 2009) were sequentially combined at an overall distance of 5.630.

21. OTUs 24 and 19 (Narayakodi and Kuriyalmundi) were clustered with the cluster formed earlier. To the cluster so formed the following OTUs were added independently and sequentially: 10 (Karimunda), 44 (Vokkalu), 26 (Nedumchola), 20 (Kuthiravally), 39 (Vadakkan) and finally 29 (Panniyur 1), the final overall distance being 8.650.

The grouping of 51 cultivars is shown in the form of a dendrogram in Fig. 6.4. From this it could be seen that cultivars could be arranged into distinct groups. The intercultivar distances represented in the form of distance matrix in shaded form in Fig. 6.5 shows patterns of such groupings. This matrix is presented in a sorted format and concentration of heavy shades indicate the groupings of

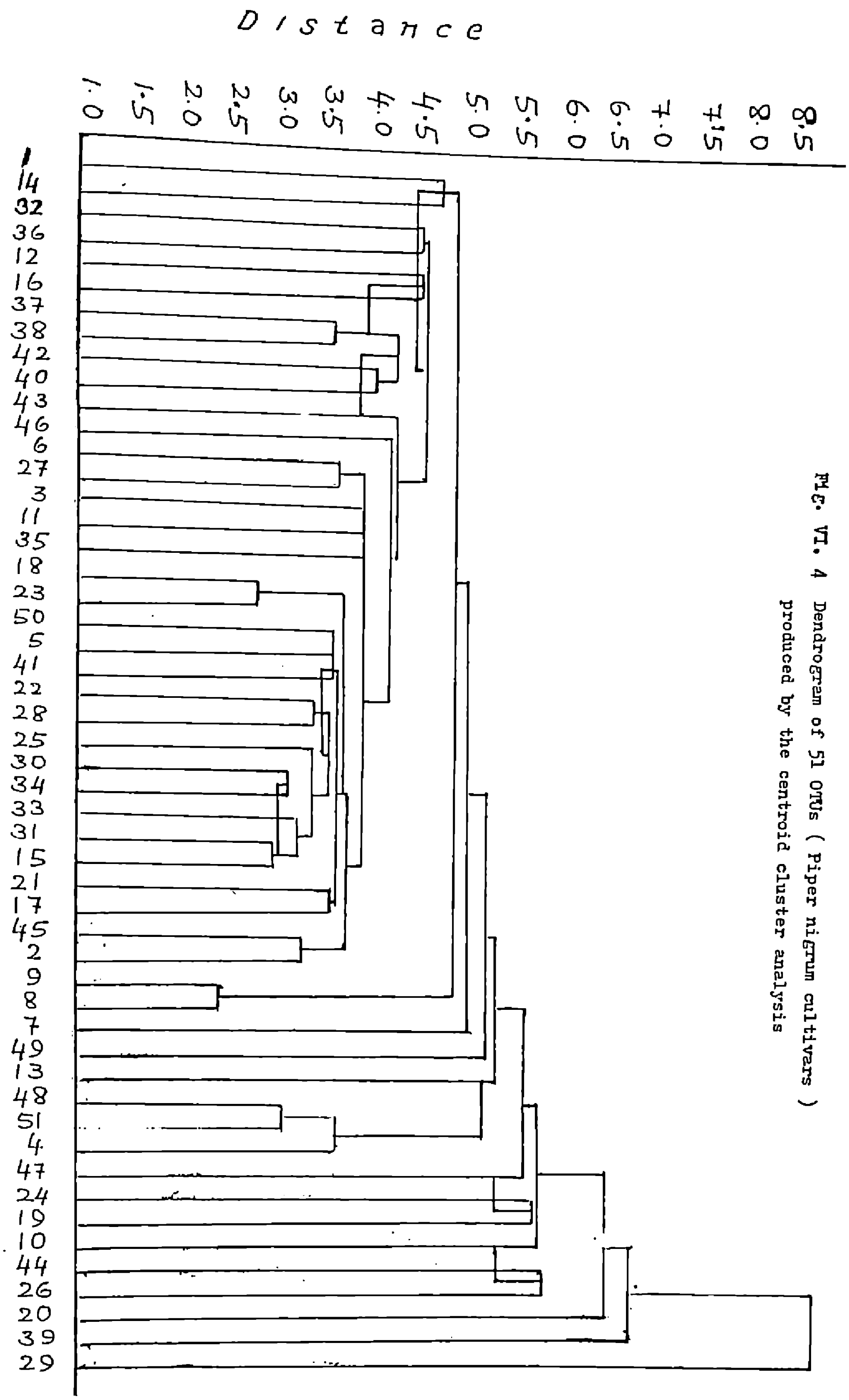


Fig. VI. 4 Dendrogram of 51 OTUs (Piper nigrum cultivars) produced by the centroid cluster analysis related cultivars. In order to be more accurate the cultivars were grouped using Tocher's method (Rao, 1952). In other words successive cultivars were added to a minimal group of closely related pair of cultivars and for each such addition the ratio of increase in D^2 to the increase in number of cultivars in the grouping was worked out and whereever the ratio showed sudden increase the grouping was stopped with the previously included cultivars. Thus 11 distinct clusters of cultivars were identified. The inter and intracluster distances for these 11 groups of cultivars are shown in Fig. 6.6 in a matrix of shades. From this figure it can also be concluded that groups B is somewhat close to group C, and to some extent group B, C and D are related. However the other groups are distinct from one another.

The eleven groups and the cultivars included in each of them are given below:

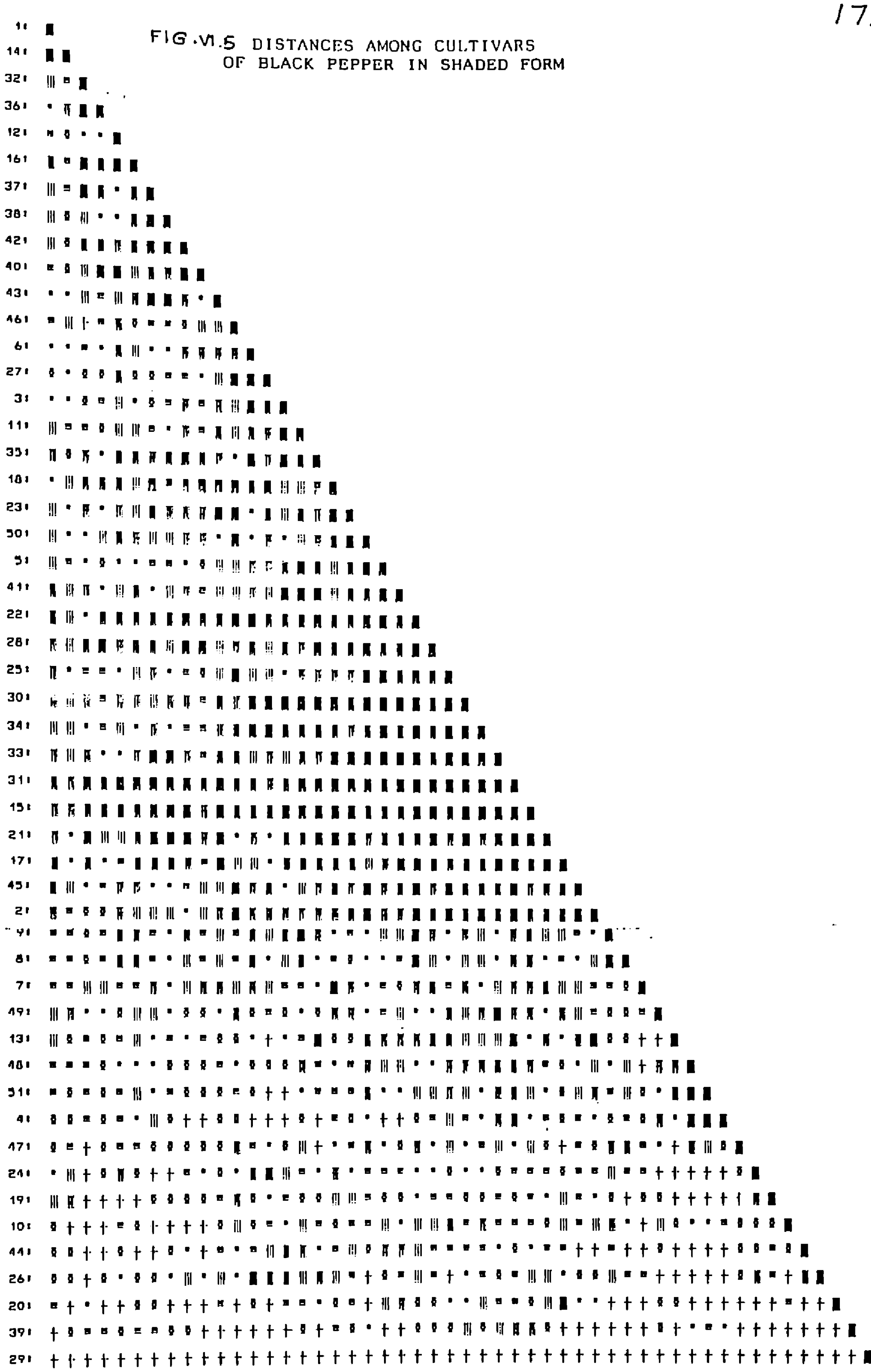
Group A. OTU Nos. 1 & 14. (Cvs. Aimpiriyan & Kalluvally)

Group B. OTU Nos. 32 & 36 (Poonjaranmunda & Thulamundi)

Group C. OTU Nos. 12, 16, 37, 38, 40, 42, 43 (Karivilanchy, Kallubalancotta, Udakkere, Uthirancotta, Vellanamban. Valiakaniakkadan and Velliyarenmunda).

Group D. OTU Nos. 46, 6, 27, 3, 11, 35, 18, 23, 50, 5, 41,22, 28, 25, 30, 34, 33, 31, 15, 21,17, 45, 2,9, 8, 7, 49, 13 (Wild coll. 2071; Cheriyakaniakkadan, Neyyattinkaramundi, Arimulaku, Kaniakkadan, Thommankodi, Kuching, Mundi, Wild coll.

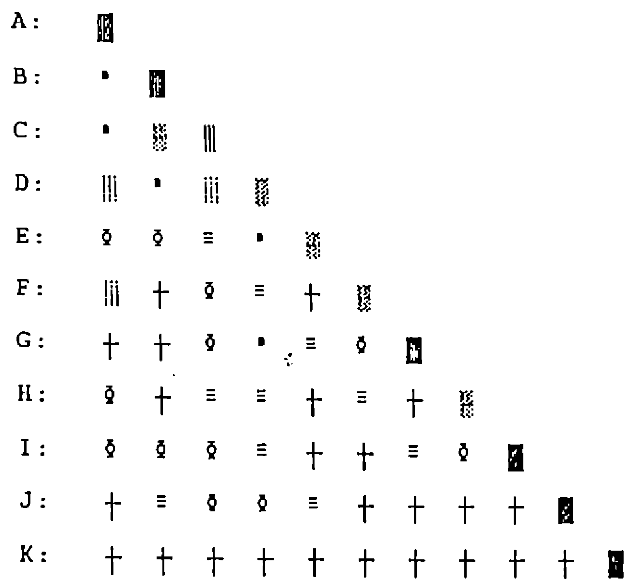
FIG.VI.5 DISTANCES AMONG CULTIVARS OF BLACK PEPPER IN SHADED FORM



EXPLANATION:

- Distance between OTVs < 4.910
- Distance between OTVs 4.910 - 5.499
- Distance between OTVs 5.499 - 5.971
- Distance between OTVs 5.971 - 6.403
- Distance between OTVS 6.403 - 6.796
- Distance between OTVs 6.796 - 7.306
- Distance between OTVs 7.306
- Distance between OTVs > 8.013

FIG. VI. 6 INTER AND INTRA-CLUSTER DISTANCES AMONG CULTIVARS OF *Piper nigrum* L. IN SHADED FORM



CLUSTER A:	OTU	NOs	1,14
CLUSTER B:	OTU	NOs	32,36
CLUSTER C:	OTU	NOs	12,16,37,38,40,42,43
CLUSTER D:	OTU	NOs	2,3,5,6,7,8,9,11,13,15,17,18,21,22,23, 25,27,28,30,31,33,34,35,41,45,46,49,50
CLUSTER E:	OTU	NOs	48,51,4,47
CLUSTER F:	OTU	NOs	24,19
CLUSTER G:	OTU	NO	10
CLUSTER H:	OTU	NOs	44,26
CLUSTER I:	OTU	NO	20
CLUSTER J:	OTU	NO	39
CLUSTER K:	OTU	NO	29

EXPLANATION :

- : Distance between OTUs < 4.910
- : Distance between OTUs 4.910 - 5.499
- : Distance between OTUs 5.499 - 5.971
- : Distance between OTUs 5.971 - 6.403
- : Distance between OTUs 6.403 - 6.796
- : Distance between OTUs 6.796 - 7.306
- : Distance between OTUs 7.306 - 8.013
- : Distance between OTUs > 8.013

2015, Billimalligesara, Vattamundi, Malamundi, Ottaplackal, Neelamundi, Perambramunda, Thevanmundi, Sagar Local, Perumkodi, Kaluvally (2), Kurimalai, Kottanadan, Wild coll. 2077, Arakkulam munda, Jeerakamundi, Cholamundi, Cheppukulamundi, Wild coll. 2060, Karimkotta).

Group E. OTU Nos. 48, 51, 4, 47 (Wild coll. 2059, 2062, Balancotta, wild coll. 2009).

Group F. OTU Nos. 24, 19 (Narayakkodi, Kuriyalmundi)

Group G. OTU 10 (Karimunda)

Group H. OTU Nos. 44, 26 (Vokkalu and Nedumchola)

Group I. OTU 20 (Kuthiravally)

Group J. OTU 39 (Vadakkan)

Group K. OTU 29 (Panniyur 1)

The pattern of grouping shows that 28 of the 51 black pepper cultivars fall in just one group (Group 4), and four groups have just one cultivar each. Thus Karimunda, Kuthiravally, Vadakkan and Panniyur 1, got into independent groups, which indicates their uniqueness among the pepper cultivars.

The dispersion of cultivars in factor space:

The grouping of the 51 cultivars presented above has taken into consideration all the 22 characters with their individual identity. However, it is also worthwhile to consider the dispersion of cultivars with respect to any specific group of characters. It is possible to construct a dispersion map of the cultivars by plotting the factor scores of the cultivars, so that it is possible to generate dispersion of the cultivars between any two principal components. Figs. 6.7 to 6.12 show the dispersion patterns with regard to first four factors or principal components, each taking two factors at a time. In these figures it can be interpreted, that certain cultivars with large values (+ve or -ve) on the X-axis are said to differ from others for the corresponding factor represented by the X-axis; similarly the cultivars showing large value (+ve or -ve) on the Y-axis are said to differ from others for the corresponding factor represented by the Y-axis. Nevertheless, it may be seen from the Figs. 6.7 and 6.12 that studying the dispersion patterns of the original set of cultivars in factor space taking two factors at a time is a tedious process and may not lead to any clear conclusions as the grouping pattern will differ obviously for any two sets of factors taken at a time.

One useful method of studying the dispersion in factor space would be to examine in detail the role of individual factors on the grouping of cultivars that has been already arrived at in data space, rather than examining the regrouping on a fresh basis based on individual factors. To do this the intra and inter cluster D^2 (Mahalanobis-D^2) were computed for each group that had already been arrived at and their combinations thereof (Tables 6.11,12) For each factor in this table the clusters were sorted again in the order of D^2 value. For a minimal set of 2 closest clusters additional

TABLE VI.11. AVERAGE INTRA-CLUSTER D^2 VALUES IN FACTOR SPACE

(F1 and F2 etc. are the Factors; A-K are the Groups)

	F - 1	F - 2	F - 3	F - 4	F - 5	F - 6	F - 7	F - 8	Total Dsqr
A	Ø.26	Ø.Ø6	2.74	Ø.98	Ø.94	Ø.Ø8	Ø.48	Ø.29	5.85
B	1.55	Ø.22	1.91	1.5Ø	Ø.Ø1	Ø.19	Ø.86	Ø.14	6.38
C	1.65	1.Ø5	Ø.4Ø	2.Ø7	2.Ø4	1.Ø7	1.Ø8	Ø.87	1Ø.22
D	1.5Ø	1.41	1.43	Ø.86	2.Ø8	1.89	1.82	Ø.51	11.5Ø
E	1.95	Ø.9Ø	3.56	Ø.6Ø	Ø.26	Ø.26	Ø.73	Ø.Ø5	8.31
F	Ø.84	Ø.89	2.89	4.55	4.25	Ø.42	1.46	Ø.1Ø	15.41
G	Ø.ØØ	Ø.ØØ	Ø.ØØ	Ø.ØØ	Ø.ØØ	Ø.ØØ	Ø.ØØ	Ø.ØØ	Ø.ØØ
H	Ø.ØØ	1.48	Ø.45	Ø.Ø1	8.99	1.Ø9	Ø.57	Ø.26	12.85
I	Ø.ØØ	Ø.ØØ	Ø.ØØ	Ø.ØØ	Ø.ØØ	Ø.ØØ	Ø.ØØ	Ø.ØØ	
J	Ø.ØØ	Ø.ØØ	Ø.ØØ	Ø.ØØ	Ø.ØØ	Ø.ØØ	Ø.ØØ	Ø.ØØ	
K	Ø.ØØ	Ø.ØØ	Ø.ØØ	Ø.ØØ	Ø.ØØ	Ø.ØØ	Ø.ØØ	Ø.ØØ	

TABLE VI.12. AVERAGE INTER-CLUSTER D^2 VALUES IN FACTOR SPACE

(F1, F2 etc. are the Factors; A, B, C etc. are the Groups)

	F - 1	F - 2	F - 3	F - 4	F - 5	F - 6	F - 7	F - 8	TOTAL Dsqr
A, B	Ø.45	1.37	9.42	Ø.81	Ø.27	Ø.Ø7	1.63	1.87	9.89
A, C	Ø.81	1.Ø5	2.47	1.53	1.19	Ø.64	1.63	1Ø.1Ø	19.43
A, D	Ø.89	1.16	1.84	1.Ø2	1.46	Ø.93	1.53	9.72	18.54
A, E	2.52	Ø.52	2.11	Ø.58	Ø.38	3.76	Ø.4Ø	11.65	21.91
A, F	Ø.46	Ø.25	1.77	2.89	5.15	Ø.14	Ø.5Ø	1.38	12.53
A, G	Ø.12	2.57	Ø.78	5.62	Ø.24	5.92	Ø.61	6.85	22.71
A, H	2.64	1.Ø2	2.66	1.24	2.48	Ø.35	4.42	1Ø.Ø3	24.86
A, I	Ø.92	2.79	7.Ø8	11.32	Ø.27	Ø.Ø3	1.15	3.39	26.95
A, J	3.5Ø	Ø.Ø9	1.1Ø	6.55	Ø.25	Ø.48	4.21	11.98	28.16
A, K	4.62	6.17	5.24	Ø.26	Ø.5Ø	1.52	12.29	Ø.1Ø	3Ø.69
B, C	1.12	Ø.64	Ø.7Ø	2.4Ø	1.Ø7	Ø.73	Ø.69	3.58	1Ø.94
B, D	1.23	4.Ø6	1.84	1.87	1.4Ø	Ø.97	1.26	3.31	15.93
B, E	2.94	2.78	3.28	Ø.61	Ø.1Ø	4.Ø6	1.59	4.35	19.43
B, F	Ø.75	1.8Ø	5.62	4.27	5.59	Ø.19	2.11	Ø.1Ø	2Ø.43
B, G	Ø.46	7.56	1.9Ø	7.95	Ø.Ø2	6.3Ø	3.6Ø	1.67	29.46
B, H	2.84	4.19	8.82	2.43	2.28	Ø.35	1.17	3.41	25.49
B, I	1.31	7.93	1.53	14.53	Ø.13	Ø.Ø5	Ø.23	Ø.28	25.99
B, J	3.96	Ø.81	1.22	4.69	Ø.ØØ	Ø.41	1.ØØ	4.55	16.64
B, K	5.1Ø	13.18	Ø.87	6.48	Ø.46	1.73	5.74	2.27	29.83
C, D	1.67	3.23	1.2Ø	1.3Ø	1.91	1.51	1.43	Ø.62	12.88
C, E	3.69	2.16	2.47	2.Ø5	1.21	2.81	1.61	Ø.48	16.47
C, F	Ø.98	1.41	4.39	2.38	4.77	Ø.64	2.Ø9	4.3Ø	2Ø.96
C, G	Ø.88	6.Ø4	1.Ø9	3.73	Ø.97	4.55	3.44	Ø.63	21.33
C, H	2.71	3.27	7.24	1.Ø2	3.19	1.15	1.64	Ø.44	2Ø.66

C, I	1.94	6.38	1.75	8.15	0.99	0.70	0.46	2.05	22.29
C, J	4.87	0.69	0.57	10.77	1.04	1.63	1.46	0.49	21.52
C, K	6.09	11.00	0.92	1.43	0.93	1.13	6.53	11.10	39.13
D, E	2.47	1.10	2.18	1.53	1.55	4.54	1.56	0.38	15.30
D, F	1.48	1.25	3.06	1.94	4.31	1.02	1.93	4.01	19.00
D, G	0.73	1.52	0.83	3.36	1.25	6.67	2.92	0.46	17.73
D, H	4.37	1.06	5.00	0.57	3.46	1.26	2.74	0.32	18.78
D, I	1.10	1.64	4.09	7.84	1.08	0.92	0.96	1.80	19.44
D, J	3.11	1.60	0.69	10.11	1.35	1.41	2.56	0.40	21.22
D, K	4.06	3.91	2.79	0.92	1.01	2.34	8.50	10.70	34.23
E. F	3.99	0.66	2.85	3.81	5.85	3.39	0.67	5.19	26.41
E. G	1.90	1.76	1.34	7.29	0.13	0.37	0.89	0.65	14.33
E, H	9.24	0.86	4.20	2.01	2.39	5.01	4.23	0.15	28.09
E, I	0.88	1.93	6.34	13.67	0.25	4.10	1.13	2.51	30.81
E, J	1.02	0.80	1.46	4.95	0.10	6.78	4.02	0.02	19.15
F, G	0.65	2.49	1.55	2.23	5.02	5.42	0.73	2.19	20.39
F, H	1.58	1.09	1.42	1.19	7.12	0.51	5.08	4.15	22.15
F, I	2.05	2.69	10.51	5.55	4.21	0.15	1.60	0.50	27.26
F, J	5.43	0.36	2.26	15.11	5.43	0.74	4.87	5.40	39.60
F, K	6.79	5.92	8.19	2.92	3.17	1.32	13.23	1.71	43.25
G, H	3.37	1.01	2.92	1.75	2.25	7.42	7.66	0.36	26.75
G, I	0.48	0.00	4.92	1.02	0.05	6.35	2.94	0.61	16.37
G, J	2.62	3.50	0.11	23.33	0.01	9.64	7.43	0.72	47.36
G, K	3.61	0.78	3.32	5.89	0.29	1.45	17.56	7.68	40.57
H, I	6.39	1.12	15.28	5.43	2.28	0.30	1.20	1.82	33.81
H, J	11.94	1.52	4.14	12.32	2.27	0.46	0.14	0.16	32.95
H, K	13.97	3.20	12.35	1.22	2.50	2.43	2.24	11.04	48.95
I, J	0.86	3.76	3.56	34.09	0.10	0.34	1.02	2.66	46.39
I, K	1.46	0.67	0.16	11.80	0.10	1.73	6.12	3.95	25.99

clusters were added successively till such an addition permitted a reasonable value of the ratio of increase in intra cluster D^2 to the increase in number of cultivars added by such addition. Any abrupt increase in the ratio indicates that the addition did not permit the grouping of the said cluster with the earlier one. While doing this process the total number of cultivars in the grouped clusters were taken into consideration for working out the intra cluster D^2 values.

The conclusions arrived at in this study are the following:

1. Factor 1 delineateS the cluster H from the group of clusters E,I, J and K and also from the group of clusters A, B, C, D, F and G. Also the group of clusters E, I, J and K could be considered as distant from the group of clusters A, B, C, D, F and G, though the distinction was only marginal.
2. Factor 2 could join the clusters B and C, and the rest (A, D, E, F, G, H, I, J and K) separately. In other words the nine cultivars represented in clusters B and C were distinct from the remaining 42 cultivars as far as factor 2 was concerned.
3. Factor 3 could join the clusters F and H, and delineated these groups of 4 cultivars from the remaining 47 OTUs.
4. Factor 4 could further delineate the original group of 11 clusters into 4 groups, where the cluster F and J were quite distinct between themselves as well as from others. The clusters G and I (two cultivars)_ could be joined with

respect to factor 4 and the rest i.e., A, B, C, D, E, H & K could be joined as another group of clusters.

5. Factor 5 could delineate cluster H and F and also these two clusters from the rest.

6. Factor 6 could join the clusters E and G and the rest separately.

7. Factor 7 could show cluster K as a separate group from the rest.

8. Factor 8 could show three major groups namely clusters A and K; B, I and F and clusters C, D, E, G, H and J.

Thus the original 11 clusters were grouped into 8 individual factors, and these are summarised below.

Factor 1. (A, B, C, D, F, G) (E, I, J, K) and H

Factor 2. (B, C), (A, D, E, F, G, H, I, J, K)

Factor 3. (F, H) (A, B, C, D, E, G, I, J, K)

Factor 4. (A, B, C, D, E, H, K) (G, I) F and J

Factor 5. (A, B, C, D, E, G, I, J, K) F and H

Factor 6. (A, B, C, D, F, H, I, J, K) (E, G)

Factor 7. (A, B, C, D, F, G, H, I, J) K

Factor 8. (A, K) (B, F, I) and (C, D, E, G, H, J)

The results indicate that the group of clusters A, B, C, D are closely related among themselves as the combination B, C occur for 7 out of 8 factors and the combination B, C, D or A, B, C, D occur for 6 out of 8 factors. This was also the conclusion that was arrived at using the D^2 analysis in the data space earlier.

Distribution of cultivars between factors

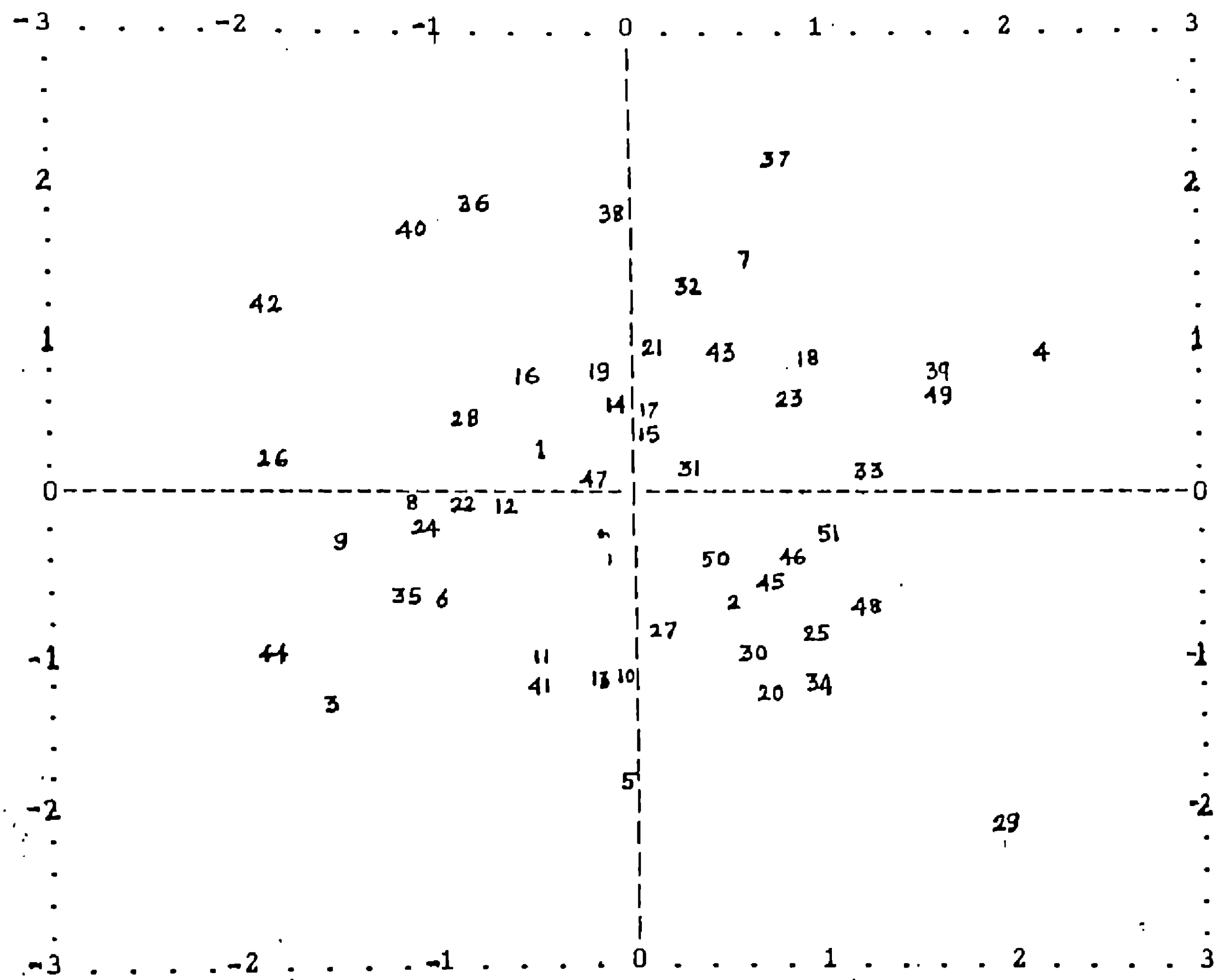
The first factor consisted of leaf size index, leaf length and leaf breadth. The second factor consisted of leaf thickness, lower epidermal thickness and upper epidermal thickness. The dispersion of cultivars between these two principal components (Fig.6.7) highlights the following points.

OTU 29 (Panniyur 1) has large difference both with regard X- and Y-coordinates indicating that both factors 1 and 2 are important in differentiating this cultivar from others. OTU 4 (Balancotta) exhibits large difference from the X-coordinate, thereby indicating that factor 1 is important in differentiating this cultivar. OTUs 39 and 49 (Vadakkan and wild 2060) have large differences with regard to the X-coordinate, thereby showing that these are differentiated from other cultivars mainly due to the first factor. OTUs 42 (Vellanamban), 26 (Nedumchola) 44 (Vokkalu) 3 (Arimulaku) show large negative differences in the X-coordinate thereby indicating that these have characteristically smaller leaves and the leaf size index, leaf breadth are important in differentiating them from other OTUs.

OTU 5 (Bilimalligesara) has large negative difference in the Y-coordinate representing factor 2, while OTU 37 (Udakkere) has a large positive difference from the Y-coordinate. This factor therefore is important in differentiating the OTUs 5

FIG. VI. 7

DISPERSION PATTERN OF CULTIVARS OF BLACK PEPPER (*Piper nigrum* L.) IN RELATION TO FACTOR -1 AND FACTOR -2

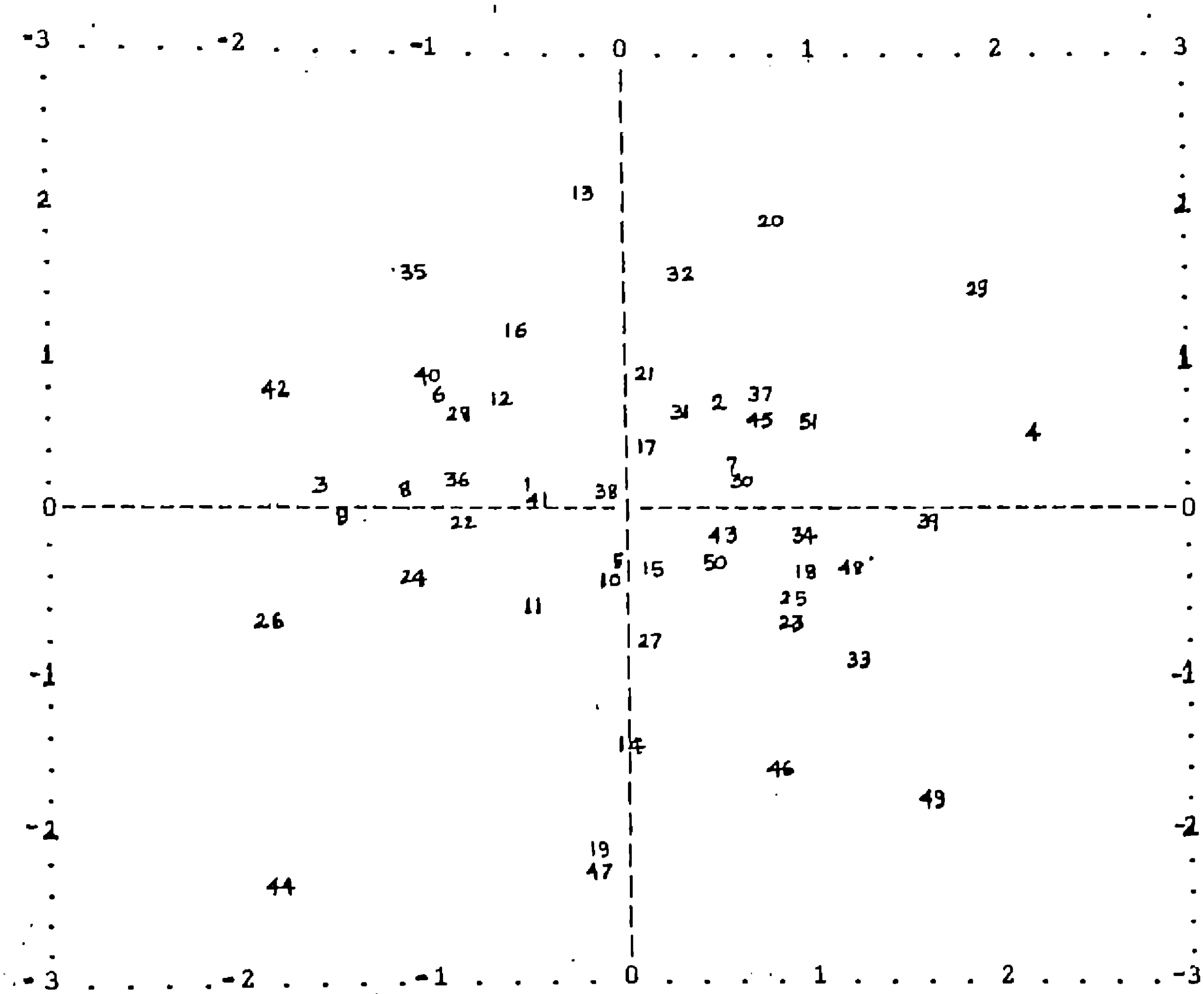


X -Axis is FACTOR -1 & Y -Axis is FACTOR -2

FIG. VI. 8

DISPERSION PATTERN OF CULTIVARS OF BLACK PEPPER (*Piper nigrum* L.)

IN RELATION TO FACTOR -1 AND FACTOR -3

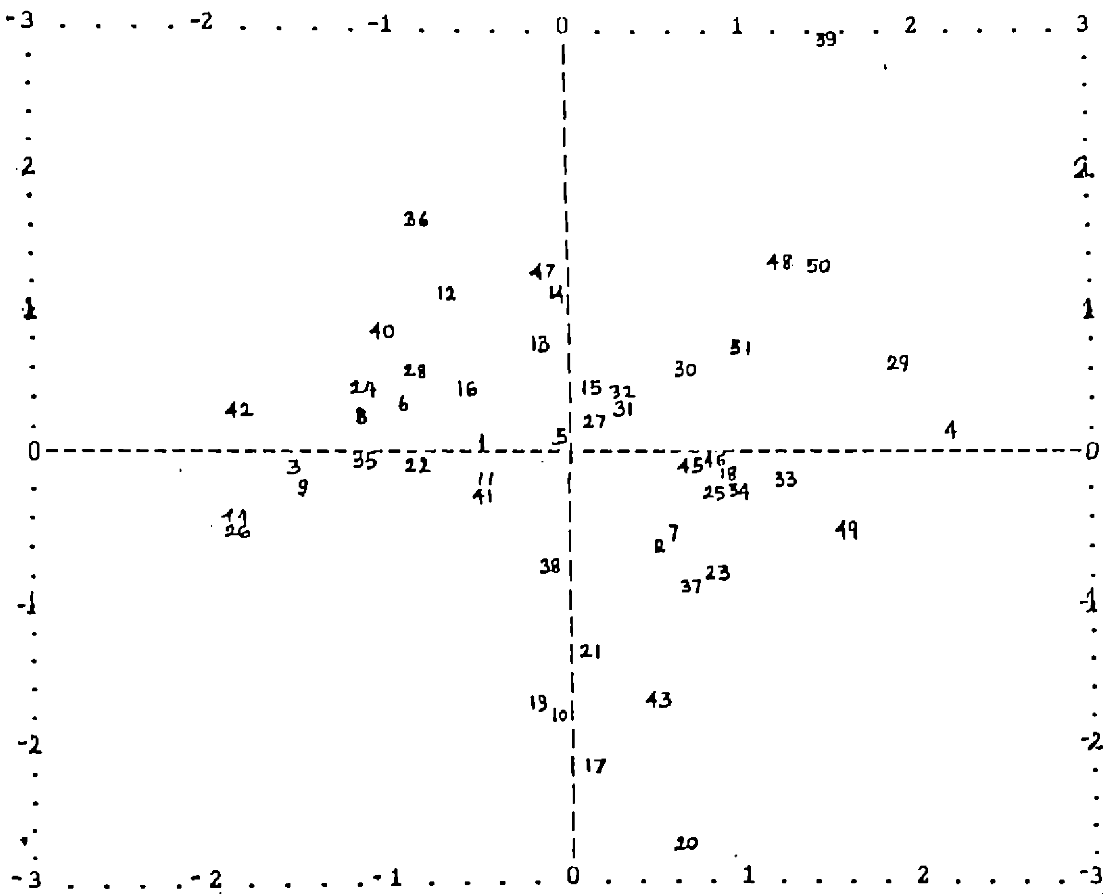


X -Axis is FACTOR -1 & Y -Axis is FACTOR -3

FIG. VI. 9

DISPERSION PATTERN OF CULTIVARS OF BLACK PEPPER (*Piper nigrum* L.)

IN RELATION TO FACTOR -1 AND FACTOR -4

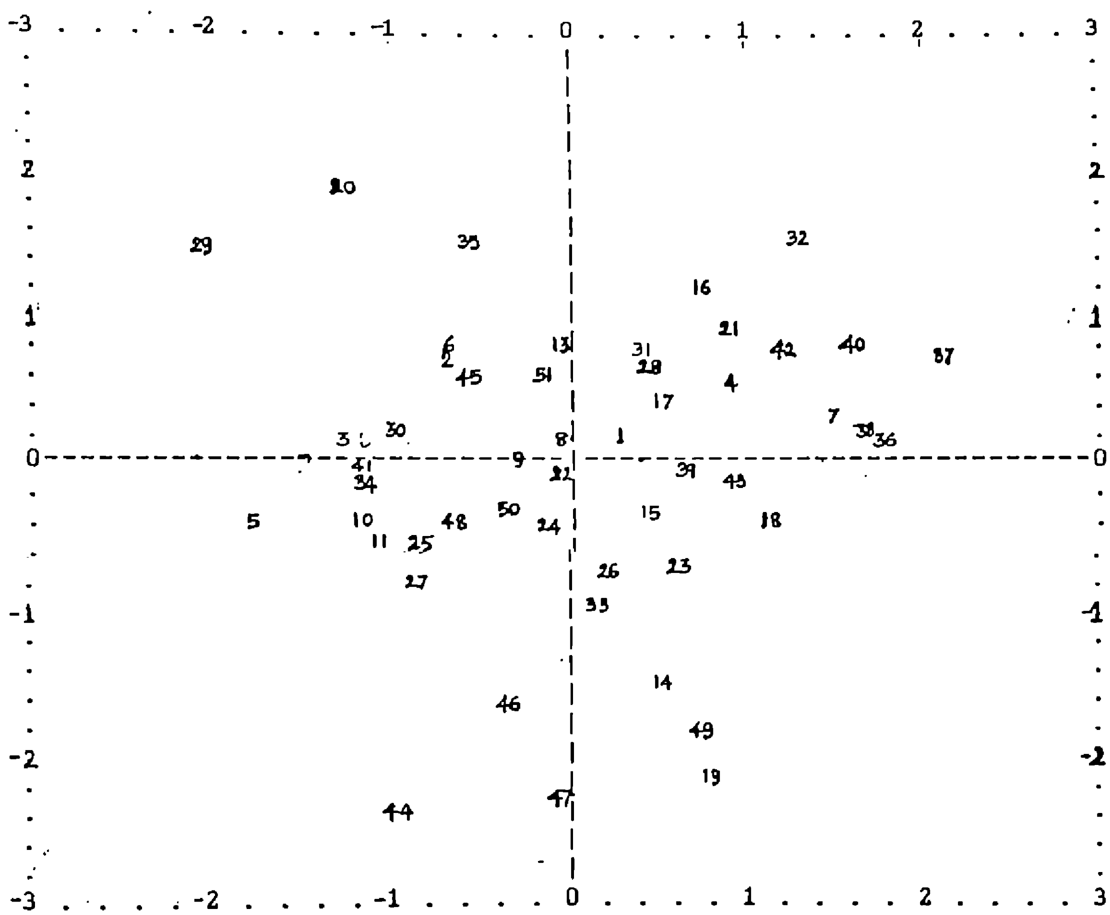


X -Axis is FACTOR -1 & Y -Axis is FACTOR -4

FIG. VI. 10

DISPERSION PATTERN OF CULTIVARS OF BLACK PEPPER (*Piper nigrum* L.)

IN RELATION TO FACTOR -2 AND FACTOR -3

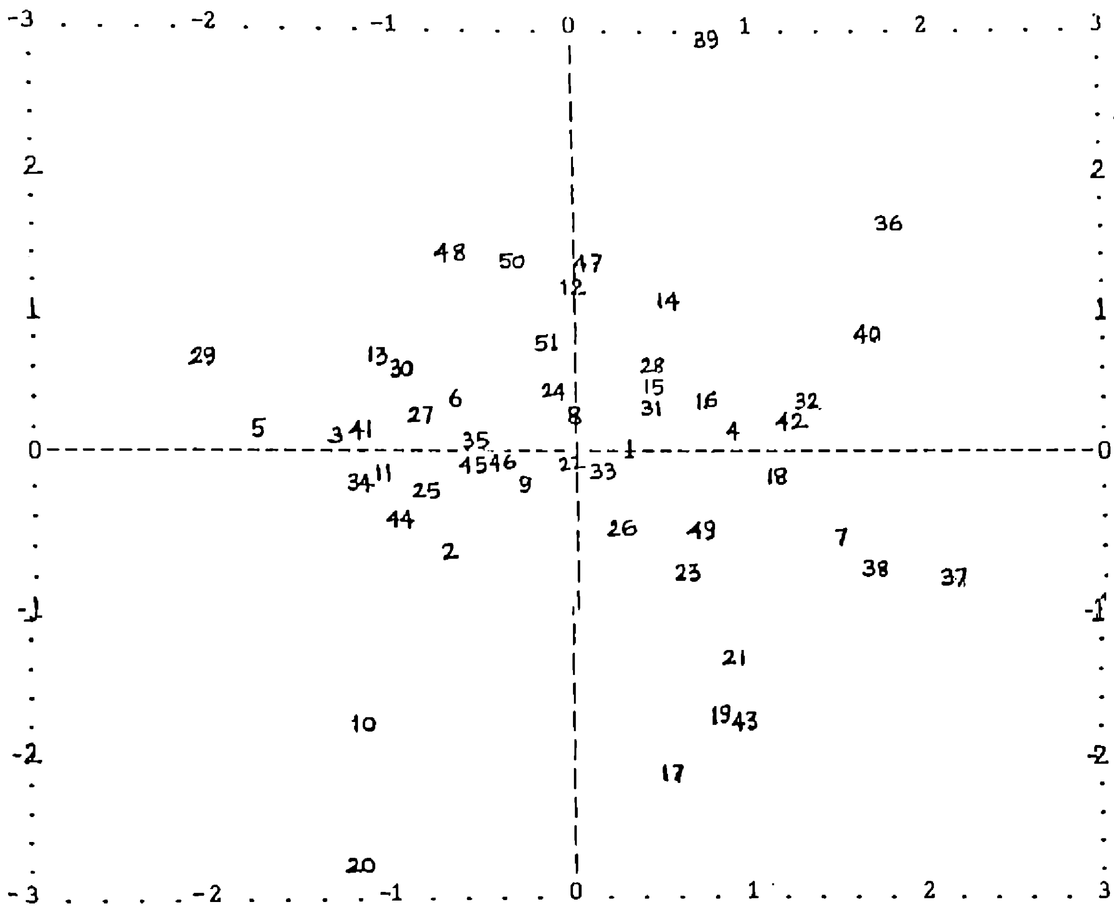


X -Axis is FACTOR -2 & Y -Axis is FACTOR -3

FIG. VI. 11

DISPERSION PATTERN OF CULTIVARS OF BLACK PEPPER (*Piper nigrum* L.)

IN RELATION TO FACTOR -2 AND FACTOR -4

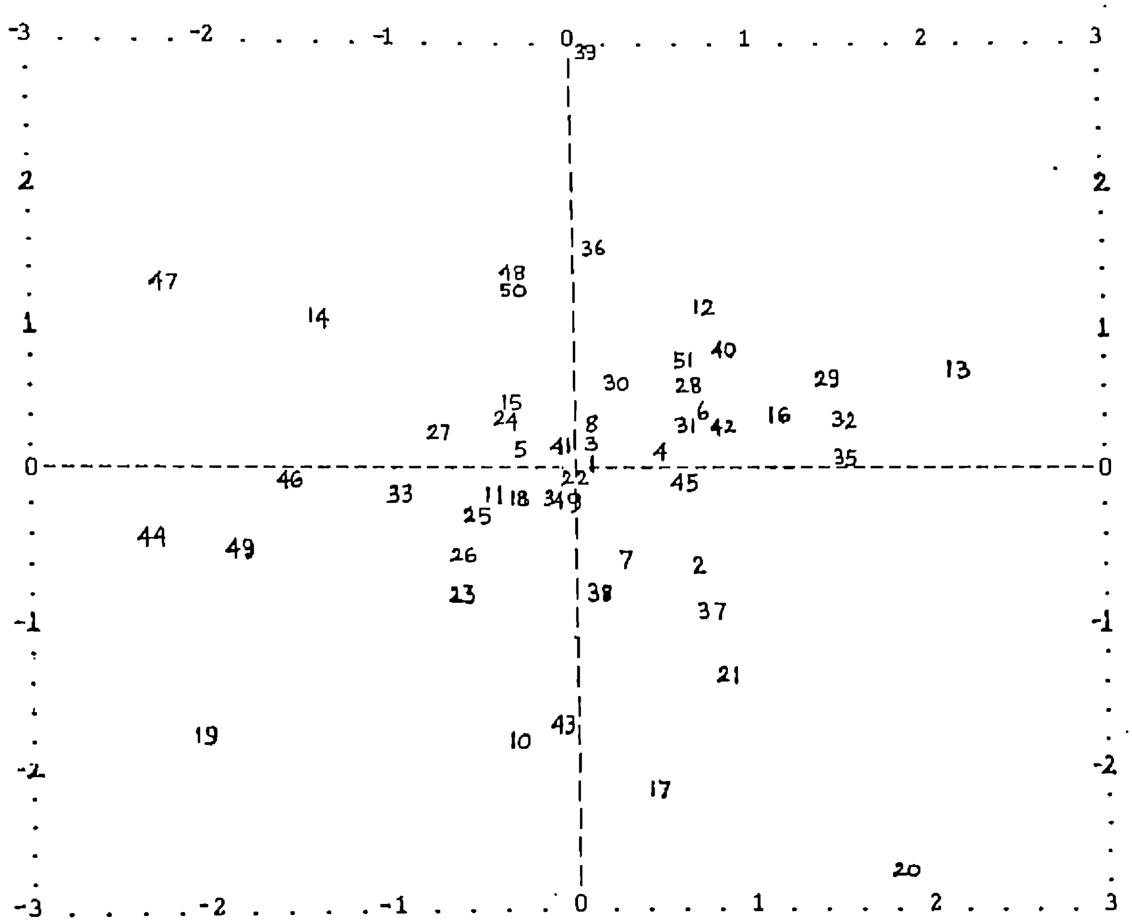


X -Axis is FACTOR -2 & Y -Axis is FACTOR -4

FIG. VI. 12

DISPERSION PATTERN OF CULTIVARS OF BLACK PEPPER (*Piper nigrum* L.)

IN RELATION TO FACTOR -3 AND FACTOR -4



X -Axis is FACTOR -3 & Y -Axis is FACTOR -4

and 37 from all the other OTUs.

Fig. 6.8 represents the dispersion of OTUs between the first and 3rd factors. The largest variation with regard to these factors was found in OTU 44 (Vokkalu), in which case there is a large negative difference both with regard to the 1st and 3rd factors, thereby indicating that both leaf and spike characters are critical in distinguishing this cultivar from all others. Factor 3 (represented by leaf length-spike length ratio, spike length and peduncle length) is important in differntiating OTU 19 (Kuriyalmundi) 47 (coll.2009) and 49 (coll.2060), all the three having large negative differences from the Y-coordinate. These cultivars therefore get differentiated from others mainly by the short spikes, peduncles or large L.L/Sp.L. values.

OTUs 13 and 20 (Karimkotta and Kuthiravally) have large positive difference from the Y-coordinate indicating that these cultivars are differentiated from the others mainly by the long spikes, peduncles and small L.L/Sp.L. values. OTUs 35 (Thommankodi) 32 (Poonjaranmunda) and 29 (Panniyur 1) are the other cultivars having large positive differences in the Y-coordinates indicating that the 3rd factor is important in differentiating them from other cultivars. All these have long spikes and low L.L/Sp.L. values.

Fig. 6.9 gives the dispersion of OTUs between the 1st and 4th factors (the 4th factor is represented by guard cell length and guard cell breadth). The cv.Vadakkan (OTU 39) exihibited the largest positive difference with respect to the Y-coordinate indicating that guard cell length and breadth are important characters in differentiating this OTU from all the others. So also cv. Kuthiravally (OTU 20) exhibited a large negative difference on Y-coordinate indicating that this OTU is different from all the others with regard to factor 4. Kottanadan (OTU 17) also exhibited large negative difference on the Y-coordinate. Other OTUs showing large differences on the Y-coordinate are 19 (Kuriyalmundi), 10 (Karimunda), 43 (Velliyaranmunda) and 36 (Thulamundi).

Fig. 6.10 shows the distribution of OTU's between second and third factors and Fig. 6.11 gives the dispersion of OTUs betweem the 2nd and 4th factors. The dispersion of OTUs between 3rd and 4th factor is given in Fig.6.12.

From these factor score diagrams or dispersion figures it can be seen that with respect to the first four factors the OTUs fall into some distinct groups. The dispersion pattern also reveals the variability between the cultivars included in the same group based on the centroid clustering. For example, group I consisted of OTU's 1 and 14 (Aimpiriyan and Kalluvally). A study of the dispersion figures showed that these differ with respect to the 1st and 3rd factors, 1st and 4th factors, 2nd and 3rd factors, 2nd and 4th factors and 3rd and 4th factors. The group consisted of OTUs 32 and 36

(Poonjaranmunda and Thulamundi) were different distinctly with regard to 1st and 3rd factors, 1st and 4th factors, 2nd and 3rd factors, and 3rd and 4th factors.

The centroid group VI consists of OTU s 19 and 24 (Narayakkodi and Kuriyalmundi). These were differentiated by 2nd and 3rd factors, 1st and 4th factors, 2nd and 3rd factors, 2nd and 4th factors and 3rd and 4th factors. Again OTU's 26 and 44 of group VIII could be differentiated by factor 3.

In other words factor analysis helps to bring out the finer differences among the related cultivars, which are grouped by centroid linkage by taking into consideration all the 22 characters.

A study of the scatter plots leads to the following general conclusions with regard to the interrelationships of the cultivars.

1) Certain cultivars remain as independent entities, thereby indicating their divergence from each other and from other cultivars. Such cultivars include Panniyur-1, Vokkalu, Nedumchola, Kuthiravally, Vadakkan and Karimunda.

2. Panniyur 1, believed to be a hybrid pepper from a cross involving Uthirancotta and Cheriyakaniakkadan, surprisingly did not show any similarity with its parents. This absence of any sort of resemblance was seen in all the scatter plots. In the centroid linkage also this cultivar has fallen into an independent group as seen in the dendrogram and correlation

diagram (Fig. 6.4 and 6.5)

3) The majority of the cultivars are distributed around the central point indicating their relative similarity, and thereby can be included in a single group. This is comparable to the group IV obtained from centroid linkage clustering. The more distant ones are distributed outside this central group. Cultivars such as Panniyur 1, Vadakkan and Kuthiravally are so distinct that they stand out in all the scatter plots.

Numerical Taxonomic Study on Piper Spp.

Average Linkage of Characters

Table VI.13 gives the Piper.Spp. (OTUs) used in the present study. Table VI.14 gives the characters and their states considered for analysis. Table VI.15 gives the statistics of each biometrical character over the 17 OTUs studied. Table VI.16 gives the inter-character correlations among the 30 characters used in the present study. These character correlations are presented in a sorted and shaded form in Fig.6.13 in which the heavier shading represents closer relationship. Fig. 6.14 & Table VI.17 give the clustering of 30 characters by the average linkage method. The amalgamation process is similar to the one discussed in the previous section on pepper cultivars.

Table VI.18 gives the principal components of the 30

TABLE. VI.13 : PIPER Spp. USED IN THE PRESENT STUDY

Sn. No.	Species (OTU)		
1.	Piper attenuatum		
2.	P. argyrophyllum		
3.	P. galeatum		
4.	P. hymenophyllum		
5.	P. longum		
6.	P. mullesua		
7.	P. schmidtii		
8.	P. silentvalleyensis		
9.	P. trichostachyon		
10.	P. wightii		
11.	P. nigrum	(1)	Acc. 2077
12.	-do-	(2)	Acc. 2071
13.	-do-	(3)	Acc. 2009
14.	-do-	(4)	Acc. 2059
15.	-do-	(5)	Acc. 2060
16.	-do-	(6)	Acc. 2015
17.	-do-	(7)	Acc. 2062

TABLE VI.14 CHARACTERS AND THEIR STATES USED IN THE STUDY OF *PIPER* Spp.

Character Code number	Details of characters and their states
1	Leaf length in mm
2	Leaf breadth in mm
3	Leaf length / leaf breadth
4	Leaf size index
5	Petiole length in mm
6	Spike length in mm
7	Peduncle length in mm
8	Leaf length / spike length
9	Stomatal density per mm^2
10	Guard cell length in mm
11	Guard cell breadth in mm
12	Distance from leaf base to the 2nd pair of ribs
13	Number of ribs
14	Leaf shape (1 : ovate to ovate-elliptic; 2 : cordate 3: ovate-lanceate; 4: elliptice to elliptic-lanceate)
15	Leaf base (1: round; 2: cordate; 3: acute to attenuate)
16	Leaf texture (1: glabrous; 2: sparsely hairy mainly on the veins; 3: hirsute)
17	Leaf nature (1: membraneous; 2: coriaceous)
18	Spike shape (1: filiform; 2: cylindrical; 3: globose)
19	Spike orientation (1: pendulous; 2: erect)
20	Spike texture (1: gfsabrous; 2: hirtellous)
21	Bract type (1: sessile, adnate to rachis; 2: stalked, peltate, orbicular; 3: cupular with decurrent base; 4: fleshy, cup like; 5: oblong, angular and free all around)

22 Stamen number (1: two; 2: three to four)

23 Fruit nature (1: free; 2: fused)

24 Fruit shape (1: ovate-oblong; 2: spherical; 3: elliptical 4: obovate)

25 Fruit colour change on ripening (1: green to orange and red; 2: green to yellow; 3: green to black)

26 Fruit taste (1: pungent; 2: Spicy and mildly pungent 3: bitter)

27 Plant type (1: dioecious; 2: monoecious 3: predominantly monoecious)

28 Growth habit (1: shrubby climber; 2: stout woody climber 3:no climbing habit and trailing on the ground)

29 Distribution in the natural habitat (1: plains to lower elevations (from Ø - 5ØØ,); 2: plains to higher elevations (from Ø - 15ØØ m); 3: lower elevations to higher elevations (from 5ØØ - 15ØØ m); 4: found only at high elevations (above 15ØØ m).

3Ø Presence of marginal gall forming strips (1 : present; 2: absent)

FIG. VI. 13 ABSOLUTE VALUES OF CORRELATIONS AMONG BIOMETRICAL CHARACTERS OF *Piper* SPECIES

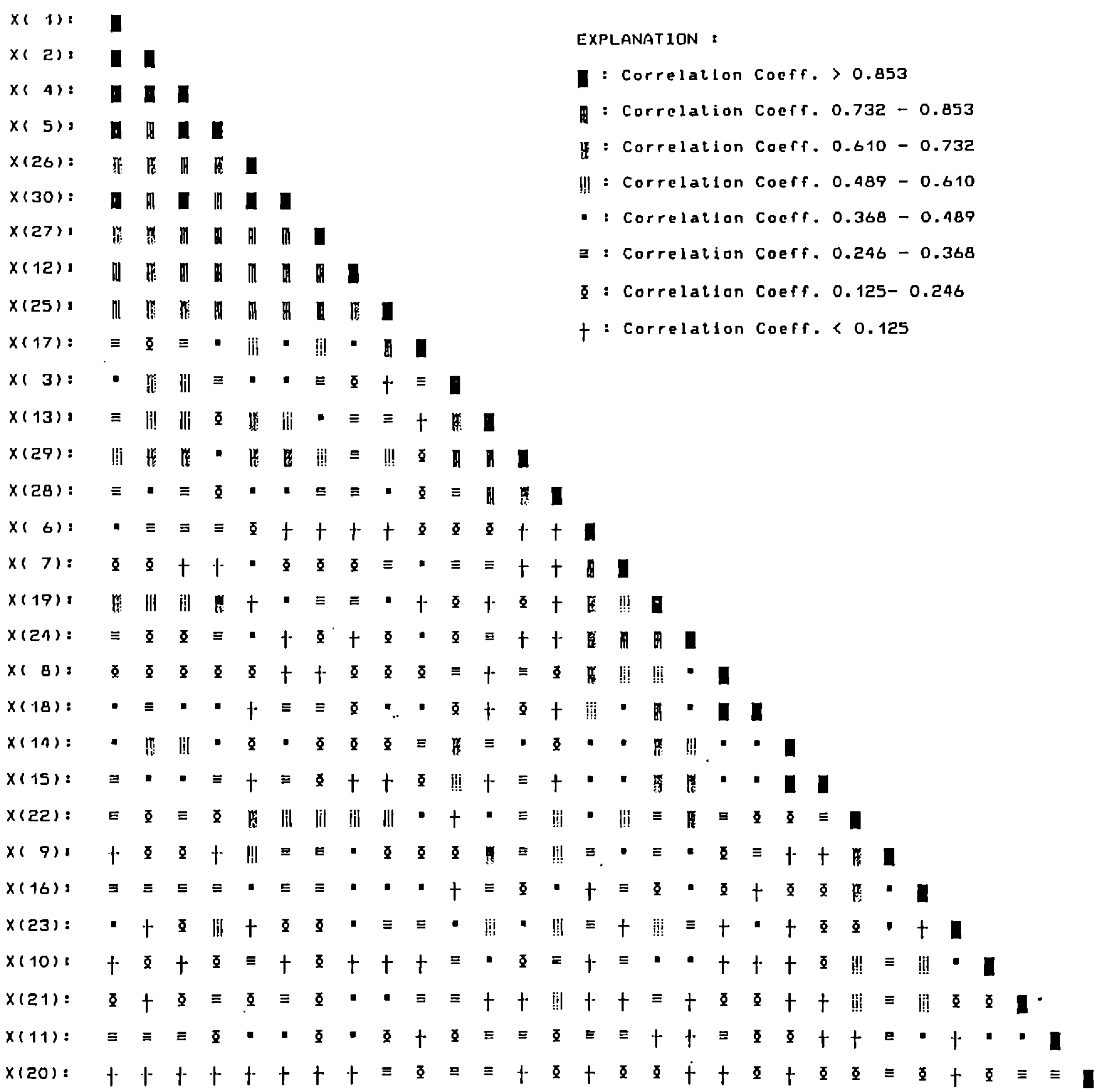


FIG. VI.14 CLUSTERING OF CHARACTERS BY AVERAGE DISTANCE METHOD

(Number of Piper Species =17)

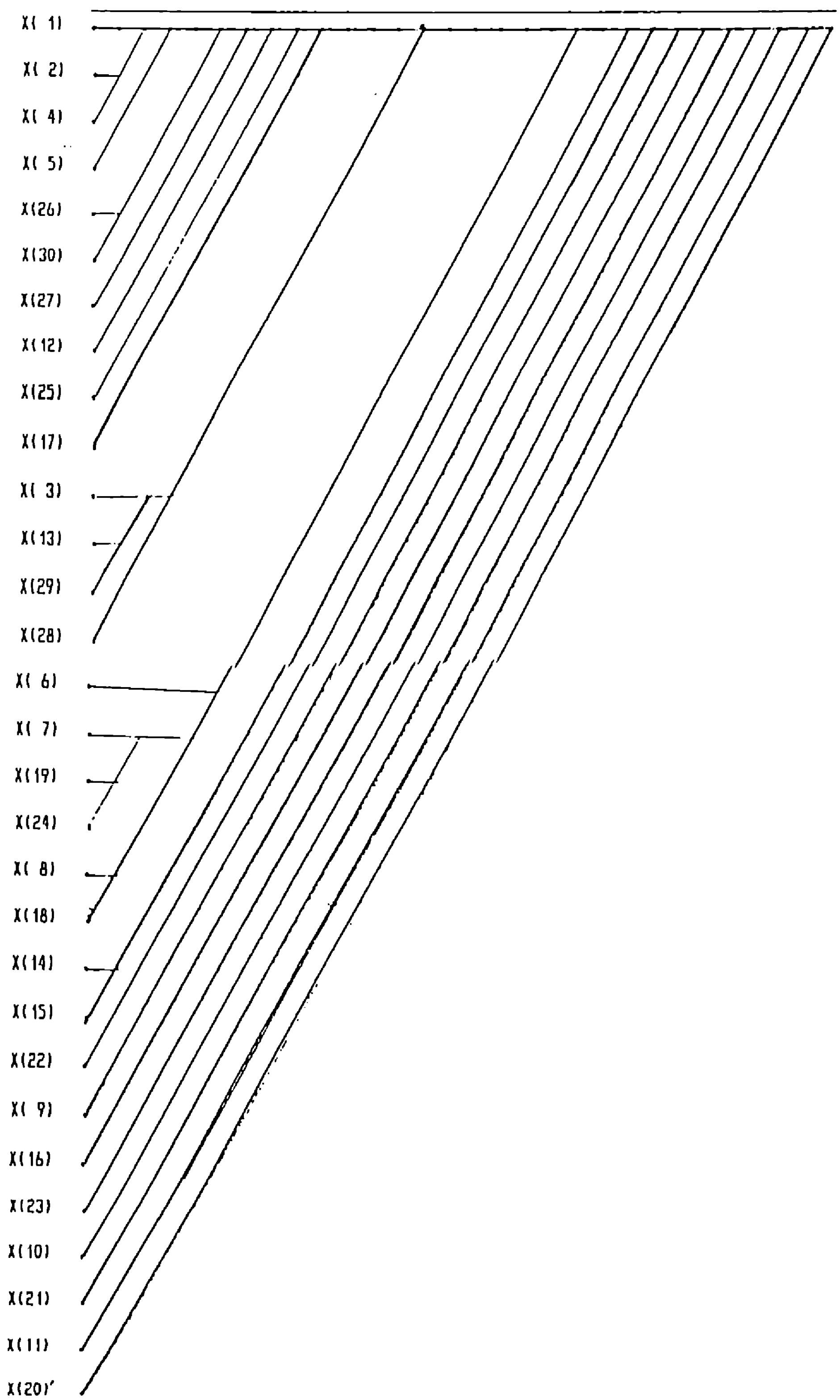


TABLE VI.15 : STATISTICS FOR EACH VARIABLE USED IN THE STUDY

VARIABLE NO. NAME	MEAN	STANDARD DEVIATION	SMALLEST VALUE	SMALLEST CASE	LARGEST VALUE	LARGEST CASE
1	121.81Ø6	34.7388	6Ø.3ØØØ	8	171.8ØØØ	11
2	59.6176	22.4442	22.4ØØØ	8	96.5ØØØ	16
3	2.1359	Ø.4373	1.37ØØ	5	2.92ØØ	9
4	79.2212	45.794Ø	13.5ØØØ	8	145.81ØØ	16
5	12.2847	5.3473	2.1ØØØ	5	21.ØØØØ	13
6	89.6ØØØ	43.1676	9.2ØØØ	6	183.ØØØØ	2
7	14.2671	6.8536	1.3ØØØ	8	25.2ØØØ	2
8	1.9235	1.9255	Ø.66ØØ	2	9.Ø9ØØ	6
9	94.1141	12.6597	68.41ØØ	1	114.47ØØ	14
1Ø	Ø.Ø265	Ø.ØØ23	Ø.Ø23Ø	5	Ø.Ø33Ø	4
11	Ø.Ø186	Ø.ØØ17	Ø.Ø16Ø	7	Ø.Ø22Ø	4
12	14.1865	9.5387	Ø.ØØØØ	5	31.3ØØØ	15
13	1.5294	Ø.6243	1.ØØØØ	1	3.ØØØØ	5
14	1.7647	1.1472	1.ØØØØ	1	4.ØØØØ	6
15	1.5294	Ø.8745	1.ØØØØ	1	3.ØØØØ	6
16	1.1765	Ø.5286	1.ØØØØ	2	3.ØØØØ	4
17	1.7Ø59	Ø.5879	1.ØØØØ	1	3.ØØØØ	8
18	1.1765	Ø.5286	1.ØØØØ	1	3.ØØØØ	6
19	1.1765	Ø.393Ø	1.ØØØØ	1	2.ØØØØ	5
2Ø	1.1176	Ø.3321	1.ØØØØ	1	2.ØØØØ	9
21	2.7Ø59	1.1Ø48	1.ØØØØ	1	5.ØØØØ	7
22	1.2353	Ø.4372	1.ØØØØ	5	2.ØØØØ	1
23	1.Ø588	Ø.2425	1.ØØØØ	1	2.ØØØØ	5
24	1.9412	Ø.8269	1.ØØØØ	1	4.ØØØØ	8
25	1.8235	Ø.951Ø	1.ØØØØ	9	3.ØØØØ	1
26	1.8824	Ø.9275	1.ØØØØ	1Ø	3.ØØØØ	1
27	1.8824	Ø.9926	1.ØØØØ	1	3.ØØØØ	11
28	1.7647	Ø.5623	1.ØØØØ	1	3.ØØØØ	5
29	2.5882	Ø.87Ø3	1.ØØØØ	5	4.ØØØØ	6
3Ø	1.5294	Ø.5145	1.ØØØØ	1Ø	2.ØØØØ	1

TABLE VI.16 INTER CHARACTER CORRELATION AMONG 30 CHARACTERS

		X(1) 1	X(2) 2	X(3) 3	X(4) 4	X(5) 5	X(6) 6	X(7) 7	X(8) 8	X(9) 9	X(10) 10	X(11) 11	X(12) 12	X(13) 13
X(1)	1	1.000												
X(2)	2	0.896	1.000											
X(3)	3	-0.369	-0.709	1.000										
X(4)	4	0.958	0.974	-0.553	1.000									
X(5)	5	0.911	0.813	-0.276	0.875	1.000								
X(6)	6	0.399	0.320	-0.178	0.317	0.286	1.000							
X(7)	7	0.162	0.166	-0.300	0.107	0.120	0.737	1.000						
X(8)	8	-0.190	-0.205	0.281	-0.176	-0.141	-0.646	-0.587	1.000					
X(9)	9	0.076	0.183	-0.244	0.183	-0.055	-0.333	-0.463	0.184	1.000				
X(10)	10	0.063	-0.143	0.253	-0.076	0.132	0.085	0.316	0.008	-0.319	1.000			
X(11)	11	0.277	0.271	-0.244	0.315	0.174	-0.298	-0.251	0.298	0.315	0.411	1.000		
X(12)	12	0.810	0.681	-0.132	0.790	0.805	0.010	-0.221	0.187	0.395	0.014	0.389	1.000	
X(13)	13	0.354	0.569	-0.676	0.496	0.226	-0.211	-0.248	-0.041	0.646	-0.398	0.306	0.352	1.000
X(14)	14	-0.486	-0.512	0.694	-0.519	-0.444	-0.386	-0.487	0.445	-0.035	-0.050	-0.142	-0.203	-0.252
X(15)	15	-0.368	-0.465	0.537	-0.379	-0.364	-0.409	-0.444	0.412	0.052	-0.161	-0.077	-0.118	-0.088
X(16)	16	-0.258	-0.272	-0.045	-0.289	-0.253	-0.008	0.366	-0.147	-0.398	0.590	0.423	-0.386	-0.301
X(17)	17	0.314	0.188	0.250	0.313	0.374	-0.150	-0.479	-0.185	0.131	-0.121	0.015	0.378	0.110
X(18)	18	-0.436	-0.357	0.152	-0.392	-0.472	-0.582	-0.418	0.875	0.248	-0.123	0.144	-0.126	0.078
X(19)	19	-0.694	-0.535	0.179	-0.567	-0.701	-0.669	-0.585	0.551	0.326	-0.371	0.006	-0.367	0.105
X(20)	20	0.083	-0.093	0.322	-0.045	0.121	-0.042	0.230	-0.080	-0.322	0.167	-0.366	-0.047	-0.319
X(21)	21	0.246	0.059	0.322	0.145	0.311	0.080	-0.066	-0.138	0.258	-0.162	-0.393	0.387	0.059
X(22)	22	-0.248	-0.234	-0.024	-0.299	-0.239	0.473	0.574	-0.299	-0.645	0.500	-0.050	-0.536	-0.485
X(23)	23	-0.384	-0.099	-0.451	-0.245	-0.491	-0.308	-0.010	-0.011	0.391	-0.385	-0.098	-0.383	0.607
X(24)	24	-0.268	-0.183	0.157	-0.147	-0.269	-0.718	-0.788	0.451	0.457	-0.440	0.118	0.045	0.306
X(25)	25	-0.768	-0.617	0.036	-0.722	-0.768	0.013	0.249	0.149	-0.178	0.012	-0.158	-0.711	-0.359
X(26)	26	-0.696	-0.715	0.373	-0.768	-0.627	0.233	0.427	-0.168	-0.514	0.260	-0.466	-0.782	-0.641
X(27)	27	0.715	0.678	-0.275	0.755	0.780	-0.070	-0.221	-0.042	0.248	-0.137	0.234	0.790	0.409
X(28)	28	0.295	0.373	-0.365	0.328	0.221	-0.074	0.004	-0.224	0.505	-0.341	-0.158	0.273	0.733
X(29)	29	-0.581	-0.730	0.739	-0.658	-0.444	-0.012	-0.100	0.249	-0.326	0.133	-0.274	-0.358	-0.839
X(30)	30	-0.893	-0.849	0.405	-0.909	-0.833	-0.046	0.161	0.059	-0.339	0.092	-0.418	-0.845	-0.538

		X(14) 14	X(15) 15	X(16) 16	X(17) 17	X(18) 18	X(19) 19	X(20) 20	X(21) 21	X(22) 22	X(23) 23	X(24) 24	X(25) 25	X(26) 26
X(14)	14	1.000												
X(15)	15	0.880	1.000											
X(16)	16	-0.236	-0.215	1.000										
X(17)	17	0.262	0.200	-0.426	1.000									
X(18)	18	0.485	0.461	-0.118	-0.426	1.000								
X(19)	19	0.652	0.621	-0.159	-0.032	0.743	1.000							
X(20)	20	0.077	0.203	-0.126	0.188	-0.126	-0.169	1.000						
X(21)	21	0.041	-0.023	-0.548	0.340	-0.227	-0.305	0.271	1.000					
X(22)	22	-0.132	-0.346	0.620	-0.443	-0.191	-0.257	-0.203	-0.495	1.000				
X(23)	23	0.053	0.139	-0.086	-0.309	0.401	0.540	-0.091	-0.165	-0.139	1.000			
X(24)	24	0.577	0.651	-0.404	0.476	0.454	0.803	0.027	-0.089	-0.651	0.330	1.000		
X(25)	25	0.131	0.044	0.439	-0.769	0.439	0.423	-0.326	-0.469	0.557	0.319	-0.173	1.000	
X(26)	26	0.207	0.082	0.427	-0.526	0.045	0.061	0.048	-0.158	0.689	0.033	-0.417	0.754	1.000

		X(27) 27	X(28) 28	X(29) 29	X(30) 30
X(27)	27	1.000			
X(28)	28	0.283	1.000		
X(29)	29	-0.494	-0.721	1.000	
X(30)	30	-0.849	-0.407	0.657	1.000

TABLE VI.17 AVERAGE CLUSTERING OF CHARACTERS

VARIABLE NO.	OTHER BOUNDARY OF CLUSTER	NUMBER OF ITEMS IN CLUSTER	DISTANCE OR SIMILARITY WHEN CLUSTER FORMED
1	2Ø	3Ø	36.61
2	4	2	97.41
4	1	3	95.78
5	1	4	91.Ø5
26	3Ø	2	92.45
3Ø	1	6	9Ø.92
27	1	7	84.95
12	2	8	84.55
25	1	9	84.16
17	1	1Ø	76.94
3	28	4	73.32
13	29	2	83.91
29	3	3	73.93
28	1	14	72.98
6	18	6	73.68
7	18	5	74.34
19	24	2	8Ø.33
24	7	3	78.78
8	18	2	87.5Ø
18	1	2Ø	7Ø.Ø6
14	15	2	87.95
15	1	22	69.44
22	1	23	68.9Ø
9	1	24	64.55
16	1	25	62.Ø4
23	1	26	6Ø.71
1Ø	1	27	59.Ø2
21	1	28	58.59
11	1	29	46.58
2Ø	1	3Ø	36.61

characters with variance explained by each factor, the cumulative proportion of variance explained by the successive factor both in the data space as well as in the factor space.

Fig. 6.15 shows the cumulative proportion of variance explained by the factors in a graphical form to bring out the major factors involved in data space reduction by means of principal components.

Table VI.19 gives the factor loadings for the first seven factors on each of the thirty variables. Table VI.2Ø gives the factor loadings after orthogonal rotation and arranging the rows and columns, so that the columns appear in decreasing order of variance explained by the factor and the rows rearranged so that factor loadings greater than Ø.5 appear first.

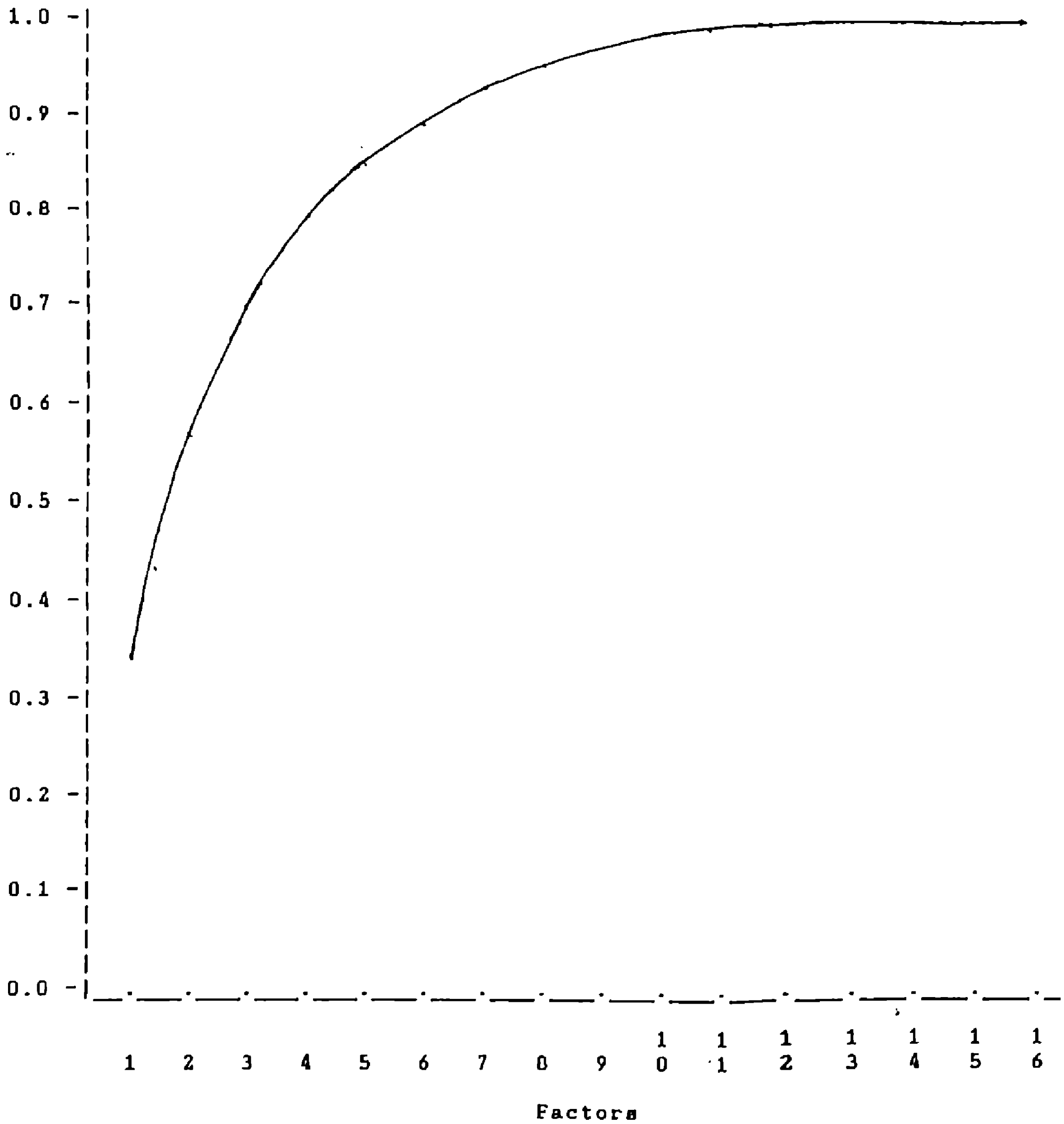
Table VI.21 gives the estimated factor scores for each of the 17 OTUs (Taxa).

The process of amalgamation of characters in the average linkage analysis is given in Fig. 6.13. Characters (leaf breadth) and 4 (leaf size index) are grouped and then character 1 (leaf length) was linked with this group. Character 5 (petiole length) though remains not in direct linkage with any character, is close enough to be linked with the group consisting of 1, 2 and 4. Characters 26 (berry taste) and 3Ø (thrips infestation) are in a distinct group, neverthless they are close enough to get linked with the

TABLE VI.18: VARIANCE EXPLAINED BY THE FACTORS AND THE CORRELATIVE PROPORTION OF VARIANCE

FACTOR	VARIANCE EXPLAINED	CUMULATIVE PROPORTION OF VARIANCE IN DATA SPACE	IN FACTOR SPACE
1	1Ø.2517	Ø.3417	Ø.37Ø6
2	6.6616	Ø.5638	Ø.6115
3	3.8556	Ø.6923	Ø.75Ø9
4	2.9259	Ø.7898	Ø.8566
5	1.4423	Ø.8379	Ø.9Ø88
6	1.3628	Ø.8833	Ø.9581
7	1.1599	Ø.922Ø	1.ØØØØ
8	Ø.78Ø4	Ø.948Ø	
9	Ø.4869	Ø.9642	
1Ø	Ø.3568	Ø.9761	
11	Ø.3Ø93	Ø.9864	
12	Ø.1594	Ø.9918	
13	Ø.1166	Ø.9956	
14	Ø.Ø636	Ø.9978	
15	Ø.Ø398	Ø.9991	
16	Ø.Ø273	1.ØØØØ	
17	Ø.ØØØØ	1.ØØØØ	
18	Ø.ØØØØ	1.ØØØØ	
19	Ø.ØØØØ	1.ØØØØ	
2Ø	Ø.ØØØØ	1.ØØØØ	
21	Ø.ØØØØ	1.ØØØØ	
22	Ø.ØØØØ	1.ØØØØ	

FIG. VI.15 CUMULATIVE PROPORTION OF VARIANCE EXPLAINED BY FACTORS OF BIOMETRICAL CHARACTERS OF 17 *Piper* SPECIES



earlier group.

Characters 27 (plant type), 12 (distance from base to the 2nd pair of ribs), 25 (berry colour change) and 17 (leaf nature) are linked with 1. Character 3 (L.L/L.B), 13 (rib number), 29 (distribution) and 28 (growth habit) are in one compact cluster and they are again linked with the previous group. From the figure it is also seen that character 6 - 18 are first linked among themselves and then linked with the earlier ones. However 14 (Leaf shape) and 15 (leaf base) form a separate cluster and seem to be only distantly related with the group of other characters. Characters 22 (stamen number) and 28 (bract type) and 20 (spike texture) are again independent and linked separately with the main group.

The correlation diagram (6.14) gives a clear picture of the character groupings. From this diagram (as well as from Fig. 6.13) we find that the characters leaf length, leaf breadth, leaf size index, petiole length, berry taste thrips infestation, plant type, distance from the leaf base to the 2nd pair of ribs, and berry colour change form one major group of characters which are closely linked. Though 17 (leaf nature) seems to be closer to this group in the cluster tree, from the correlation diagram we tend to omit this character from this group in view of the lighter shades in the diagram for this particular character.

Principal Component:

Comparing the results obtained by the average linkage method with the factors (Table VI.17) we find that factor I has high loadings on all these nine characters considered above, thus conforming the results of cluster analysis. Thus factor 1 represents the set of following characters:-

Factor 1: Leaf length, leaf breadth, leaf size index, petiole length, distance from base to the 2nd pair of ribs, plant type, berry colour, berry taste and thrips infestation.

From Fig. 6.13 we find that characters 3 (L.L/L.B) 13 (number of ribs), 29 (distribution) and 28 (growth habit) form a closely linked group of characters, and that these characters are closely related as explained by heavier shades in the diagram, and is also seen to be quite independent of the earlier set represented by factor 1 (the correlation between the two sets being very low).

From Table VI.20 it can be seen that factor 3 shows high factor loadings for these four characters, namely L.L/L.B (3) rib number (13); distribution (29); and growth habit (28); in addition to the character berry nature (23). However, from the correlation diagram and also in the cluster tree the character berry nature seems to be removed from these characters. Hence we may conclude that Factor 3 represents the characters 3, 13, 29 and 28.

Principal Component:

Comparing the results obtained by the average linkage method with the factors (Table VI.17) we find that factor I has high loadings on all these nine characters considered above, thus conforming the results of cluster analysis. Thus factor 1 represents the set of following characters:-

Factor 1: Leaf length, leaf breadth, leaf size index, petiole length, distance from base to the 2nd pair of ribs, plant type, berry colour, berry taste and thrips infestation.

From Fig. 6.13 we find that characters 3 (L.L/L.B) 13 (number of ribs), 29 (distribution) and 28 (growth habit) form a closely linked group of characters, and that these characters are closely related as explained by heavier shades in the diagram, and is also seen to be quite independent of the earlier set represented by factor 1 (the correlation between the two sets being very low).

From Table VI.2Ø it can be seen that factor 3 shows high factor loadings for these four characters, namely L.L/L.B (3) rib number (13); distribution (29); and growth habit (28); in addition to the character berry nature (23). However, from the correlation diagram and also in the cluster tree the character berry nature seems to be removed from these characters. Hence we may conclude that Factor 3 represents the characters 3, 13, 29 and 28.

TABLE VI.19 UNROTATED FACTOR LOADINGS (PATTERN)

FOR PRINICIPAL COMPONENTS

	VAR. NO.	FACTOR 1	FACTOR 2	FACTOR 3	FACTOR 4	FACTOR 5	FACTOR 6	FACTOR 7
X(1)	1	Ø.915	-Ø.236	Ø.147	Ø.118	Ø.1Ø9	Ø.Ø47	-Ø.147
X(2)	2	Ø.91Ø	-Ø.175	-Ø.2Ø4	Ø.Ø9Ø	Ø.Ø76	-Ø.Ø83	-Ø.235
X(3)	3	-Ø.498	Ø.18Ø	Ø.794	-Ø.Ø37	Ø.Ø65	Ø.115	Ø.174
X(4)	4	Ø.945	-Ø.142	-Ø.Ø22	Ø.136	Ø.Ø69	-Ø.Ø7Ø	-Ø.186
X(5)	5	Ø.862	-Ø.246	Ø.294	Ø.125	Ø.1Ø6	Ø.Ø51	-Ø.136
X(6)	6	Ø.Ø71	-Ø.766	Ø.Ø4Ø	-Ø.278	Ø.173	-Ø.278	-Ø.131
X(7)	7	-Ø.-27	-Ø.84Ø	-Ø.2Ø2	-Ø.245	Ø.Ø34	Ø.222	-Ø.187
X(8)	8	-Ø.212	Ø.6Ø5	Ø.Ø94	Ø.5Ø7	Ø.448	Ø.22Ø	-Ø.2Ø6
X(9)	9	Ø.335	Ø.6Ø4	-Ø.339	-Ø.Ø34	Ø.197	-Ø.Ø49	Ø.464
X(1Ø)	1Ø	-Ø.134	-Ø.466	Ø.246	Ø.487	-Ø.143	Ø.51Ø	Ø.238
X(11)	11	Ø.274	Ø.12Ø	-Ø.2Ø2	Ø.83Ø	-Ø.148	Ø.137	Ø.252
X(12)	12	Ø.818	Ø.166	Ø.268	Ø.257	Ø.3Ø8	Ø.Ø48	Ø.Ø63
X(13)	13	Ø.598	Ø.4Ø9	-Ø.618	-Ø.Ø92	-Ø.Ø86	Ø.Ø21	Ø.Ø86
X(14)	14	-Ø.5Ø7	Ø.584	Ø.416	-Ø.Ø29	-Ø.Ø79	-Ø.ØØ9	-Ø.126
X(15)	15	-Ø.373	Ø.636	Ø.323	-Ø.Ø4Ø	-Ø.139	Ø.Ø79	-Ø.262
X(16)	16	-Ø.38Ø	-Ø.5Ø6	-Ø.2Ø6	Ø.5Ø9	-Ø.336	Ø.196	Ø.198
X(17)	17	Ø.448	Ø.334	Ø.566	-Ø.123	-Ø.484	-Ø.248	Ø.131
X(18)	18	-Ø.423	Ø.617	-Ø.241	Ø.269	Ø.411	Ø.257	-Ø.233
X(19)	19	-Ø.521	Ø.783	-Ø.218	Ø.Ø57	-Ø.Ø84	-Ø.115	-Ø.12Ø
X(2Ø)	2Ø	Ø.Ø21	-Ø.Ø5Ø	Ø.443	-Ø.37Ø	-Ø.232	Ø.616	-Ø.325
X(21)	21	Ø.329	Ø.118	Ø.42Ø	-Ø.592	Ø.351	Ø.182	Ø.4Ø5
X(22)	22	-Ø.476	-Ø.744	-Ø.143	Ø.198	-Ø.1Ø8	-Ø.1ØØ	-Ø.Ø61
X(23)	23	-Ø.154	Ø.387	-Ø.783	-Ø.356	-Ø.161	Ø.198	-Ø.Ø6Ø
X(24)	24	-Ø.Ø34	Ø.924	Ø.Ø52	Ø.Ø39	-Ø.291	-Ø.128	-Ø.118
X(25)	25	-Ø.833	-Ø.158	-Ø.422	Ø.Ø78	Ø.226	-Ø.118	-Ø.Ø32
X(26)	26	-Ø.852	-Ø.434	Ø.Ø1Ø	-Ø.211	Ø.Ø55	Ø.Ø33	Ø.Ø46
X(27)	27	Ø.83Ø	Ø.18Ø	Ø.195	Ø.14Ø	-Ø.135	-Ø.Ø96	-Ø.Ø95
X(28)	28	Ø.523	Ø.276	-Ø.331	-Ø.596	Ø.Ø26	Ø.341	Ø.184
X(29)	29	-Ø.726	-Ø.Ø63	Ø.52Ø	Ø.1Ø7	Ø.26Ø	-Ø.263	Ø.1Ø7
X(3Ø)	3Ø	-Ø.966	-Ø.Ø92	-Ø.Ø74	-Ø.169	Ø.Ø18	-Ø.Ø14	-Ø.ØØ4

TABLE VI.20 : SORTED, ROTATED FACTOR LOADINGS

	FACTOR 1	FACTOR 2	FACTOR 3	FACTOR 4	FACTOR 5	FACTOR 6	FACTOR 7
30	-0.947	0.000	0.000	0.000	0.000	0.000	0.000
4	0.928	-0.258	0.000	0.000	0.000	0.000	0.000
1	0.922	-0.321	0.000	0.000	0.000	0.000	0.000
5	0.906	-0.288	0.000	0.000	0.000	0.000	0.000
12	0.890	0.000	0.000	0.304	0.000	0.000	0.000
27	0.861	0.000	0.000	0.000	0.000	0.000	0.000
26	-0.860	-0.323	-0.304	0.000	0.000	0.000	0.000
2	0.850	-0.331	0.325	0.000	0.000	0.000	0.000
25	-0.823	0.000	0.000	-0.287	0.350	0.000	0.000
24	0.000	0.949	0.000	0.000	0.000	0.000	0.000
7	0.000	-0.855	0.000	0.000	0.000	0.000	0.329
6	0.000	-0.791	0.000	0.000	0.000	-0.299	0.000
19	-0.450	0.773	0.000	0.000	0.000	0.000	0.000
15	0.000	0.735	0.000	0.000	0.000	0.000	0.299
14	-0.327	0.712	-0.328	0.000	0.000	0.000	0.000
22	-0.445	-0.568	-0.257	-0.466	0.000	0.000	0.000
23	-0.397	0.000	0.868	0.000	0.000	0.000	0.000
13	0.380	0.000	0.824	0.000	0.000	0.000	-0.267
29	-0.519	0.000	-0.808	0.000	0.000	0.000	0.000
28	0.000	0.000	0.743	0.551	0.000	0.000	0.000
3	-0.306	0.376	-0.719	0.358	0.000	0.000	0.274
21	0.000	0.000	0.000	0.912	0.000	0.000	0.000
18	-0.275	0.484	0.000	0.000	0.808	0.000	0.000
8	0.000	0.547	0.000	0.000	0.786	0.000	0.000
17	0.474	0.492	0.000	0.000	-0.650	0.000	0.000
10	0.000	0.000	-0.312	0.000	0.000	0.808	0.000
16	-0.343	-0.278	0.000	-0.396	0.000	0.727	0.000
11	0.375	0.000	0.000	0.000	0.000	0.722	-0.372
20	0.000	0.000	0.000	0.000	0.000	0.000	0.914
9	0.000	0.352	0.472	0.457	0.000	0.000	-0.501

TABLE VI 21: ESTIMATED FACTOR SCPRES

CASE NO.	FACTOR 1	FACTOR 2	FACTOR 3	FACTOR 4	FACTOR 5	FACTOR 6	FACTOR 7
1	-Ø.7Ø4	-1.Ø56	-Ø.459	-1.835	-Ø.Ø37	-Ø.348	-Ø.Ø72
2	-Ø.396	-1.582	-Ø.514	-1.688	Ø.383	-1.297	-Ø.13Ø
3	-Ø.916	-Ø.685	-Ø.745	1.Ø24	-Ø.613	Ø.Ø52	Ø.226
4	-1.Ø98	-Ø.648	-Ø.Ø83	-Ø.758	-Ø.274	3.247	-Ø.17Ø
5	-1.54Ø	Ø.695	3.366	-Ø.175	Ø.484	-Ø.568	Ø.Ø54
6	-Ø.393	1.699	-1.225	-Ø.Ø98	3.177	Ø.2ØØ	-Ø.226
7	-1.223	-1.265	-1.56Ø	2.238	Ø.288	-1.Ø74	-1.Ø14
8	-Ø.896	2.466	-1.Ø33	-Ø.753	-2.Ø97	-Ø.698	-Ø.743
9	-Ø.634	Ø.412	-Ø.451	1.Ø31	-Ø.431	-Ø.ØØ1	2.728
1Ø	Ø.515	-Ø.Ø47	Ø.444	Ø.477	-Ø.376	Ø.446	-Ø.857
11	1.252	Ø.216	-Ø.1Ø8	-Ø.3ØØ	-Ø.Ø17	-Ø.4Ø7	Ø.3Ø4
12	Ø.84Ø	-Ø.141	Ø.177	-Ø.Ø47	-Ø.376	Ø.446	-Ø.857
13	1.Ø59	Ø.Ø89	Ø.172	-Ø.111	-Ø.Ø45	Ø.Ø37	-Ø.Ø71
14	Ø.779	Ø.319	Ø.215	Ø.946	-Ø.26Ø	Ø.8Ø4	-Ø.997
15	1.222	-Ø.225	Ø.229	Ø.424	Ø.Ø93	Ø.451	-Ø.498
16	1.214	-Ø.Ø5Ø	Ø.369	-Ø.24Ø	Ø.Ø89	-Ø.3Ø3	-Ø.387
17	Ø.919	-Ø.196	Ø.2Ø5	-Ø.135	Ø.Ø59	Ø.Ø37	2.126

From the Fig. 6.13 another distinct cluster can be located, that consists of characters spike length (6), peduncle length (7) spike orientation (19), berry shape (24), L.L/Sp.L (8), and spike shape (18). From Table VI.20 it is found that characters 18 and 8 can be taken as a separate cluster in view of the correlations. Again referring to Table 6.20 we see that factor 2 has high loadings on the characters 6, 7, 19 and 24 along with 14 (leaf shape) and 15 (leaf base). However, from Figs. 6.13 and 6.14 it can be concluded that 14 and 15 can be treated as a separate group. Hence factor 2 can be taken to represent characters 6, 7, 19 and 24.

A study of the cluster tree (Fig. 6.14) as well as the correlation matrix (fig. 6.13) indicates that the other characters in the lower half are more or less independent. In Table VI.20 Factor 4 has high loadings on the character 21 (bract type) Factor 5 has high loadings on the characters 8 (L.L/Spike.L) and 18 (spike shape), thus justifying the decision to consider these two variables as a separate group.

Factor 6 shows high loadings on 16 (leaf texture) 10 (guard cell length) and 11 (guard cell breadth), though neither the cluster tree, nor the correlation matrix shows this pattern. Factor 7 shows high factor loadings only on the character 20 (spike texture) and thus can be taken to represent this character.

Thus the principal component leads to the following seven factors.

Factor 1 : Leaf length, leaf breadth, leaf size index, petiole length, distance from leaf base to the 2nd pair of ribs, berry colour changes, berry taste, plant type and thrips infestation.

Factor 2 : Spike length, peduncle length, spike orientation and berry shape.

Factor 3 : Leaf length/leaf breadth; rib number, growth habit, distribution..

Factor 4 : Bract type

Factor 5 : Leaf length/spike length; spike shape.

Factor 6 : Guard cell length, guard cell breadth, and leaf texture

Factor 7 : Spike texture

Dispersion of *Piper* Spp. in factor space:-

As in the case of pepper cultivars it is possible to construct dispersion maps of *Piper* spp. by plotting factor scores. Fig. 6.16, 6.17 and 6.18 show the dispersion of *Piper* spp. with regard to the first three factors taking two factors at a time. Fig. 6.16 shows the dispersion of the 17 OTUs with respect to factors 1 and 2. It is seen that the 8 OTUs from 10 - 17 are grouped into a close cluster, seven of these are *P. nigrum* wild collections and eighth one is *P. nigrum* var. *hirtellosum*.

OTU 8 (P.silentvalleyensis) was found to have a large difference on the Y-axis representing factor 2 (characters spike length, peduncle length, spike orientation, berry shape). OTU 6 (P.mullesua) is also found to show a large difference on the Y-axis. OTUs 8, 6, 5, 9, 7 and 4 are more or less well spread indicating the relative independence of these OTUs with respect to factors 1 and 2. OTUs 1 and 2 (P.argyrophyllum and P.attenuatum) are the only species showing close positioning, indicating their closeness with respect to factors 1 and 2. This is further supported by the centroid analysis also.

Fig. 6.17 gives the dispersion of the OTUs between factor 1 and 3. The most interesting feature of this pattern is the position occupied by OTU 5 (P.longum) which showed a very large difference from the Y-axis representing factor 3 (L.L/L.B, rib number, growth habit and distribution). All other OTUs cluster into two groups, one representing OTU 10 - 17 (P.nigrum) and other consisting of the remaining OTUs.

Fig. 6.18 shows the dispersion pattern with respect to factors 2 to 3. Both OTUs 6 and 8 show large differences from the Y-axis. It is also seen that 5, 6, 8, 3 and 9 are more or less independently distributed with respect to factor 2 and 3, while OTUs 10 - 17 and 4 form one cluster. OTUs 2, 7, 1 and 3 form yet another cluster indicating the closeness of these OTUs with respect to these characters.

FIG. VI. 16 DISPERSION OF PIPER Spp. BETWEEN 1st AND 2nd PRINCIPAL COMPONENTS

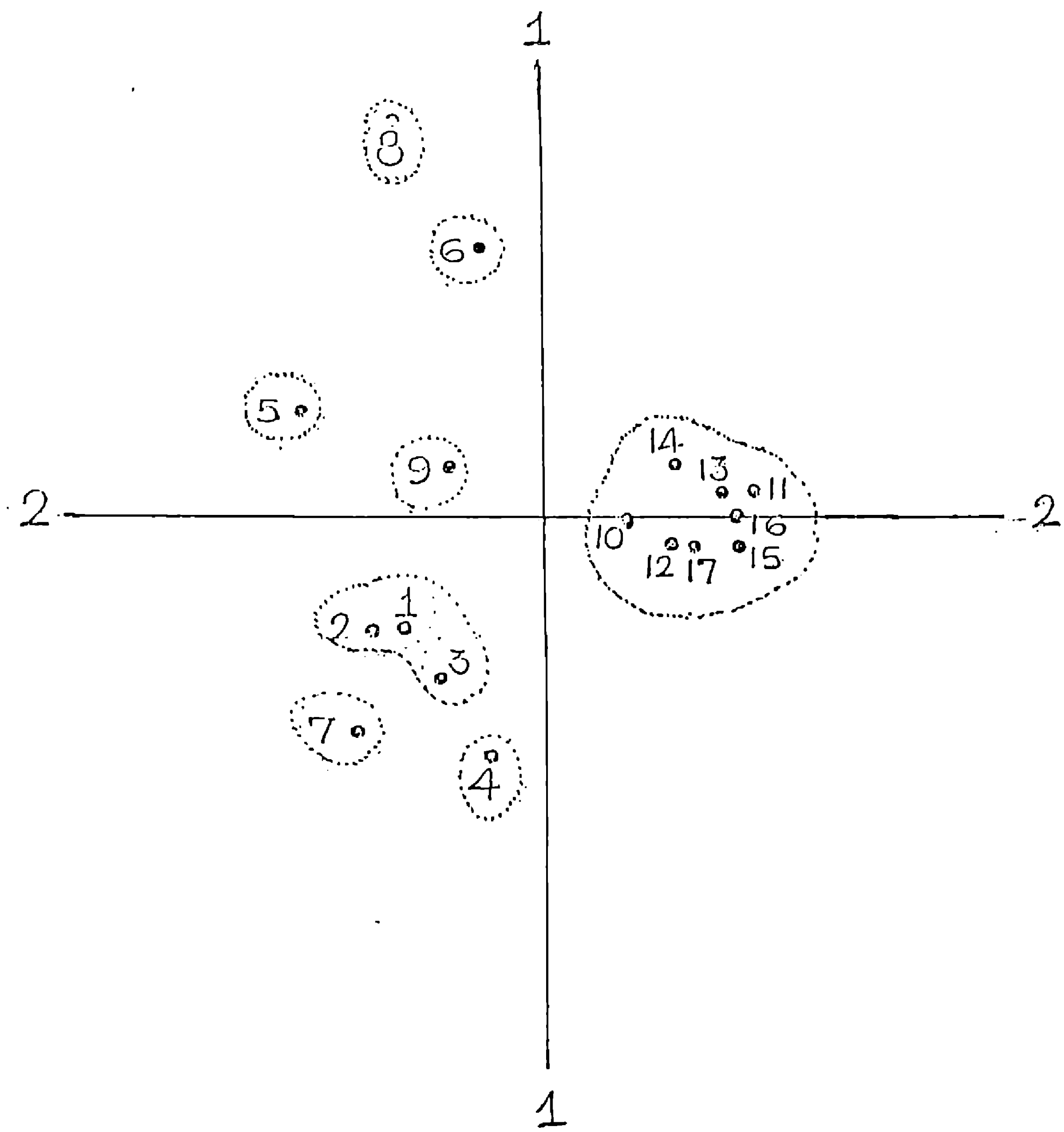


FIG. VI. 17 DISPERSION OF PIPER Spp. BETWEEN 1st AND 3rd PRINCIPAL COMPONENTS

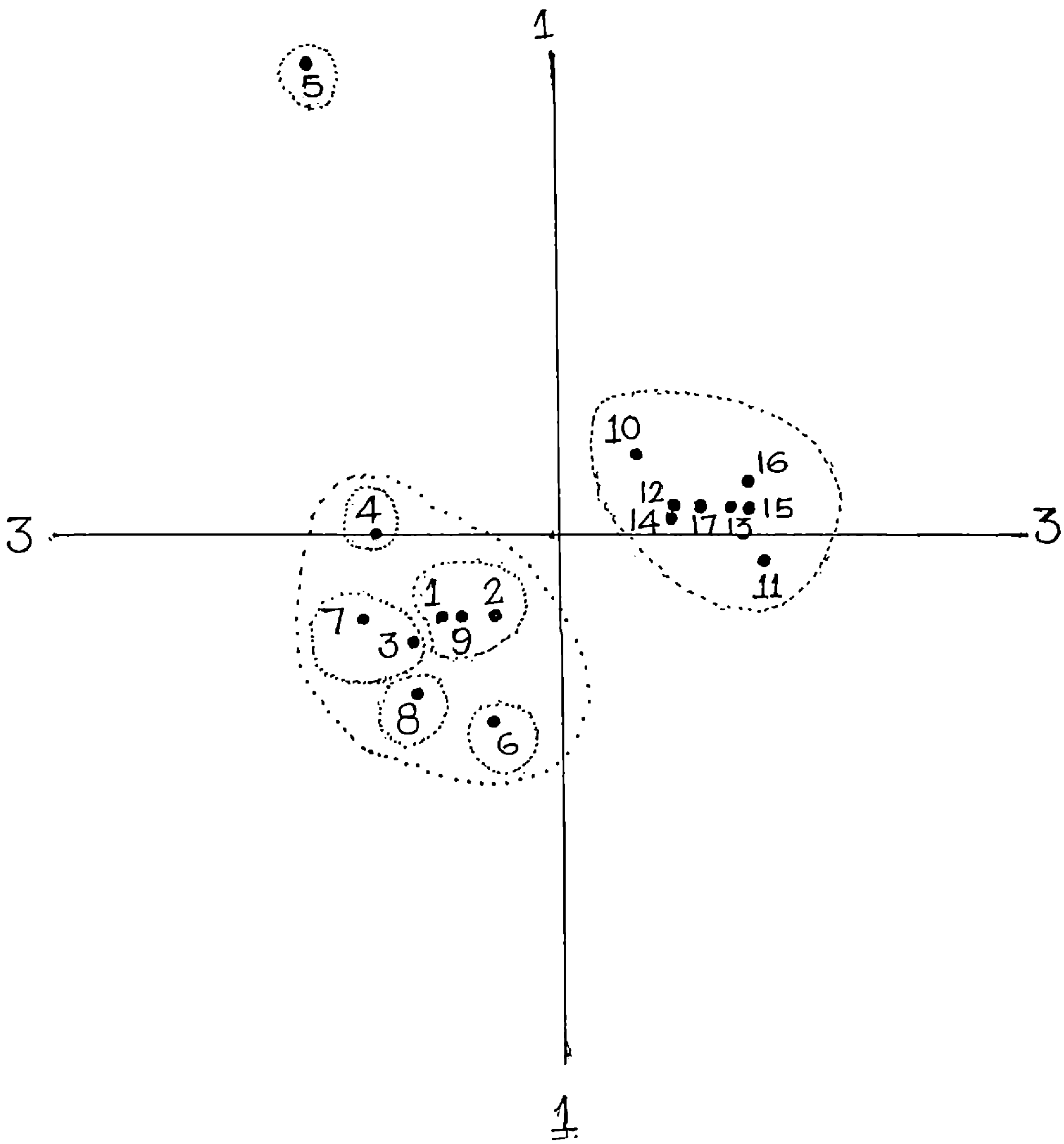
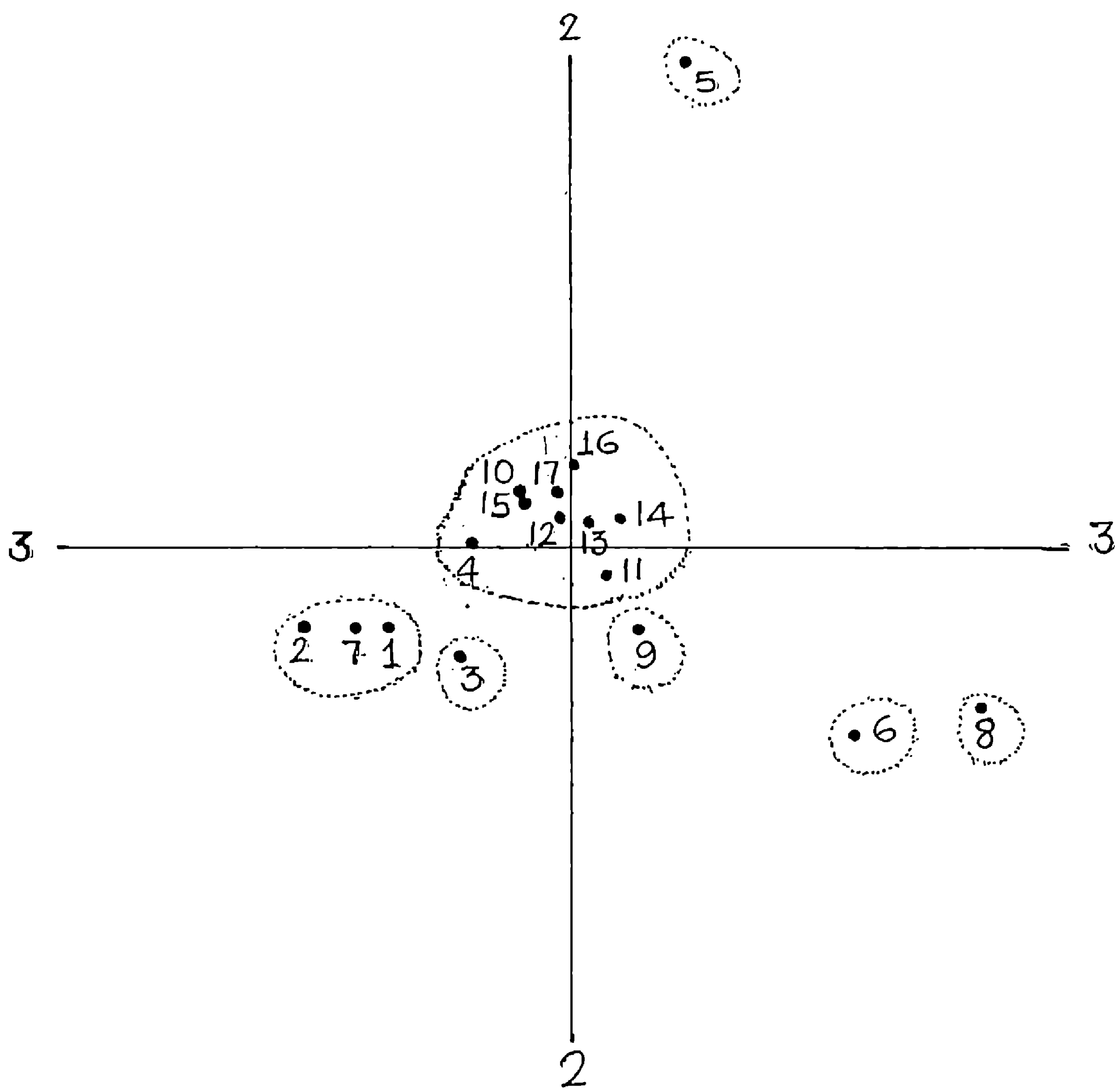


FIG. VI. 18 DISPERSION OF PIPER Spp. BETWEEN 2nd AND 3rd PRINCIPAL COMPONENTS



Clustering of Piper spp. by centroid linkage

The results of the centroid linkage analysis is presented in Table VI.22 which gives the details of the amalgamation process. In Fig. 6.19 the distances between the combinations of the 17 OTUs are presented in a shaded form. The advantage of this matrix of shades is that it gives an idea on the possible grouping of species based on the intensity of shading (heavier shades indicate closer spacing). The clustering of species is diagrammatically shown in the form of a dendrogram in Fig. 6.20. The Tocher's clustering method (Rao, 1952) was used to work out groups of related species, arriving finally at six distinct groups. The intra and inter cluster distances are again shown in the form of a distance matrix (in 8 different shades) in Fig. 6.21.

The cluster A represents OTU's 1 (P.argyrophyllum) and 2 (P.attenuatum), cluster B consists of OTU 3 (P.galeatum), 7 (P.schmidtii) and 9 (P.trichostachyon).

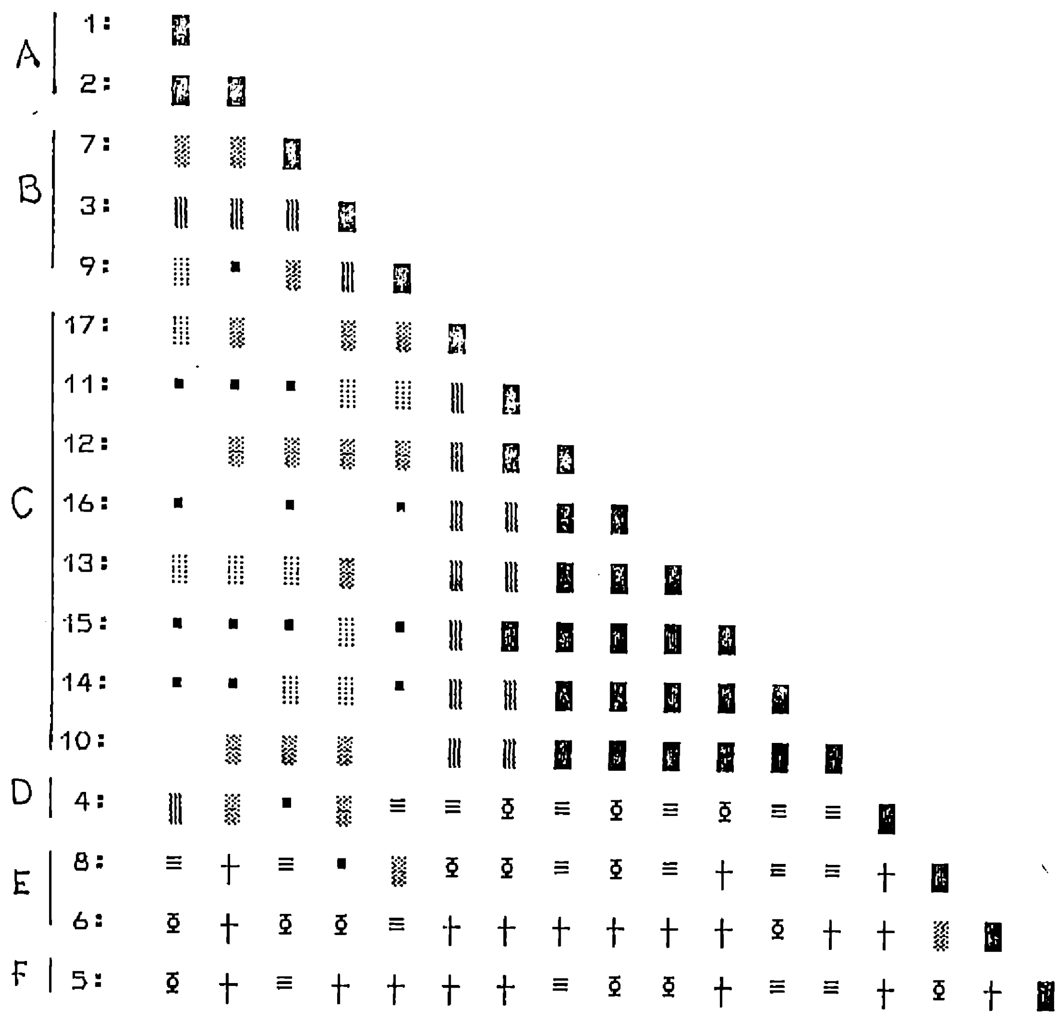
Cluster C is the largest group consisting of 8 OTU s (10 - 17). All the P.nigrum collections and P.nigrum var. hirtellosum have clustered under this group.

Cluster D consists of P.hymenophyllum (OTU 4), Cluster E consists of OTU s 8 and 6 (P.silentvalleyensis and P.mullesua respectively). Cluster F consists of P.longum.

TABLE. 22 : CENTROID LINKAGE OF *Piper* Spp.

No.	Cases		No. of Cases	Distance
1	16	13	2	1.782
2	13	12	3	2.Ø68
3	15	12	4	2.483
4	14	12	5	2.425
5	12	1Ø	6	2.783
6	2	1	2	3.244
7	11	1Ø	7	3.477
8	17	1Ø	8	4.Ø95
9	7	3	2	4.83Ø
1Ø	3	1	4	5.ØØ7
11	9	1	5	5.921
12	1Ø	1	13	6.2Ø8
13	8	6	2	7.137
14	4	1	14	7.472
15	6	1	16	7.694
16	5	1	17	8.325

FIG. VI.19 DISTANCES AMONG *Piper* Species IN SORTED AND SHADED FORM



EXPLANATION :

: Distance between OTUs < 3.593

: Distance between OTUs 3.593 - 6.086

: Distance between OTUs 6.086 - 7.296

||| : Distance between OTUs 7.296 - 7.846

▪ : Distance between OTUs 7.846 - 8.579

≡ : Distance between OTUs 8.579 - 9.275

ō : Distance between OTUs 9.275- 9.899

† : Distance between OTUs > 9.899

FIG. VI. 20 CLUSTERING OF Piper Species BY CENTRIOD LINKAGE

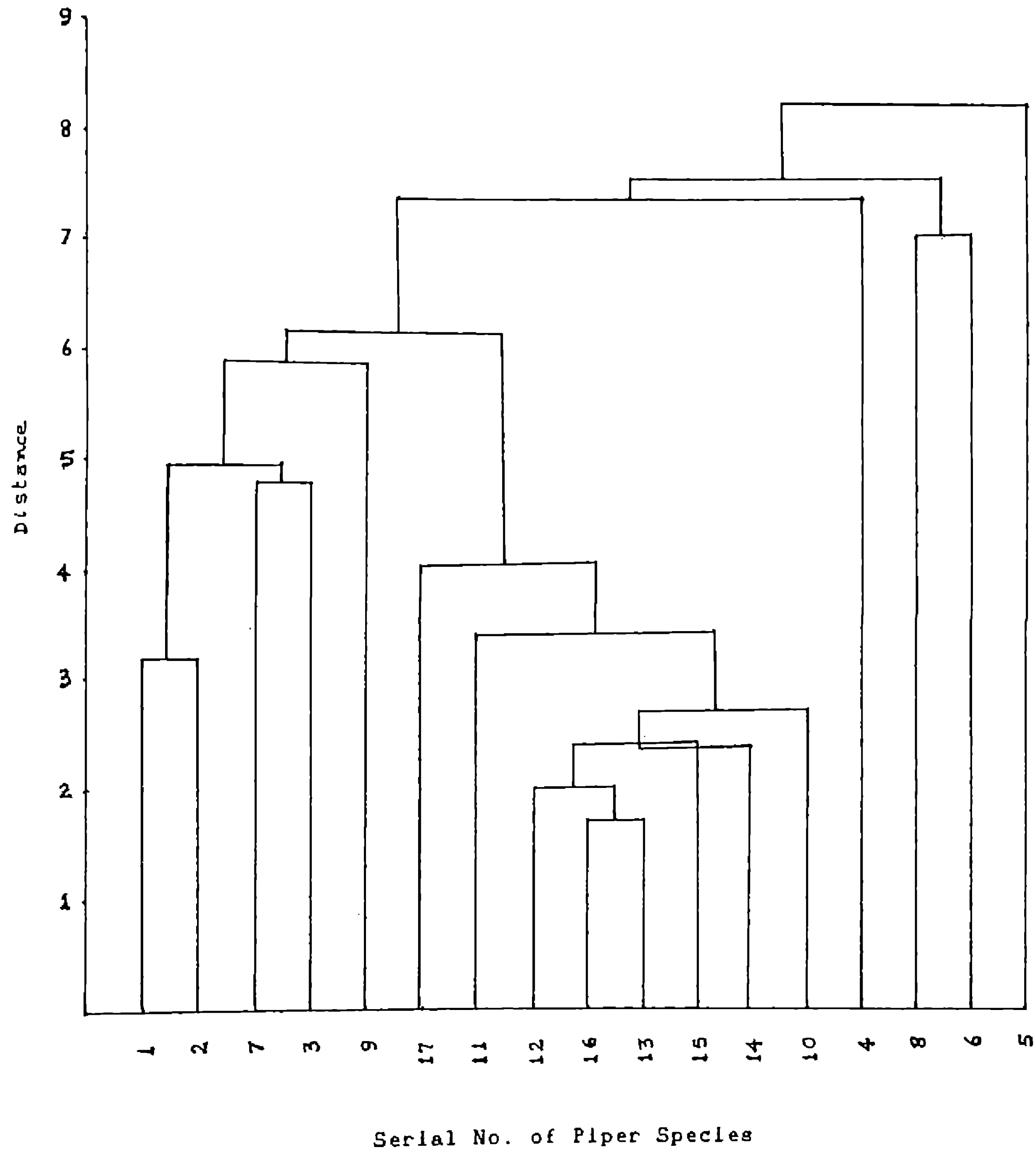
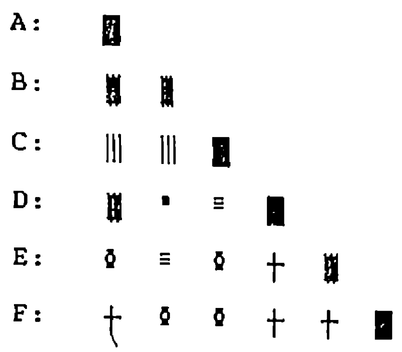


FIG. VI. 21

INTRA AND INTER CLUSTER DISTANCES AMONG *Piper* Species IN SHADED FORM



CLUSTER A: OTU Nos 1,2

CLUSTER B: OTU Nos 3,7,9

CLUSTER C: OTU Nos 10,11,12,13,14,15,16,17

CLUSTER D: OTU No 4

CLUSTER E: OTU Nos 8,6

CLUSTER F: OTU No 5

EXPLANATION :

■ : Distance between OTUs < 3.593

▓ : Distance between OTUs 3.593 - 6.086

▒ : Distance between OTUs 6.086 - 7.296

||| : Distance between OTUs 7.296 - 7.846

▪ : Distance between OTUs 7.846 - 8.579

≡ : Distance between OTUs 8.579 - 9.275

ǫ : Distance between OTUs 9.275- 9.899

+ : Distance between OTUs > 9.899

The inter cluster differences in Fig. 6.20 also shows that cluster A, B and D are somewhat related. The clusters E and F are the most distinct.

The role of 7 factors in species divergence

In the previous section on clustering of Piper spp., the distance between any two species was computed in data space (i.e. based on the variability shown by the 30 characters over 17 OTUs). It is now important to know how far the characters themselves have contributed to the divergence of the given set of 17 OTUs. The results of the factor analysis come in handy to achieve this aim. We know that when a set of characters are closely related, it is better to consider the divergence between species in terms of this related group rather than the individual variables themselves. In other words we can as well consider the distance between the species in terms of the factor we have arrived at: thus a regrouping of the species in factor space could well be considered. But such a regrouping based on each factor will be less useful from practical point of view. Rather, we can just take the grouping that we arrived at using the distance in data space and see how far the factors play their role in such a grouping. Table 6.21 gives the factor scores for the 17 OTUs for the seven factors and based on these factor scores the D^2 values between all possible combinations were worked out for individual factor scores. Again based on the earlier scheme of grouping the average intra and inter cluster D^2 values were computed. The results are presented in Table VI.23. From this table it is clear that for factor 1 the inter cluster D^2 values for the cluster C with the other clusters are relatively high (combination AC, BC, CD, CE and CF), thus showing the importance of this factor in delineation of cluster C from others.

Coming to factor 2 we find that the inter cluster D^2 values for the cluster E with the other clusters are quite high, thus highlighting, the importance of factor 2 in dilineating cluster E from others. Taking factor 3 it is the inter-cluster distance between cluster F and others that are fairly high relative to other inter-cluster distances showing the importance of factor 3 in dilineating clusters F from others.

Factor 4 like-wise is important in delineating cluster B from others. Factor 5 is important in differentiating cluster E (in addition to factor 2) from others. Factor 6 is important in differentiating cluster D from others and factor 7 is important in differentiating cluster B (in addition to factor 4).

Thus the factor analysis not only helps in identifying related characters but also in identifying the role of factors in species diversification.

TABLE VI.23 : AVERAGE INTER AND INTRA-CLUSTER DISTANCES (D^2) IN FACTOR SPACE:

D^2-VALUES WITH RESPECT TO INDIVIDUAL FACTORS

Combinations	FAC-1	FAC-2	FAC-3	FAC-4	FAC-5	FAC-6	FAC-7	TOTAL
A, A	Ø.Ø9	Ø.28	Ø.ØØ	Ø.Ø2	Ø.18	Ø.9Ø	Ø.ØØ	1.48
A, B	Ø.18	1.2Ø	Ø.Ø2	1Ø.52	Ø.38	Ø.73	2.98	16.Ø6
A, C	2.41	1.83	Ø.51	3.74	Ø.16	1.21	Ø.85	1Ø.71
A, D	Ø.33	Ø.52	Ø.17	1.Ø1	Ø.25	16.79	Ø.Ø1	19.Ø6
A, E	Ø.1Ø	11.79	Ø.43	1.9Ø	7.13	Ø.76	Ø.22	21.56
A, F	1.Ø1	4.13	14.84	2.53	Ø.14	Ø.29	Ø.Ø3	22.95
B, B	Ø.17	1.45	Ø.Ø4	Ø.98	Ø.45	Ø.81	7.27	11.18
B, C	3.73	Ø.78	Ø.67	2.2Ø	Ø.21	Ø.63	3.8Ø	12.Ø1
B, D	Ø.Ø9	Ø.5Ø	Ø.27	5.12	Ø.15	13.14	3.36	22.36
B, E	Ø.2Ø	7.37	Ø.32	3.88	7.73	Ø.48	3.77	23.74
B, F	Ø.44	1.94	15.63	2.9Ø	Ø.69	Ø.32	2.77	24.7Ø
C, C	Ø.14	Ø.Ø8	Ø.Ø5	Ø.39	Ø.Ø9	Ø.46	1.93	3.14
C, D	4.36	Ø.45	Ø.11	Ø.95	Ø.Ø7	1Ø.36	Ø.85	17.14
C, E	2.74	4.54	1.83	Ø.58	7.41	Ø.5Ø	1.Ø7	18.69
C, F	6.38	Ø.52	9.97	Ø.26	Ø.39	Ø.6Ø	Ø.86	18.99
D, D	Ø.ØØ	Ø.ØØ	Ø.ØØ	Ø.ØØ	Ø.ØØ	Ø.ØØ	Ø.ØØ	Ø.ØØ
D, E	Ø.27	7.61	1.1Ø	Ø.22	7.62	12.42	Ø.16	29.4Ø
D, F	Ø.2Ø	1.8Ø	11.9Ø	Ø.34	Ø.57	14.55	Ø.Ø5	29.41
E, E	Ø.25	Ø.59	Ø.Ø4	Ø.43	27.82	Ø.81	Ø.27	3Ø.2Ø
E, F	Ø.87	2.Ø8	2Ø.22	Ø.17	6.96	Ø.3Ø	Ø.36	3Ø.94
F, F	Ø.ØØ	Ø.ØØ	Ø.ØØ	Ø.ØØ	Ø.ØØ	Ø.ØØ	Ø.ØØ	Ø.ØØ

CLUSTER A: OTU NOs. 1,2
CLUSTER B: OTU NOs. 3, 7, 9
CLUSTER C: OTU NOs. 1Ø to 17
CLUSTER D: OTU NO. 4
CLUSTER E: OTU NOs. 6, 8
CLUSTER F: OTU NO. 5

VALUES SIGNIFICANT ARE UNDERSCORED

CHAPTER VII

CHEMOTAXONOMICAL STUDIES ON *PIPER*

Introduction

Most chemical studies devoted to taxonomical problems deal with groups of secondary metabolites such as alkaloids, flavonoids, terpenoids etc. The usefulness of these chemical compounds in taxonomy and phylogeny has been discussed by many authors (Alston and Turner, 1963; Swain, 1963; Smith, 1976; Harborne and Turner, 1984 etc.)

Flavonoids are the most important group of secondary metabolites used in taxonomic studies. Considerable amount of information has been accumulated on their application in systematics and phylogeny (Harborne, 1975, 1977; Harborne *et al* 1975; Swain, 1976; Giannasi, 1978; Crawford, 1978; Harborne and Turner, 1984). In the 1960's Bate-Smith and colleagues (Bate Smith, 1962; Bate-Smith and Whitmore, 1959; Bate-Smith and Richer, 1973) applied flavonoid and phenolics data for elucidating the taxonomy of various groups and genera. Alston and Turner (1959) have extended the study of comparative chemical data to the investigation of natural hybridisation, including the validation of hybrids, population structure and introgression. Their studies proved that flavonoids were extremely reliable taxonomic guides. Even widespread phenolics such as leucoanthocyanidins, phenolic acids and flavonols may have taxonomic value, but greater taxonomic interests are attached to the occurrences and distribution of rare phenolic glycosides and aglycones. As stated by Smith (1976) "it is the discontinuous distribution of rarer phenolics and the correlated occurrences or absences of commoner ones which offer potential valuable evidence to a taxonomist".

Flavonoids and their role in taxonomic categorisation have been studied in Aristolochaceae (Das et al 1966); Rutaceae (Fish and Waterman, 1973); Pomoideae (Challice, 1973); Saxifragaceae (Collins & Bohm, 1974; Collins et al 1976); Dilliniaceae (Gurni and Kubitzski, 1981) etc. Generic relationships in Ulmaceae were studied by Giannasi based on flavonoid chemistry.

In the present study stress has been given to the qualitative similarities and differences in flavonoids among the black pepper cultivars and the related species of Piper. These were studied based on flavonoid spot patterns appearing on paper chromatograms.

Flavonoid patterns of black pepper cultivars

The flavonoids analysed by descending paper chromatography gave 15 spots in total. The number of spots obtained varied from 8 to 13 in the different cultivars. The lowest number of spots was given by two cultivars -- Cholamundi and Vadakkan, the highest was in Panniyur-1. The spot pattern is given in Table VII.1.

Table VII.1 Analysis of methanol extract by paper chomatography: Spot Pattern among Pepper cultivars

Spot numbers and their Rf values

Cultivar code No.	.25 1	.32 2	.40 3	.45 4	.50 5	.56 6	.60 7	.65 8	.70 9	.75 10	.80 11	.84 12	.86 13	.89 14	.93 15
1	+	-	+	-	+	+	+	-	+	+	-	+	-	+	+
2	-	-	+	-	+	+	-	+	+	+	+	+	-	-	+
3	+	+	+	-	+	+	+	+	+	-	+	-	-	+	+
4	-	+	+	-	+	+	-	+	+	-	+	+	-	-	+
5	+	-	-	+	+	-	+	+	+	+	+	-	+	+	+
6	-	-	+	-	+	+	+	+	-	+	+	+	-	+	+
7	+	+	+	+	-	-	+	-	+	+	+	-	+	-	+
8	+	-	-	-	+	+	+	-	+	-	+	-	-	+	+
9	-	+	-	-	+	+	-	+	+	+	+	+	-	+	+
10	-	+	-	+	+	+	+	-	+	+	+	+	+	+	+
11	-	+	+	+	-	+	+	+	-	+	+	+	-	+	+
12	+	+	+	-	+	+	+	+	-	+	+	+	-	-	+

Table VII.1 Cont...

Spot numbers

Cv. No.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
13	+	+	-	+	+	+	-	+	+	+	+	-	+	+	+
14	+	+	+	-	+	+	-	+	+	+	-	+	-	-	+
15	+	-	+	+	+	+	+	-	+	+	+	+	-	+	+
16	+	+	-	+	-	-	+	+	+	-	+	+	-	+	+
17	+	-	+	-	+	+	+	+	-	+	-	+	+	+	+
18	-	+	-	+	+	+	-	+	+	-	+	+	+	-	+
19	+	+	+	-	+	-	+	+	+	-	+	-	+	-	+
20	-	+	+	+	+	-	+	-	+	-	+	+	-	+	+
21	-	+	+	+	+	+	-	+	+	+	-	+	-	-	+
22	+	-	+	+	-	+	+	+	+	+	+	-	-	+	+
23	+	-	-	+	+	+	-	+	+	+	+	-	-	+	+
24	+	-	-	+	+	-	-	+	+	+	+	+	-	+	+
25	+	-	+	+	-	+	+	+	+	+	-	+	-	-	+
26	+	-	+	+	-	+	+	+	+	-	+	+	-	-	-
27	+	+	-	-	+	+	+	+	-	+	+	+	-	+	+
28	-	+	+	-	+	+	+	-	+	-	+	+	-	+	+

Table VII.1 Cont...

Spot numbers

Cv. No.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
29	+	+	+	+	+	+	+	+	+	-	+	+	+	-	+
30	+	+	-	-	+	+	+	+	-	+	-	+	+	+	+
31	-	-	-	+	+	+	+	+	+	+	-	+	-	+	+
32	-	+	-	-	+	+	+	+	+	-	+	+	+	+	+
33	+	+	+	-	+	+	+	+	-	+	-	+	-	+	+
34	+	+	-	+	+	+	-	+	+	+	+	+	-	+	+
35	-	+	+	+	-	+	+	+	+	-	+	-	-	+	+
36	+	-	+	+	+	+	-	+	+	+	+	+	-	+	+
37	+	+	-	+	+	+	+	+	-	+	+	-	+	+	+
38	-	+	-	-	+	-	+	+	+	+	-	+	+	-	+
39	+	-	-	-	+	-	+	+	-	+	+	+	-	-	+
40	+	+	+	-	+	+	+	+	+	+	+	-	-	+	+
41	+	+	+	+	-	-	+	+	+	+	+	-	-	+	+
42	+	+	+	+	+	+	-	+	-	+	+	-	+	+	+
43	-	+	+	-	-	+	+	-	+	+	+	-	+	+	+
44	+	-	+	+	+	+	-	+	+	-	+	-	-	+	+

Table VII.1 Cont...

Spot numbers

Cv. No.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
45	+	-	-	-	+	+	-	+	+	+	+	-	+	+	+
46	+	-	-	+	+	+	-	+	+	-	+	+	-	+	+
47	+	+	-	+	+	+	+	[illegible]	+	+	+	+	-	+	+
48	+	-	-	+	-	+	+	+	+	-	+	-	+	-	+
49	+	+	+	+	-	+	+	[illegible]	+	+	+	+	-	-	+
50	+	-	-	+	-	+	+	+	-	+	+	+	-	-	+
51	+	-	-	+	-	+	+	+	-	+	-	+	+	-	+

The first spot at Rf Ø.25 appeared in 36 cases out of the 51 studied. This spot was blue green to blue under UV. The second spot at Rf Ø.32 was recorded in 3Ø cases. This spot was yellow to yellow brown under UV in 27 cases, but in three cultivars the spot was pale purple under UV light. The third spot at Rf Ø.4 was noted in 26 cases. Under UV light this spot was yellowish brown in 9 cases, while in 15 cases the colour was yellowish green. In two cultivars the spot was pale pink. The spot at Rf Ø.45 was present in 3Ø of the cultivars studied. This spot was present in six out of seven wild collections studied. This spot was yellowish brown in 19 types, bluish green in 6, and pale pink in five cases. Among the wild collections 5 of them showed bluish green spot while in one it was pale pink. The spot at Rf Ø.5 was prsent in 38 of the 51 cases studied. In 17 of them the spot was yellowish brown, in 13 it was greenish yellow and in 8 pale pink.

The spot at Rf Ø.55-Ø.56 had shown up in 4Ø of the 51 cases studied. This spot was found in all the seven wild nigrum types studied. The spot was yellow to yellowish brown in most of the cases though in a few the colour was yellowish green. The spot at Rf Ø.6 was recorded in 36 cases studied. The spot colour under UV was yellowish green or rarely bluish green. The spot at Rf Ø.65 appeared in 41 of the 51 cases studied. The spot was yellowish brown or bluish green in all the cases except in two instances where the spot was pale purple. The spot at Ø.8 had shown up in 41 of the cases. This spot was bluish to yellowish green in 24 of the cases, in 14 the spot colour was yellowish brown and in three the spots were purple.

The spot at Ø.84 had shown up in 33 cases out of 51. This spot was bluish green or yellowish brown in 3Ø cases, while in three the spots were purple. The spot at Ø.86 appeared in 17 cases. This spot was yellow to yellowish brown in 12 cases, bluish green in 3 cases, and light purple in 2 cases. The spot at Ø.89 was present in 33 cultivars and it was yellowish brown in all the cases. The spot at Ø.93-Ø.94 appeared in 5Ø of the cases, the only exception being the cv. Nedumchola. The spot was reddish orange under UV light.

Chemical Similarity

Based on the flavonoid pattern the percentage chemical similarities were computed between each of the cultivars. These values, known as paired affinity indices (PAI) or Percentage similarity indices (PSI), are measures of chemical similarities between any two cases (Table VII.2).

Aimpiriyan (cv.1) showed 75% chemical similarity, with two cultivars, Kalluvally and Kottanadan. Lesser resemblances were noticed with Thulamundi and Valiakaniakkadan (69%), Cheriyakaniakkadan (67%), Ottaplackal (67%), Perumkodi and

Sagar Local (67%), Cholamundi (64%) and Arimulaku (62%). The least affinities were noticed with wild pepper Acc.2059 (36%), Kuching (40%), and Cheppukulamundi (43%).

Arrakkulammunda (No.2) had close chemical similarity with Balancotta (80%) followed by Thulamundi (75%). Lesser affinities were noted with Cheriyakaniakkadan, Jeerakamundi, Kalluvally (Pulpelly) and Kurimalai (all 73%). Kallubalancotta, Cheppukulamundi (36% each) Acc.2059, 2062 (38% each) had very poor affinity to Arakkulammunda.

Arimulaku (No.3) exhibited close resemblances to Valiakaniakkadan (92%), and to a lesser degree to Kuriyalmundi, Ottaplackal 1, Thommankodi and Vokkalu (all 75%). This cultivar had least similarity to Acc.2062 (33%) followed by Acc.2015 (43%) and Uthirancotta (43%).

Balancotta (No.4) had 80% chemical affinity with Arrakkulammunda, followed by Jeerakamundi, Kalluvally (Pulpelly) Kuriyalmundi and Ottaplackal 1 (all 73%). The affinity was lowest with Acc. 2062 and Bilimalligesara (33%) followed by Cheppukulamundi (36%).

Bilimalligesara (No.5) was having 77% affinity to Uddakkere and Karimkotta; 75% affinity with Acc.2077 and 73% affinity with Mundi as well as Narayakkodi. The lowest affinity was with Balancotta (33%) followed by Kalluvally and Sagar Local (40%).

Cheriyakaniakkadan (No.6) displayed 75% affinity with Kaniakkadan, Karuvilanchy, Kottanadan and Neyyattinkaramundi. The affinity was least in the case of Cheppukulamundi (33%) followed by Acc. No.2059 (38%). This cultivar was reported to be the pollen parent of the hybrid Panniyur 1, but the two exhibited only 53% chemical similarity.

Cheppukulamundi (No.7) had 75% chemical affinity with Vattamundi and to the wild pepper collection Acc. 2060. This cultivar had very poor affinity with Perumkodi (31%), Jeerakamundi and Cheriyakaniakkadan (33%).

The highest PSI given by Cholamundi (No.8) was 73% with Arimulaku. With Acc. 2062 and Uthirancotta, Cholamundi showed the lowest affinities (31%). The other cultivars, having very low affinity with Cholamundi are Kaniakkadan (36%), Cheppukulamundi, Kuching, Neelamundi and Sagar Local (38%).

Jeerakamundi (No.9) exhibited 75% affinity with Thevanmundi, Poonjaranmunda and Neyyattinkaramundi and 73% affinity with Balancotta. Jeerakamundi had the lowest PSI with Cheppukulamundi (33%), Nedumchola and with Acc. 2059 and 2062 (all 36%).

Karimunda (No.10) displayed rather high chemical affinity of 85% to one of the wild pepper collection (Acc. 2009). It had shown 71% PSI with Kalluvally (Type 2), Sagar Local and

Thulamundi. Its relationship was least with Nedumchola and Poonjaranmunda (40% each).

Kaniakkadan (No.11) had 75% chemical affinity with Cheriyakaniakkadan and Thommankodi. Kaniakkadan had shown 69% affinity to Karivilanchy, Malamundi, Neyyattinkaramundi, Vattamundi and to the wild collections Acc. 2015 and 2060. It had low affinity with Cholamundi (36%) and Kuriyalmundi (40%).

Karuvilanchy (No.12) displayed 91% chemical similarity with Sagar Local; 83% similarity with Neyyattinkaramundi, 77% with Valiakaniakkadan, and 75% with Kalluvally (Pulpelly) and Cheriyakaniakkadan. The lowest PSI (43%) was noted with a wild pepper (Acc. 2059) followed by Cholamundi (46%).

The cultivar Karimkotta (No.13) had 85% PSI with Thevanmundi, Udakkere and Vellanamban and 83% PSI with the wild coll. Acc. 2077. Karimkotta had also shown 77% flavonoid affinity with Billimalligesara. The least chemical affinity was noted with Vadakkan (43%).

Kalluvally (Pulpelly-No.14) has shown the highest PSI of 82% with Kurimalai and Sagar Local and 77% PSI with Karuvilanchy. Arakkulammunda and Balancotta gave 73% PSI with Kalluvally (Pulpelly). The lowest PSI were given by a wild collection (Acc. 2059) and by Cholamundi (38%).

Kalluvally (Malabar, No.15) had 85% similarity with Thulamundi and also with a wild coll. (Acc. 2060). This cultivar has given 83% PSI with Aimpiriyan and 77% with Malamundi. Its chemical affinity was least with Uthirancotta (40%).

Kallubalancotta (No.16) gave the highest PSI of 75% with Vattamundi, followed by 69% with wild pepper Acc.2009. This has given the lowest PSI of 36% with Arrakkulammunda.

Kottanadan (No.17) displayed 83% affinity with Perambramunda and 75% affinity with Aimpiriyan, Cheriyakaniakkadan and Sagar Local. Cheppukulamundi, Kallubalancotta, Kuching, Kuthiravally and Thommankodi had the lowest chemical affinity with Kottanadan giving a PSI of 40%.

Kuching (No.18), a cultivar introduced from Srilanka had given 77% PSI with Ottaplackal and 75% PSI with Poonjaranmunda. The lowest PSI were noted in the case of Cholamundi and Vadakkan.

Kuriyalmundi (No.19) exhibited 77% PSI with Panniyur 1; 75% PSI with Balancotta. Perumkodi showed the lowest PSI with Kuriyalmundi (33%).

Kuthiravally (No.20) was found to be chemically almost identical to Thommankodi (92%). Ottaplackal displayed 82% similarity with Kuthiravally. Wild pepper collections Acc.2062, 2077 and 2015 had very low affinity with Kuthiravally (PSI 27%, 33% and 36% respectively). Among the cultivars Vadakkan (38%), Perambramunda and Kottanadan (40% each) had very low affinity with Kuthiravally.

Kurimalai (No.21) exhibited somewhat good chemical affinity (82%) only with Kalluvally (Pulpelly). The chemical similarity was least with Cholamundi (29%) and with the wild pepper Ac.2059 (36%).

Malamundi (No.22) displayed chemical similarity of 83% with Vattamundi; 77% with Valiakaniakkadan and Kalluvally (Malabar), 75% with Mundi, Neelamundi, Thommankodi and Vokkalu. The lowest PSI were noted in the case of Uthirancotta (38%) and Kuching (40%).

Mundi (No.22) displayed 83% chemical affinity with Karimkotta, Thevanmundi and Thulamundi and 82% similarity with Narayakkodi, Vokkalu and with wild Acc.2071 and 2077. Both Malamundi and Bilimalligesara showed 75% chemical affinity with Mundi. Uthirancotta was the least related cultivar with a PSI of 36%.

Narayakkodi (No.24) provided 83% chemical affinity with Thulamundi and Thevanmundi and 82% affinity with Mundi. Bilimalligesara had 75% affinity with Narayakkodi. The lowest PSI was given by Velliyaranmunda (33%).

Neelamundi (No.25) displayed 86% flavonoid similarity with Thevanmundi, and 75% similarity with Malamundi and with a wild type collection (No.2060). It showed 73% similarity with Nedumchola and also with two of the wild collections (No.2015, 2062). The lowest PSI were noted with Jeerakamundi (36%) and Poonjaranmunda (40%).

(33%).

Poonjaranmunda (No.32) displayed 75% similarity with Jeerakamundi, Kuching and Ottaplackal 1. Its PSI values are very low with Cholamundi, Karimunda and Neelamundi (40% in all the cases).

Sagar Local (No.33) had very high chemical affinity (91%) with Karuvilanchy. This cultivar had also given 82% affinity with Kalluvally (Pulpelly) and 75% affinity to Kottanadan, Neyyattinkaramundi and Perambramunda. The affinity was lowest with Cholamundi and wild type No.2059 (38%).

Thevanmundi (No.34) displayed 86% PSI with Neelamundi, 85% with Karimkotta, Thulamundi and with a wild collection (No.2009). Thevanmundi also showed 83% similarity with Mundi, Narayakkodi and wild coll. 2071. Velliyarammunda had the lowest affinity to Thevanmundi (40%).

Thommankodi (No.35) had high chemical affinity to Kuthiravally (92%). This cultivar exhibited 75% PSI with Arimulaku, Kaniakkadan, Malamundi and Vattamundi. Its affinity was lowest (36%) with Uthirancotta, Vadakkan and with wild coll. 2062.

Thulamundi (No.36) has shown 85% chemical affinity with Kalluvally (Malabar) and Thevanmundi; 83% PSI with Malamundi, Mundi, Vokkalu and wild coll. 7071; and 75% affinity with Arakkulammunda and Perumkodi. The lowest PSI of 40% was noted in the case of Uthirancotta.

Nedumchola (No.26) exhibited 73% chemical affinity with Neelamundi. Its chemical affinity was found to be least with Uthirancotta (29%), followed by Perambramundi (32%) and Jeerakamundi (36%).

Neyyattinkaramundi (No.27) exhibited 83% chemical similarity with Karivilanchy and Perambramundi; 77% similarity with Thevanmundi, Vadakkan, Valiakaniakkadan and wild pepper Acc.2509. This cultivar also displayed 75% affinity to Cheriyakaniakkadan, Jeerakamundi and Sagar Local. Neyyattinkaramundi had the least affinity to Cheppukulamundi (40%) followed by Neelamundi and Coll. No.2059 (43% each).

Ottaplackal (No.28) showed 82% similarity with Kuthiravally and 77% similarity with Kuching and 75% similarity with Arimulaku and Poonjaranmunda. Its affinity was very low with the collection Acc.2062 (27%), 2015 (36%) and to the cultivar Vadakkan (38%).

Panniyur 1 (No.29) a hybrid black pepper cultivar, was found to exhibit the highest PSI of 77% with the cultivar Kuriyalmundi. Surprisingly its affinities to its reported parents were not very high; 57% and 62% respectively to Uthirancotta and Cheriyakaniakkadan. Its affinity was lowest with Cholamundi and Vadakkan (50%).

Perumkodi (No.30) had the highest PSI of 75% with Thulamundi, the lowest PSI was noticed between Perumkodi and Kuriyalmundi

Udakkere had 85% PSI with Karimkotta and Vellanamban, 77% PSI with Bilimalligesara, Neyyattinkaramundi and Perambramundi. Uddakkere had the lowest PSI of 40% with Arakkulammunda, Balancotta and Nedumchola.

Uthirancotta on the whole had low affinity with almost all the cultivars. The highest PSI of 67% was noted in the case of Perambramundi and Poonjaranmunda. Vokkalu and Nedumchola had the least affinity with Uthirancotta (27% and 29% respectively).

Vadakkan exhibited 73% affinity to Karivilanchy and Neyyattinkaramundi. Its similarity with other cultivars were rather low. The lowest PSI (29%) was noted in the case of Velliyaranmunda.

Valiakaniakkadan (No.40) displayed high chemical similarity (92%) with Arimulaku. It had 77% affinity with Karivilanchy, Malamundi, Neyyattinkaramundi and Vattamundi. The lowest PSI of 40% was given by the wild coll. 2062.

Vattamundi (No.41) had 83% similarity with Karivilanchy, 77% with Valiakaniakkadan, 75% with Cheppukulamundi, Kallubalancotta and Thommankodi. It had the lowest PSI (40%) with Kuching.

Vellanamban (42) had 85% chemical similarity with Karimkotta and Valiakaniakkadan. The lowest similarity was noted in the case of Nedumchola and Uthirancotta (40%).

Velliyaranmunda (No.43) gave the highest PSI of 69% with Karimunda and Valiakaniakkadan. The lowest affinity (29%) was noted with Vadakkan.

Vokkalu (No.44) displayed 82% similarity with Mundi and with a wild collection (2071); and 75% affinity with Arimulaku and Malamundi. The affinity was least with Uthirancotta (27%).

Seven wild collections of P.nigrum were included in the present study. Coll. 2077 displayed 88% and 82% chemical similarity with Karimkotta and Mundi respectively. Coll. 2071 showed 82-83% similarity with five cultivars namely Mundi, Narayakkodi, Thevanmundi, Thulamundi and Vokkalu. Coll. 2009 displayed 85% affinity to Karimunda and Thevanmundi. Coll. 2059 had 85% similarity to Kalluvally (Malabar). Coll. 2060 showed 75% affinity to Cheppukulamundi and Neelamundi. Coll. 2015 and 2062 gave the highest PSI values with Neelamundi (75%). These two collections were having an affinity of 80% between them.

Analysis of Petroleum ether extract:

Tripterpenoids and Steroids

A study of the T.L.C spot patterns revealed that the triterpenoids and steroid patterns were more or less similar in the various cultivars. Five spots were distinguishable in the T.L.C plates after H_2SO_4 treatment. The first spot appearing at Rf 0.2-0.3 was colourless in visible light and appeared blue following H_2SO_4 treatment. This probably represents a flavonoid compound. The second spot appearing at Rf 0.4-0.5 was yellow to yellowish orange in visible light and appeared blue after H_2SO_4 spray. This is a carotenoid compound, as carotenoids which are yellow in visible light are known to turn blue by Con.H_2SO_4 treatment.

The third spot appearing at Rf.0.6 was colourless in visible light and given purple colour on treatment with H_2SO_4. Steroids are known to produce purple colouration with Con.H_2SO_4, hence this spot might represent steroids. Co-chrom tography with common phytosterols indicated that it is either beta-Sitosterol or Stigmasterol. Both these sterols have same or very close Rf values with most of the commonly used solvents, and hence their distinction is not easy. The fourth spot at Rf.0.8-0.85 was yellow to yellowish organge under visible light and turned blue on H_2SO_4 treatment. This also probably represents a carotenoid compound. Green spots that appeared at Rf.0.85-0.9 which turn brown on H_2SO_4 treatment may be chlorophyll. A brown spot was noted along the solvent from which probably represents a phenolic acid .

This spot pattern was found to be common to all the cultivars studied.

<u>Flavonoid analysis of Piper Spp.</u>

Fourteen taxa of <u>Piper</u> were studied by descending paper chromatography using the technique already described. The number of flavonoid spots varied from 10-16 in the different

Table VII.3 Analysis of methanolic extract by Paper Chromatography Spot pattern of *Piper* spp.

Species	Rf values																			
	.25	.32	.40	.45	.50	.53	.56	.60	.63	.65	.70	.72	.75	.80	.84	.86	.88	.90	.93	.95
1. p. argyrophyllum	-	+	-	+	+	-	+	+	-	+	+	-	+	+	-	+	-	+	-	+
2. p.attenuatum	+	+	-	+	+	-	+	+	-	+	+	-	+	+	+	-	-	+	-	+
3. p.galeatum	+	-	+	+	-	+	-	+	+	+	+	-	+	+	+	+	-	+	+	+
4. p.hymenophyllum	-	+	-	+	+	-	+	+	+	+	+	-	+	-	-	+	+	+	-	+
5. p.longum	+	+	-	+	+	-	-	-	+	+	+	+	-	+	+	-	+	+	-	+
6. p.mullesua	-	+	+	+	+	-	+	+	-	+	+	+	-	+	+	-	+	+	-	+
7. p.nigrum	+	+	+	+	-	+	+	+	+	-	+	-	+	+	+	+	-	-	+	+
8. p. nigrum var hirtellosum	+	+	+	+	-	-	+	+	+	-	+	-	+	+	+	+	-	+	-	+
9. p. Schmidtii	-	+	+	+	+	-	-	+	-	+	+	-	+	+	+	-	-	+	-	+
10. p. Silentvalleyensis	-	-	+	-	+	-	-	+	-	+	+	-	+	+	+	+	-	-	-	+
11. p. trichostachyon	+	-	+	+	-	+	-	+	+	+	+	-	+	+	-	+	-	+	-	+
12. p. wightii	+	+	+	-	+	+	-	+	-	+	+	-	+	-	+	-	-	+	+	+
13. p. sugandhi sp.nov	+	+	+	+	-	+	-	+	+	-	+	+	-	+	+	-	-	+	+	+
14. p. sugandhi var. leiospicata	+	+	+	+	-	+	-	+	+	+	+	+	-	+	+	+	-	+	+	+

taxa, the lowest being in Piper silentvalleyensis (10), and the highest (16), in P.Sugandhi var. leiospicata. P.argyrophyllum and P.schmidtii gave 12 spots each. P.attenuatumP.hymenophyllum, P.longum, P.trichostachyon and P.wightii gave 13 spots each; P.mullesua, P.nigrum var. hirtellosum and P.sugandhi gave 14 spots each; P.nigrum and P.galeatum gave 15 spots each. The presence, absence of the flavonoid spots are given in the table VII.3.

The spot at Rf 0.25, a pale grey to pale blue one, appeared in 9 taxa, and was absent in five (P.argyrophyllum, P.hymenophyllum, P.mullesua, P.schmidtii and P.silentvalleyensis). The spot at 0.32, again grey to pale blue, was found in 11 taxa, except in P.galeatum, P.silentavlleyensis and P.trichostachyon. The spot at 0.40 was found in ten taxa, and absent in four (P.argyrophyllum, P.attenuatum, P.hymenophyllum and P.longum). The spot at 0.45 appeared pale bluish to bluish green and was present in all the taxa except in P.silentvalleyensis and P.wightii. The spot at Rf 0.5 was purplish to purplish violet, and was found in eight taxa, and were absent in P.galetum, P.nigrum, P.nigrum var.hyrtellosum, P.trichostachyon, P.sugandhi, and P.sugandhi var. leiospicata.

At 0.53 a yellowish brown spot appeared in P.galeatum, P.nigrum, P.trichostachyon, P.wightii, P.sugandhi and P.sugandhi var.leiospicata. The spot at 0.56 was bluish grey, and appeared in P.argyrophyllum. P.attenuatum, P.hymenophyllum, P.mullesua, P.nigrum and in P.nigrum var. hirtellosum.

The spot at Ø.6 was purplish and found in all the species except in P.lognum. The spot at Ø.63, a light purplish one, was present in eight taxa. This was absent in P.argyrophyllum, P.attenuatum, P.mullesua, P.silentvalleyensis, P.schmidtii and P.wightii. The spot at Ø.65 appeared yellow brownish under uv light and was noted in all the taxa, except in P.nigrum, P.nigrum var hirtellosum and P.sugandhi. The spot at Ø.7, bluish green under uv, appeared in all the taxa studied . The spot at Ø.72, greenish brown under uv, was present only in four taxa - P.longum, P.mullesua, P.sugandhi and P.sugandhi var leiospicata. In these species the bluish green spot at Ø.75 was absent.

The spot at Rf Ø.8, bluish to bluish green under uv, was present in all the taxa except in P.wightii and P.hymenophyllum. The spot at Rf Ø.83 was absent in three species namely P.argyrophyllum; P.hymenophyllum and P.trichostachyon. The spot at Ø.84 was yellowish brown in colour under uv light, and was present in all the taxa except in P.argyrophyllum, P.hymenophyllum, and P.trichostachyon. The spot at Ø.86 was present in eight taxa, and was absent in P.attenuatum, P.longum, P.mullesua, P.schmidtii, P.wightii and P.sugandhi. This spot was also yellow brown under uv. The spot at Rf Ø.88 was yellowish green to bluish green under uv and was present in only three taxa, namely

P.hymenophyllum, P.longum and P.mullesua. The spot at Ø.9Ø was yellow brown under uv and was present only in P.nigrum and P.silentvalleyensis. The brown spot at Ø.93 was found only in five taxa, namely, P.galeatum, P.nigrum, P.wightii, P.sugandhi and P.sugandhi var. leiospicata. The last spot at Ø.94 - Ø.95 was reddish orange under uv and was found to occur in all the taxa.

Chemical affinity among Piper spp.

The paired affinity indices (PAI) are given in Table VII.4. These PAI provide a measure of chemical affinity among the Piper spp. The main conclusions that can be drawn from these values are given below:(also see Fig. VII. 1)

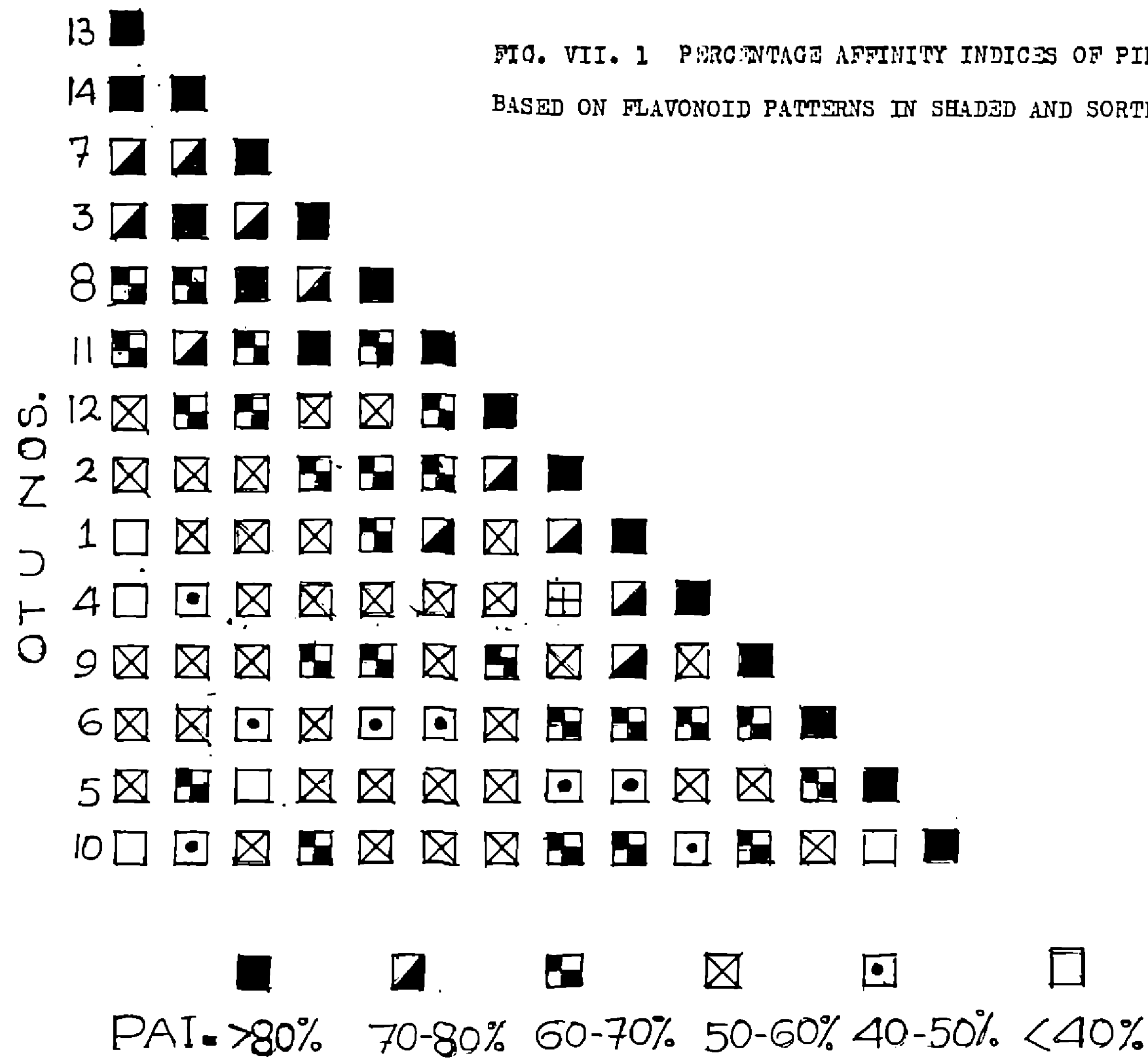
P.argyrophyllum showed high chemical similarity with P.attenuatum (78.5%) P.hymenophyllum (78%), P.schmidtii (71%) and P.trichostachyon (71%); P.longum and P.sugandhi exhibited very low chemical affinity, the PAI being 47% and 38% respectively. P.attenuatum had high similarity with P.schmidtii (78%) followed P.wightii (71%). P.longum exhibited the lowest similarity (47%) with P.attenuatum. P.galeatum had high affinity towards P.trichostachyon (87%) and P.sugandhi var leiospicata (82%). P.longum , P.mullesua and P.wightii had low affinity with P.galeatum. (The PAI being 5Ø, 53 and 53% respectively) P.hymenophyllum exhibited moderately high chemical affinity with only P.argyrophyllum (78%). while P.silentvalleyensis and P.sugandhi var. leiospicata had shown the lowest affinity (44 and 45%

Table VII.4 Paired affinity indices (Percentage similarity indices) between the *Piper* taxa

Taxa of Piper	1	2	3	4	5	6	7	8	9	10	11	12	13	14
1. P. argyrophyllum	100	79.0	59	78	47	62	50	62	71	64	71	53	38	55
2. P. attenuatum		100	64	63	47	68	59	68	78	60	67	71	53	52
3. P. galeatum			100	55	50	53	70	70	68	66	87	53	70	82
4. P. hymenophyllum				100	59	64	50	59	56	44	53	50	35	45
5. P. longum					100	69	37	50	56	35	50	50	58	61
6. P. mullesua						100	47	47	63	57	42	53	55	58
7. P. nigrum							100	87	53	50	65	61	71	72
8. P. nigrum var. hirtellosum								100	63	56	69	50	65	67
9. P. schmidtii									100	69	56	67	53	55
10.P. silentvalleyensis										100	53	53	39	47
11.P. trichostachyon											100	63	65	70
12.P. wightii												100	59	67
13.P. sugandhi													100	88
14.P. sugandhi var. leiospicata														100

FIG. VII. 1 PERCENTAGE AFFINITY INDICES OF PIPER Spp.

BASED ON FLAVONOID PATTERNS IN SHADED AND SORTED FORM



respectively).

P.longum did not show high chemical affinity with any of the taxa, the highest PAI being with P.mullesua (69%). P.mullesua, like P.longum, did not show high affinity to any of the taxa studied. P.nigrum exhibited high PAI with P.nigrum var. hirtellosum (87%) and moderate affinity with P.sugandhi (71%) and P.sugandhi var. leiospicata (72%). Same was the case with P.nigrum var hirtellosum, which apart from P.nigrum showed moderate affinity with only P.galeatum (70%) and P.trichostachyon (71%). P.longum and P.mullesua exhibited very low PAI with the above taxa.

P.schmidtii displayed 78% and 71% chemical affinity with P.attenuatum and P.argyrophyllum and 69% and 67% with P.silentvalleyensis and P.wightii. P.silentvalleyensis did not show much chemical relationship with any other taxa; the highest being with P.schmidtii. P.longum, P.hymenophyllum and P.sugandhi var.leiospicata had very low PAI with P.silentvalleyensis.

P.trichostachyon displayed close similarity with P.galeatum (87%); and moderately high PAI was observed with P.argyrophyllum (71%) and P.sugandhi var. leiospicata (70%). P.mullesua exhibited the lowest PAI with P.trichostachyon (47%) P.wightii had moderately strong affinity with P.attenuatum.

The new species reported, P.sugandhi and P.sugandhi var. *leiospicata* had a PAI of 88%. These taxa displayed moderate affinity with *P. nigrum* (71 and 72% respectively) and *P. galeatum* (70 and 82%) respectively.

Analysis of Petroleum Ether Extract:

The results of the analysis of Petroleum ether extract of *Piper* sp. by TLC on silicajel G gave more or less similar resuts in the case of all the taxa studied. Only five spots emerged in the TLC, the first one at Rf 0.2 - 0.25 was bluish on treatment with H_2SO_4. This spot probably representS carotenoids. At Rf 0.4 - 0.43 a bluish violet spot appeared on H_2SO_4 spraying and heating. This also is a carotenoid because carotenoids appear yellow in visible light and turn bluish or bluish violet on H_2SO_4 spray followed by heating. A purple spot appeared at Rf 0.65. This is probably a steroid because they are known to give purple colour on H_2SO_4 spray followed by heating. A green to bluish green spot appeared at 0.9 which probably representS a dicarboxylic acid. A brown spot appearing at the solvent front represents probably phenolic acids.

In order to identify the steroid, co-chromatography with the common phytosterols was carried out. The results indicated that the steroid can be either stigmasterol or beta-sitosterol. Both have almost the same Rf, they are infact isomeric forms.

Flavonoid types present in *Piper*

Table VII.5 gives the details of the probable flavonoid types present in *Piper* spp. In general the flavonoids fall into two groups; flavones and flavonols. Rarer flavonoid compounds such as flavanones and dihydroflavonols are absent.

Vanillin - HCL spray of chromatogram did not give any positive reaction, indicating the absence of catechins, proanthocyanindins, flavanones and dihydroflavonols. In other words this indicates the absence of flavonoids possessing phloroglucinol A-ring oxidation pattern in combination with a saturated C-ring. $FeCl_3$ spray of chromatogram did not give any positive reaction, thereby indicating the presence of O-methylation of the flavonoid nuclei. Extraction of the different flavonoid spots, their chemical identification and structure determination were not attempted here as these are beyond the scope of the present work.

Table VII.5 Probable flavonoid types present in Piper spp.

Rf.	Colour under u.v	Colour under u.v + NH_3	Probable flavonoids type
Ø.25	light blue	no colour change	Isoflavones lacking a free -OH group
Ø.32	do	do	do
Ø.4Ø	do	do	do
Ø.45	do	do	do
Ø.5Ø	Purple	Yellow green to yellow	5 -OH flavones or flavonols
Ø.53	dull yellow	no change in colour	flavones with a free 3-OH
Ø.56	bluish green	no change	flavonols with a free 3-OH and with or without a free 5- OH
Ø.6Ø	Purple	no colour change	flavones or 3-Ø substitued flavonols with 5-OH (but lacking a free 4-OH)
Ø.63	do	do	do
Ø.65	Yellow brown	do	flavones with a free 3-OH
Ø.7	blue green	do	5-hydroxyflavonol (+ve reaction with $AlCl_3$ spray)
Ø.72	greenish blue	do	flavonols with a free 3-OH and with or without a free 5-OH
Ø.75	do	do	do
Ø.8Ø	pale blue	fluorescent blue green	flavonols with a free 3-OH but lacking a free 5-OH or flavones lacking free 5-OH
Ø.83	do	do	do
Ø.84	yellow brown to dull yellow	no colour change	flavonols with a free 3-OH and with or without a free 5-OH
Ø.86	do	do	do
Ø.88	do	do	do
Ø.9Ø	do	do	do
Ø.9Ø	do	do	do
Ø.93	do	do	do
Ø.95	orange red	bluish green	Anthocyanin 3,5-diglycoside (?)

DISCUSSION

CHAPTER VIII

DISCUSSION

Piperaceae is a large family with over 3000 described species. The main centres of diversity for the family are the Central and South America in the western hemisphere and the Malaysian region in the eastern hemisphere (Yuncker, 1958). The general taxonomic features of the family are the simple, entire, alternate leaves, minute flowers arranged in compact spikes, and unilocular ovary with single ovule. Piperaceae continues to be taxonomically difficult and enigmatic and the present chaotic state of the family, is largely the result of its unfortunate past treatment. (Bornstein, 1989). The genus Piper. sensulato is perhaps the largest genus of flowering plants devoid of a natural classification (Bornstein, 1989). The flowers are small and the vegetative and the floral morphology are uniform throughout the genus (Burger, 1972). The species descriptions are often based upon insignificant characters, and are in many cases based on fragmentary materials. The earlier workers created large number of species based on such materials and materials from different geographical areas were assigned to various species (Steyermark, 1984).

In the recent past significant advances were made in solving the confusion through the works of Burger (1971), Yuncker (1972, 1973, 1974), Howard (1973), Steyermark (1984) Bornstein (1989) and Tebbs (1989). Their studies helped to solve many problems in the Central and South American Piper.

In India the genus is concentrated in the North-Eastern Himalayas in the north and Western Ghats in the South which runs parallel to the Western coast of India. The Indian taxa of this genus are quite distinctive from the New World (Central and South American) taxa. The former are mainly weak stemmed climbers or creepers while those of the latter are mostly erect shrubs or small trees. This makes the Indian species (especially the South Indian taxa) of Piper taxonomically and evolutionarily different from their New World counter parts. But unfortunately no exhaustive studies on Indian Piper have been made so far, nor is there any study on the factors controlling their distinct distribution in this subcontinent. There is not even a taxonomical treatment of this genus on a national level, except for the cursory study made by J.D. Hooker (1885). In the South, Gamble (1925) has listed eleven species in the erstwhile Madras Presidency; while Rahiman (1981, 1987) enumerated nine species in the state of Karnatala. A revised taxonomic treatment of Piper species of Kerala is still lacking.

So one who is initiated into the Peninsular Indian species of this genus is forced to rely on the scanty information provided in these works. The Herbarium specimens are rather fragmentary and often with very little useful field data which makes it all the more difficult to rely on old collections for correct identification.

The study on Piper species of Kerala provided here should be taken in this back drop. Despite possible shortcomings an earnest effort has been made here for collecting and studying these taxa from morphological, chemical and numerotaxonomical stand points.

Hooker (1886) divided the genus into six sections, five of which for Piper and the sixth one for Heckeria. Subsequent workers on Indian Piper did not follow any subgeneric classification, probably none had attempted to study the genus in a comprehensive way. Gamble (1925) included 13 of the South Indian species in his flora, but did not try to fit them into any natural grouping.. Same was the case with Rahiman, who described the Piper species from Karnataka region of South India. The present study has indicated that the South Indian taxa of Piper neatly fit into two natural groups based on just one character-orientation of the spikes, i.e., whether the spikes are erect or pendent.

An examination of the Piper species described from various geographical areas around the world clearly indicates the validity of this subgeneric classification. All the Piper species so far described fall into tow sub-genera Pippali and Maricha, the former having the erect spikes, the latter pendent spikes.

For the purpose of discussion species having close similarities are considered together, while those without much interspecific similarity are discussed separately.

P.*attenuatum* Miq. P.*argyrophyllum* Miq. and P.*hymenophyllum* Miq.

These are closely related species. P.*attenuatum* was described by Miquel (1843) in "Systema Piperacearum". As early as 1804, Vahl has listed a species, P.*diffusum*, which Hooker regarded as a synonym of P.*attenuatum*. But this was not a valid publication. So also Blume (1823) in his Catalogue described P.*Karok*, which was cited by Hooker (1886) as a synonym of P.*attenuatum*. This again was not a valid publication, and hence was not accepted. The first valid publication seems to be that of Miquel, and P.*attenuatum* Miquel is hence taken as the valid citation. Ramachandran and Nair (1988) used P.*trioecum* Roxb. for describing this species. This is evidently wrong as P.*trioecum* was used by Roxburgh (1828) to describe a plant very similar to P.*nigrum* but occurring in the wild.

The specific epithet *attenuatum* denotes the attenuate nature of the leaf base; though in many cases, the base is more or less round than attenuate and much variations are noticed even within the same plant. The leaves have seven nerves (ribs) arising from the base of the lamina, which is an important distinguishing character.

P.*argyrophyllum* was also described by Miquel (1843) in his "Systema Piperacearum". This is closely allied to P.*attenuatum* and shares many morphological characters, and when dried they are difficult to distinguish, especially the male specimens. Silvery scales were reported in some cases. Sparse hairiness is occasionally found along the ribs on the under-side of the leaves, but the old leaves often are wholly glabrous. The female vines of P.argyrophyllum can be distinguished easily from P.attenuatum by the white, shorter spikes. These two can be distinguished by the rib nature - the leaves of P.attenuatum are seven ribbed at the base, P.argyrophyllum five ribbed.

Both P.attenuatum and P.argyrophyllum are included under the series Eupiper by Hooker (1886). They are distributed at the lower (upto 500 m) to medium (500 - 1000 m) elevation and the two overlap in their habitat preference. They constitute the predominant species at the above elevational ranges.

The fruits of both species are alike, they are deciduous and on ripening turn directly black from green. The scars left by the fallen fruits are ciliate in both cases.

P.hymenophyllum is distinctly different from the other two by the hirsute nature of the vegetative parts.

P.hymenophyllum was described by Miquel in 1845, along with its related species P.hookeri, and there seems to be some confusion regarding these two species. Hooker (1886) described these two species in his Flora, under two different sections; P.hookeri in the section "Pseudochavica" along with P.schmidtii, while P.hymenophyllum in the section of Eupiper along with P.nigrum, P.attenuatum and P.argyrophyllum. Brandis (1906) and Cook (1905) reported P.hookeri from the Western Ghats and it was described as a hairy species. Gamble (1925) in his Flora treated P.hookeri and P.hymenophyllum as separate species. Saldanha and Nicolson (1976) reported a hairy species from the Hassan District of Karnataka and considered it P.hymenophyllum. Rahiman (1981, 1987) felt that the two are one and the same species, and treated them as conspecific.

The situation is thus confusing; Hooker giving separate sectional status to P.hookeri and P.hymenophyllum, while almost a century later Rahiman trying to combine the two taxa into one, treating them as conspecific. The salient features of P.hookeri as given by Hooker included sparse hairiness, and bracts which are oblong, decurrent and adnate to the rachis. On the other hand P.hymenophyllum had profuse hairs and had bracts which are linear oblong, adnate with undulated margins. Hooker mentioned that the bracts of P.hymenophyllum female are inconspicuous, being entirely confluent with the rachis, but sometimes having conspicuously raised margins. Another difference mentioned by Hooker was the ciliated scars of P.hymenophyllum and glabrous scars of P.hookeri. The two are closely related but do not seem to be conspecific as opined by Rahiman (1981, 1987). The separation of these two under two sections is not justified either. Hooker commented that P.hookeri should be included as a separate species along with P.hymenophyllum under the section Eupiper. The present study supports this view.

P.*hymenophyllum* and P.*argyrophyllum* are much variable in regard to hairiness. P.*hookeri* is more or less intermediate between P.*hymenophyllum* and P.*argyrophyllum* and may even be a hybrid. A few collections conforming to the characters of P.*hookeri* were studied during the present work. These are found to overlap with both P.*argyrophyllum* and P.*hymenophyllum*. In fact P.*hymenophyllum* - P.*argyrophyllum* - P.*hookeri* complex needs thorough investigation not only morphologically but cytologically and chemically also. Such a study is not attempted here as it is beyond the scope of the present work.

In view of the above facts, the nomenclature P.*hymenophyllum* is retained in the present study instead of P.*hookeri* as suggested by Rahiman (1981, 1987).

P.*galeatum* (Miq.) C.DC. and P.*trichostachyon* (Miq.) C.DC.

Two closely related species, Hooker (1886) included them in the section Muldera, which is then subdivided into two groups - one with stipitate receptacle, and the other having sessile receptacle. The two species were established by De candolle (1869) from the earlier descriptions of Miquel (1846) under the names *Muldera galeata* and M.*trichostachya*. Wight (1853) had described the former as M.*Wightiana*. De candolle in his monograph rejected the generic name *Muldera* in favour of *Piper*.

The most important character differentiating the two species from all others in South India is the peculiar bracts which are modified into fleshy cup like or boat shaped structures. The bracts are shortly stipitate in P.galeatum while sessile in P.trichostachyon. P.trichostachyon has microscopic hairs on the spike, especially on the receptacles.

Rahiman (1981) pointed out that the stipitate nature of the bract is not distinguishable in certain collections. This may be true in the case of female specimens after full development of fruits. In the flowering spikes the stipitate nature of the flower is very clear. In fact the stipitate nature of the flower in P.galeatum and the minute hairiness of the spike in P.trichostachyon are important diagnostic characters of these two species.

P.longum L.

P.longum is very distinct among the Piper spp. occurring in Southern India. This is one of the most widely distributed species, occurring in most of the states in India, except in the hotter and colder regions. Hooker (1886) states that this species occurs from Nepal to Assam, Khasia hills and Bengal and extends westwards upto Bombay, and southwards to Ceylon and Malaca Islands. Unlike the other species this one is a creeper with erect fruiting branches.

The species was established by Linneaus (1753) in his Species Plantarum and subsequently described by many other workers.

The first portrayal of this very valuable medicinal herb was by Rheede (1678) in his Hortus Indicus Malabaricus, but is not treated as valid. Miquel (1843) described a Malabar plant P.Sarmentosum based on Wallich's collection. This species and Hunter's P.latifolium are nothing but P.longum. Two other plants described as Chavica roxburghii and C.sarmentosa by Miquel (1843) also belong here.

P.hapnium is closely related to P.longum, but for the occurrence of sparsely pubescent leaves and climbing nature. This species seems to be very rare as it could not be collected from any of the forests surveyed during the present work. Jain (1987) included this in his red data book of endangered plants of Peninsular India.

P.mullesua Ham.

A very distinct species among the South Indian taxa of Piper, as this is the only species having globose spike. This species occurs at elevations above 1000 m.

Wallich (1832) described this plant as P.brachystachyum (Wall. cat. 6656), which was adopted by Hooker (1886), Gamble (1925) and other workers. Earlier to Wallich's description D.Don (1825) had described the same plant under P.mullesuaHam. ex D. Don.(Prodr. Fl. Nepal, 20, 1825). Hence the name P.mullesua is valid, and the plant described by Hooker (1886) and later Gamble (1925) as P.brachystachyum should be treated as P.mullesua Ham. (Raizada 1966).

Miquel (1843) in his monograph has described the same taxa under Chavica sphaerostachya (Miq. Syst. Pip. 279). Miquel has also described another plant of the same taxa as Chavica mullesua (Miq. Syst. Pip. 280).

P.silentvalleyensis Ravi, Nair et Nair

This species resembles closely P.mullesua in vegetative characters, but is distinctly different in spike characters. This is the only bisexual species occurring in the Western Ghat forests. The erect, flexuous, filiform spike is the distinguishing character of this species. The fruits are minute like that of P.mullesua and they are similar in taste.

This is a rare species, so far reported only from one locality in the Silent Valley forests.

P.Schmidtii Hook.f and P.Wightii Miq.

These two species occur at the hill tops of Kodaikanal and Ootacamund above 2000 m. Both are relatively robust woody climbers, and are distinctly different in their appearance. P.schmidtii has the thickest leaves among all the Piper Spp. occcurring in the region, while P.wightii has much thinner leaves.

Hooker (1886) treated these two species under two sections, P.schmidtii under the section Pseudochavica and P.wightii under the section Eupiper. Hooker distinguished these two groups mainly on the basis of the bract:peltate, orbicular and margins free all around in the case of Pseudochavica, while in Eupiper the bracts are wholly adnate to the rachis or with raised membraneous margins. Gamble (1925) listed both these species in his Flora, but did not follow the sectional classification of Hooker.

Hooker (1886) also mentioned the confusion in the delimitation and P.wightii. Miquel (1843) seems to have described some distinctly different plant by the same name P.wightii (cited by Hooker 1886). One specimen described by Miquel as sparsely hairy applies more to P.hymenophyllum. Yet another specimen named P.wightii with glabrous membraneous leaves is more related to P.argyrophyllum. A third one with coriaceous leaves also named P.wightii was considered by Hooker as the correct one representing the species. The present study also revealed that P.wightii is a very distinct species not only in its morphology (coriaceous leaves with strong nerves, more or less conical shaped berries etc.) but also by its restricted distribution (from above 2000 m only).

Less confusion prevailed over P.schmidtii, because, the highly coriaceous and thick leaves and the strongly reticulate venation make this distinctly different from all other taxa. The description provided by Hooker (1886) has been accepted by Gamble (1925) and later by Fyson (1932) in his Flora of South Indian Hill stations. Gamble left a typed note dated 19th Jan. 1912 along with his collections of P.schmditii (BSI, Herbanium, Coimbatore). He mentioned in this note: "Specimens very distinct, over 6000 ft. in the

Nilgiri and Kodaikanal hills, just where Schmidt who lived at Dotyp would have collected it. The picture in Wight's Icones are comparatively useless as regards foliage and bracts, but certainly that on.t. 1940, as Hooker points out, is this plant; perhaps also t. 1941 male and t. 1938 female, but the latter has bracts impossible in Piper... The description of P.arborescens in Miq. Syst. Pip. 320 agrees in part as Hooker says, but the male spikes are often longer than the female". The present study also revealed the distinctive nature of this species, both in morphology and in its habitat preference.

P.nigrum L.

The species was created by Linneaus (1753) in his Species Plantarum. The first description of black pepper was that of van Rheede (1678) in the Hortus Malabaricus Indicus where black pepper was described under the name "Mulakukodi", the vernacular name for black pepper.

Some confusion existed earlier regarding the nomenclature of P.nigrum. Many of the earlier workers, especially Roxburgh, Miquel (1843) and Hooker (1886) recognised another species P.trioecum, almost identical to p.nigrum, but occurring in the wild condition, thereby segregating the cultivated and wild black pepper into two species. Roxburgh (1832) was the first to give such a distinction, but he provided no distinguishing character between the two except that the leaves of P.trioecum are glaucous beneath. Later Miquel,

(1843) accepted the two species for his "Systema Piperacearum" and he observed that P.trioecum has less coriaceous, narrower, more lanceolate leaves, less white beneath. Later in the Flora Indica Batavia (1859) he just mentioned P.trioecum as the wild form of P.nigrum.

P.Malabarense DC and P.bacatum DC are two other names published for the same P.nigrum (DC in Prodr. XVI. 1,363, 1869). Miquel has also recognised Muldera multinervis and M.Wightiana (Miquel in Hook. Lond. J. Bot, V.557-558 1846). After examining the collections, Hooker (1885) commented that they were in no way different fron P.nigrum. Hooker included P.nigrum under the section Eupiper, along with P.attenuatum, P.argyrophyllum, P.hymenophyllum and P.wightii. The chief indentifying sectional character given by Hooker is the nature of bract (Bract and bracteole either wholly adnate to the rachis or with raised membraneous margins). The section Eupiper consists of two subsections. In one, the bracts forming a hemispherical cup under the ovary and bracteoles forming a semilunar ridge above the ovary. P.nigrum belongs to this subsection. In the other subsection bracts are adnate to the rachis with decurrent, raised, more or less membraneous margins which are also confluent with the bracteoles on either side of the ovary. Hooker has included P.attenuatum, P.argyrophyllum, P.hymenophyllum and P.wightii in this subsection. The first three are closely related species. P.wightii, on the other hand is a large woody climber resembling more to P.nigrum in leaf and spike characters.

The question of segregating the cultivated and wild forms of black pepper is not accepted by the recent workers. There is only one character that distinguishes the cultivated and wild forms, in the former, flowers are bisexual while in the latter plants are mostly dioecious. The epithet *nigrum* is used for both forms. Earlier all black pepper were collected from wildly grown pepper plants from the forests. Gradually people started selecting and growing the better ones and the present day cultivated black pepper IS the result of such selection and domestication (Ravindran and Babu, 1988).

P.sugandhi . Ravindran sp. nov.

P.sugandhi var. *leiospicata* Ravindran var. nov.

Two new taxa described here by the author; occurring along with other woody climbers such as *P.nigrum*, *P.galeatum* and *P.trichostachyon* and shrubby scandent ones such as *P.attenuatum*, *P.argyrophyllum* and *P.hymenophyllum*. A study of these taxa had shown that they resemble *P.nigrum* except for the spike characters such as its minute hairiness, and the short stipitate flowers. The bracts of *P.sugandhi* are deeply cupular while that of *P.nigrum* are shallow cups. At the same time these new taxa also resemble *P.trichostachyon* in the hirtellous nature of the spikes, fruit shape and the spaced arrangement of flowers on the spikes. Closer study points to the conclusion that *P.sugandhi* combines the characters of both *P.nigrum* and *P.trichostachyon* and probably had arisen as a hybrid between these species. Similarly P.sugandhi var. leiospicata seems to be a hybrid between P.nigrum and P.galeatum . At the same time with regard to the major taxonomic criteria these are distinct enough to be recognised as new taxa. The existance of vegetative propagation confers on these taxa independent and stable existence.

This aspect is dealt with in detail in one of the following sections.

Morphology

All species of Piper-both cultivated and wild-occurring in South Inida, are weak stemmed plants and are either scandent or woody climbers with the exception of P.longum which is a creeper . The branching is dimorphic which is the result of the modification of the terminal bud into a spike, the subsequent growth is then carried out by the axillary bud. The spike is thus leaf opposed in all species.

Prophyll and leaf sheath

A structure of much morphological interest is the prophyll which is the modified first leaf of the axillary bud. Usually dicotyledonous plants have two prophylls, while Piper has only one. The prophyll protects the leaf and the spike in the flowering node in the bud stage (of the plagiotropic shoot) and falls off after the emergence of spike and leaf. In the vegetative node, on the other hand, the bud is protected by the sheathing leaf base.

In his study on Central American *Piper*, Burger (1972) observed that the majority of the New World species of *Piper* have the prophyll developed to form a protective cap at flowering nodes, and came to the conclusion that those species with the prophyll are not all closely related and that this development may have originated independently more than once within the genus. He also distinguished two types of prophylls among the Central American species. One type is glabrous or less often puberulent throughout the abaxial surface and oblique or truncate apically. The more common type of prophyll is acute at the apex and usually minutely puberulent along the midrib abaxially. In the case of South Indian species studied here, the prophylls are acute at the apex and usually microscopically hairy in certain species such as *P.longum*, *P.argyrophyllum*, *P.trichostachyon* and *P.galeatum*, while in *P.hymenophyllum* the prophylls are profusely hairy. In *P.nigrum* cultivars the prophylls are microscopically hairy in some while in certain others the prophylls are glabrous. Berger (1972) also noted a primitive type of prophyll and these undeveloped prophylls were found enclosed in the sheathing leaf base. Such undeveloped prophylls were not noticed in the present study.

The sheathing leaf base has been described as adnate stipules by many previous workers (Rahiman, 1981, 1985 ; Chandy, Potty and Kannan, 1984; Ibrahim, Pillai and Sasikumaran, 1985a). In fact as far back as 1961 Majumdar and Pal provided anatomical evidence to show them to be sheathing leaf bases. They show that stipules when present were outgrowths at the base of the leaf and their vascular supply (stipular trace) was normally derived from the laterals of a three-bundle leaf trace. This view was supported by Mitra (1945, 1949) Mitra and Majumdar (1952), Majumdar (1956), Majumdar and Pal (1961) and Pal (1961). It has been shown that in *Piper* leaves the foliar base completely encircles the stem and the free margins, overlap each other to form the "wrap over" and the margins receive their vascular supply directly from the nodes below. The free tip of the leaf sheath may be considered as a ligule and not as a stipule because the extreme end of the free tip does not get any vascular supply (Murty, 1959).

Leaf Characters

Leaf characters are important diagnostic features in *Piper*, both at specific and cultivar levels. Considerable variability in leaf characters are met within the genus-in size, shape, texture and also structure. These characters were used in circumscribing species as well as cultivars by earlier workers (Rahiman, 1981; Chandy, Potty and Kannan 1985).

Anatomically all the species share the basic structure. Variations were noted in the case of hairs, mucilage cavities, pearl glands, in the number of mesophyll cell layers etc.

Epidermal hairs, though of no evolutionary significance, form a clear criterion of taxonomic distinction (Datta and Dasgupta, 1977). These workers were of opinion that reduction in palisade layers represent an evolutionary trend. One major distinguishing feature of taxonomic importance is the presence or absence of mucilage canals (Murty, 1959).

No published work is available on the anatomical variations among the cultivars of black pepper, and also in the case of the wild taxa occurring in South India, except in the case of the P.longum. Stomatal number and size variations are important among the pepper cultivars (number varied from 61 to 130 per mm^2). Whether such variations in stomatal number as well as leaf thickness play any role in the yield is not known. Again wax glands or pearl glands seem to be another important taxonomic marker. Such glands were noted only in P.nigrum and sparsely in P.sugandhi. Among the cultivars there were variations in the presence of pearl glands, they were abundant in some and very scanty in some others. As in the case of hairs, wax glands also did not seem to have any evolutionary significance. Such glands were not reported by earlier workers like Datta and Dasgupta (1977). Secretery glands were reported in P.betel and also in some other species by Metcalfe and Chalk (1952), which are probably the same as wax glands.

Piper has dimorphic branching. In the earlier works there were no mention as to the type of shoot used in anatomical studies - whether the orthotropic shoot or the sympodial flowering shoots. Metcalfe and Chalk (1957) summarised the salient anatomical features of the stem. Differences were noted with respect to peripheral and medullary bundles, presence of mucilage canal, and in the number of xylem elements. Similar, variations were also recorded in *P.betel*, *P.methysticum*, *P.subrubrispicum* and *P.longum* (Metcalfe and Chalk, 1957; Murty, 1959). *P.longum* and *P.trichostachyon* stand out among the species studied by the absence of central mucilage canal, an observation earlier made by Murty also (1959) in *P.longum*, though Pal (1961) reported mucilage canals in this species. Hydathodes were also reported by Murty (1959) in *P.subrubrispicum*, which were not observed in any of the species studies here.

The most outstanding feature of the anatomy of *Piper* is the nature of the vascular bundles. They are scattered in the ground tissue like that in monocotyledons. This according to Hutchinson (1959) is an indication of the Ranalian ancestry. There were also much debate among the earlier workers on the origin and nature of the vascular system in *Piper*; but were clarified later mainly by the works of Balfour (1957, 1958, Majumdar and Pal (1958), Pal (1961) and Murty (1959).

Character clustering

Sporne (1976, 1977) discussed the importance of character correlations in the taxonomy of angiosperms. Earlier to this, Sinnott and Baily (1914, 1915) showed that among dicotyledons certain characters were associated with each other i.e., they occur together more frequently than they would if they were merely randomly distributed within the group. These ideas led Chalk (1937) to make use of simple statistical tests of significance (such as Chi-square test) to test the randomness or independence of the occurrence of characters, and to discover which characters were statistically associated. Sporne (1948, 1976, 1977) carried out more detailed studies on this problem. According to him the positively correlated characters are usually the more primitive ones and that they are concentrated in the primitive taxa. Stebbins (1951) questioned these conclusions and suggested that correlated characters were those which together contributed to outstanding biological success and described organisms possessing such characters as having attained adaptive peaks. The successful organisms will therefore, possess complexes of correlated characters and these correlations allow the recognition of distinct taxa. In addition, the evolutionary divergence leads to overall phenetic divergence, though at different rates in different lineages (Sneath and Sokal, 1973).

The problem of character correlation has been examined in *Piper* species through cluster analysis by average linkage, which led to the clustering of characters based on the correlations. Six such clusters were recognised:-

(1) Leaf length, leaf breadth, leaf size index
(2) Fruit shape, fruit size
(3) Spike length, L.L/Spike length, peduncle length
(4) L.L./L breadth, guard cell length, guard cell breadth
(5) Leaf shape, leaf base
(6) Leaf thickness, upper epidermal thickness, lower epidermal thickness.

Characters such as leaf shape of the orthotropic shoot, colour of the new shoot, leaf margin, spike shape, mesophyll thickness and stomatal frequency are more or less independent, the correlation of these characters with other characters being very low.

In cultivars, leaf and spike characters are very important diagnostic features. In the case of leaf length and leaf breadth there is almost a continuous spectrum of variations ranging from the small leaves of Nedumchola to the large leaves of Balancotta. Chandy <u>et al</u> (1984) and Kanakamony <u>et al</u> (1985) have used leaf characters including the colour variations of the abaxial surface in the classification of the cultivars. But in the present study it was found that colour variations of the underside of leaves is not a reliable criterion. Ibrahim <u>et al</u> (1984) used leaf characters in a discriminant function analysis between the Malabar and

Travancore cultivars. This study did not show any significant difference between the two groups.

Fruit shape and fruit size, though highly correlated are less useful in the delimitation of cultivars, except in the case of cultivars having significantly discernable traits such as the oblong fruit shape as in Karuvilanchy. The vast majority of the cultivars have spherical fruit shape and hence are not very much useful in cultivar identification.

On the other hand, the spike characters are very useful in cultivar identification. Spike length also exhibits a wide spectrum of variations. They can be grouped based on leaf length/spike length values into cultivars with spikes shorter than leaf, spikes more or less equal to the leaf length, and spikes longer than leaf. The cultivars included in the first and third groups are very few. In the cultivars Karimkotta, Kuthiravally, Poonjaranmunda, Thommankodi and Vellanamban the spikeS are longer than the leaf. In Kalluvally, (Pulpelly), Kuriyalmundi,, Vokkalu, wild collections 46 (Acc. 2071) 47 (Acc.2009) and 49 (Acc. 2060) the spikes are significantly shorter than the leaves. In the rest of the 40 cultivars the leaf length and spike length are more or less equal. It seems that during the process of domestication the selection pressure for longer spikes might not have been strong, indicating that the farmer might have looked for many other characters, such as profuse bearing, regular yielding capacity, bold fruit size etc. It may also be mentioned here that the cultivars included in the first category are not that popular inspite of the long spikes, though Kuthiravally and Vellanamban are potential high yielders.

Clustering of cultivars

The centroid linkage analysis based on twenty two characters led to the grouping of the 51 OTUs into 11 groups. The OTUs in the same group are to be treated as similar having high coefficient of similarity. As a result of this analysis more than half of the cultivars got included in a single group (group H). Four of the groups consisted of only one cultivar each, thereby indicating the divergence of these cultivars from the others. Karimunda, Kuthiravally, Vadakkan and Panniyur-1 are the cultivars occupying such unique positions.

Karimunda is the most popular among all the cultivars grown in Kerala. A study of the dispersion figures had shown that Karimunda can be best differentiated based on the leaf anatomical as well as stomatal characters. The leaf thickness was lowest in Karimunda, and so also the stomatal frequency. Karimunda is a highly productive cultivar and is a regular bearer. Whether the thinner leaves and lower stomatal frequency per unit area have anything to do with its higher productivity and regular bearing is to be investigated. In the flavonoid analysis Karimunda has shown 85% similarity with a wild collection (Acc. 2009), though these two did not show much closeness in its leaf anatomical or stomatal characters.

Kurthiravally is another cultivar showing unique placement in group 9. This cultivar is originally from the South Kerala; now found sporadically in many areas all over Kerala. This has characteristically long spikes, and widely ovate leaves. Centroid clustering has shown that its resemblance with other cultivars are rather low. The dispersion diagrams have shown that factors 2 and 3 are important in delineating Kuthiravally to an independent position. In other words, this cultivar gets differentiated from all other cultivars based on the characters leaf thickness, upper and lower epidermal thickness, spike length, and stomatal characters.

Flavonoid analysis has shown that Kuthiravally is closely related to the cultivar Thommankodi the PSI between them being 92%. They also resemble in their leaf shape, but based on anatomical and other morphological characters they got grouped separately. Probably morphological divergence might have happened more rapidly than chemical divergence.

The cultivar Vadakkan forms the only member of the 10th group. This was collected from Coorg district of Karnataka state, probably was taken there from Kerala as indicated by the name. The most important distinguishing feature of this cultivar is the very bold berries. Factor analysis and the dispersion of OTUs between the factors have shown that this occupies a distinct position in relation to the factors 1,2,3 and 4. This cultivar has the second largest leaf size, has the broadest stomata and produces the boldest fruits (berries). This did not show high flavonoid similarity with any other cultivar. The highest chemical affinity was with Karuvilanchy and Neyyattinkaramundi (73%). This is of very restricted occurrence and might have originated from wild forms from nearby forests.

The centroid analysis sorted out Panniyur 1 into the last group. Panniyur 1 is reported to be a hybrid between two cultivars, Uthirancotta and Cheriyakaniakkadan. The parents and the progeny do not show any resemblance, morphologically or chemically. Panniyur 1 gets differentiated from the other cultivars by the factors 1 and 2, 1 and 3 and 2 and 3. In other words leaf size, leaf and epidermal thickness and leaf spike relation are critical in the divergence of this cultivar. Panniyur 1 had shown the highest chemical affinity with Kuriyalmundi, though these two differ much in their spike characters. Panniyur 1 did not show much similarity to either of its parents.

The cluster analysis led to the clubbing of Aimpiriyan and Kalluvally. Both these are commonly grown in the Pulpelly area of the Wynad district. These two seem to be morphologically close as observed from the dendrogram and correlation diagram. Yet, factor analysis had provided clues of their divergence as evidenced by their dispersion pattern based on the factors 1 and 3, 2 and 3 and 4. Chemically Aimpiriyan and Kalluvally showed 75% similarity. The chemical as well as morphological similarities indicate that these two cultivars might be related by their origin, but later underwent divergence with regard to certain characters.

Similarly Poonjaranmunda and Thulamundi were clustered in one group. These two shared many morphological characters, though they did not show much flavonoid similarity. They can be distinguished in relation to factors 1, 2 and 3.

One of the clusters formed contained 28 of the cultivars included in the study. They share many characters that are similar indicating probably common ancestry which subsequently underwent varying degrees of divergence during the course of their domestication.

Clustering of Piper Spp.

The clustering of *Piper* spp. using the centroid linkage technique led to the recognition of six distinct clusters (Fig. VI. 19). The group A consisted of *P.attenuatum* and *P.argyrophyllum*, two of the most closely related species. Hooker (1886) included these two species under the section Eupiper, while Gamble (1925) treated them as closely related, having membraneous leaves, and the flowers subtended by bracts adnate to the rachis. In a D^2 analysis study employing five characters Rahiman (1981, 1985) reported the grouping of *P.attenuatum* and *P.argyrophyllum* along with (*P.hymenophyllum*) *P.hookeri*. In the present study *P.hymenophyllum* gets separated into a different cluster. Ecologically also *P.attenuatum* and *P.argyrophyllum* occupy the same habitat, and morphologically not easy to distinguish them without close examination. Their flavonoid patterns have shown reasonably high chemical affinity, the PAI being 79%. Rahiman (1981) reported 83% chemical similarity between these two species. The chemical evidence thus supports the relationship arrived at by the centroid linkage. These results also support the taxonomic treatment of these two species by the earlier workers (Hooker 1886, Gamble 1925).

The second cluster comprised of three species - P.galeatum, P.trichostachyon and P.schmidtii. The first two are very closely related species, and treated accordingly by both Hooker (1886) and Gamble (1925). P.schmidtii on the other hand is a distinct species, occupying a different elevational habitat (above 1800 m). Rahiman (1981, 1985) in his study found that P.galeatum and P.trichostachyon grouped with P.mullesua in his D^2 analysis (he has not included P.schmidtii in his study). This seems to be a very unlikely combination as P.mullesua is very distinct in all respects. Such a clustering resulted from the use of too few characters for the analysis.

P.galeatum and P.trichostachyon had 87% chemical affinity between them. Morphologically also they resemble much but for the minutely hairy spikes of trichostachyon and the shortly stipitate nature of the flowers in galeatum. Rahiman (1981) observed high chemical affinity (90%) between these two species. The present results are in agreement with the treatment of these species by the earlier taxonomists (Hooker, 1886; Gamble 1925).

All the P.nigrum collections including P.nigrum var.hirtellosum were included in the same cluster; and the fact that no other species grouped with it shows that P.nigrum is a unique species. Such a position is also supported by Rahiman (1981).

Flavonoid analysis has shown that P.nigrum and P.nigrum var. hirtellosum had 87% affinity. P.nigrum had shown 71% and 72% chemical affinity with the new species P.sugandhi and P.sugandhi var. leiospicata. Unfortunately these could not be included in the numerotaxonomic study because of their late collection. But they are related to P.nigrum morphologically and to some extent chemically too.

Taxonomically P.nigrum is treated along with species like P.attenuatum, P.argyrophyllum, P.hymenophyllum and P.wightii under the section Eupiper (Hooker 1886). Gamble also treated P.nigrum along with the other species mentioned. But in the present study both in morphological analysis and chemical studies P.nigrum is found to be distinct, showing no resemblance to the other species. In its ecological adaptation P.nigrum is far superior to all the other species. This is also the only species (with the exception of P.silentavallevensis) having bisexual flowers. Indeed different states of dioecy is met within this species indicating a gradual evolution from dioecy to bisexuality or vice versa. Among the species occurring in South India this is the only one (with the exception of the recently discovered *P.sugandhi*) having pungent berries, resulting from the presence of the alkaloid piperine; and having the set of terpenes and related compounds that contribute to the characteristic black pepper flavour. Thus chemically this species is unique. In *P.sugandhi* we have the closest relative of *P.nigrum*, morphologically and chemically sharing both pungency and flavour that are characteristic of black pepper.

P.hymenophyllum forms the fourth cluster. This species, as mentioned already under the previous section, is more or less closely related to the first group (*P.attenuatum* and *P.argyrophyllum*), the most important distinguishing feature being its prominently hirsute nature. Both Hooker (1886), Gamble (1925) and later Rahiman (1981, 1987) treated this species as related to *P.argyrophyllum* and *P.attenuatum*. This treatment is also supported by the present studies. Though the cluster analysis has separated this into an independent cluster, its relationship with the other two species is high, the factor distinguishing the species from the other two being guard cell length, guard cell breadth and leaf texture (i.e. factor 6). The chemical studies have shown that *P.hymenophyllum* showed 78% flavonoid affinity with *P.argyrophyllum* thereby indicating their closeness.

The fifth cluster consisted of *P.silentvalleyensis* and *P.mullesua*. *P.silentavlleyensis*, a new species described recently by Ravindran, Nair and Nair (1987) is unique in having erect, flexuous, filiform spikes and is the only bisexual wild species reported so far from Western Ghats. Morphologically P.mullesua and P.silentvalleyensis resemble very much, they are indistinguishable if not carrying spikes.

Hooker (1886) included P.mullesua (Syn. P.brachystachyum) under the section Chavica along with the species like P.longum. Gamble treated them as related. P.mullesua is a very distinct species, the only species having globose spike occurring in South India. In the present study the relationship between P.mullesua and P.silentvalleyensis is well brought out by the centroid analysis. At the same time factor analysis has delineated them from all the other species by the factors 2 and 5.

Chemataxonomical studies had shown that the two are chemically distinct. P.mullesua had shown highest PAI with P.longum (69%) while P.silentvalleyensis showed the same amount of relationship with P.schmidtii; a result that is difficult to explain.

P.longum formed a separate cluster during the analysis. This is a creeper while all the other South Indian species are climbers. The centroid analysis had shown that this species is the most distant from the other Piper taxa studied. Rahiman (1981) also reported such a distant grouping of P.longum in his D^2 analysis. The dispersion of Piper spp. following the factor analysis had shown that P.longum gets differentiated from the other species by the 1st, 2nd and 3rd factors. Anatomically P.longum is distinct by the absence of central mucilage canal in the stem and petiole, an observation also made by the earlier workers (Murty 1959, Dasgupta and Datta, 1977). Chemically P.longum showed 69% similarity with P.mullesua, while with all other taxa the affinities were low; the chemical evidence thus supported the centroid grouping arrived at by cluster analysis.

It may also be mentioned here that the sectional classification of Hooker (18896) is not acceptable, because P.schmidtii and P.hookeri are very distinct taxa and should be segregated from the others; P. hookeri be aligned with P.argyrophyllum and P.schmidtii probably with P.wightii.

Infra specific variability in P.nigrum

The dispersion patterns arrived at after the factor analysis revealed the extent of variability existing in the species P.nigrum. From the figures it can be seen that all seven collections of P.nigrum clustered together very closely indicating the basic similarity underlying within the species. At the same time considering the dispersion patterns of black pepper cultivars (figs. VI.12) one reaches the conclusion that considerable infraspecific variability existed at the cultivar level. This difference is reflected in the dendrogram also. Here the same seven wild collections of P.nigrum were found to be included under two clusters, four in cluster D and three in cluster E. In the dispersion diagrams it was found that factors 1 and 3 led to the delineation of OTUs 46, 47 and 49 from OTUs 45, 48,50 and 51. Similarly in relation to factor 1 and 4, OTUs (48, 50), 47 and 49 occupied a distant position from OTUs 45 & 46. In relation to factor 3 and 4 OTU 51 was found to be quite far away from the position occupied by OTUs 46, 47 and 49. These findings lead one to conclude that these seven OTUs from the wild habitat have already undergone divergence in relation to certain characters and the extent of such divergence is reflected in the factor plots. In a similar study Shylaja (1984) had shown such infraspecific variation existing in the species complex Cinnamomum malabatrum. Such infraspecific variations could be highly overlapping as well as extensive in cross breeding species as shown by Small (1980, 1981) in Humulus lupulus, Classan, Nozzolillo and Small (1982) in Medicago etc.

The centroid linkage analysis led to the grouping of black pepper cultivars in different clusters. The nature of this dissimilarity or divergence is seen more explicitly in the factor analysis. From these studies certain characters or character combination (factors) are discovered that contributed towards a major share of variability.

The deliniation of cultivars results from even minor differences and often the same cultivars grown in two locations would be later known by two names (often named after the place or with some plant character or with some particular persons). Many cultivar names thus are in vogue.

The numerical taxonomic studies have shown that 28 out of 51 OTUs clustered in one group, thereby indicating the absence of significant morphological divergence among them. On the other hand,the remaining 23 fell into ten groups thereby indicating the morphological divergence undergone by these cultivars. It is very plausible that the domestication of P.nigrum could have started at many centres at different points of time, as suggested by Ravindran and Babu (1988). More on the origin of cultivated pepper is discussed in the following section.

Application of chemistry and numerical techniques in the taxonomy of Piper

Chemical and numerical taxonomical techniques are being used increasingly in taxonomy and the results from various sources indicate that they are powerful tools in elucidating taxonomic and phylogenetic relationships (Sneath and Sokal, 1973; Challice and Westwood, 1973; Parks et al 1975; Giannasi, 1975; Smith, 1976; Bisby et al 1980; Harborne and Turner, 1984). Gottlieb (1972) had shown that in the case of Lauraceae in general secondary metabolities are taxonomically important, and he has indicated the probable evolutionary trends in the family based on chemical constituents. Excellent studies have been carried out in Ulmeceae by Giannasi (1978) who demonstrated that the chemical dichotomy in the family is very much comparable with the morphological division of Ulmaceae into Ulmoideae and Celtidoideae.

Unfortunately, in Piperaceae no such chemotaxonomical studies have been carried out; though many species of Piper were studied chemically, none had attempted to correlate the chemical information with taxonomy. Rahiman (1981, 1985) carried out the first study on the distribution of flavonoids in some of the Piper species from Karnataka region. He observed close chemical similarities between certain species known to be morphologically related, such as P. galeatum and P. trichostachyon; P. attenuatum, P. argyrophyllum and P. hookeri. At the same time flavonoid variation existed among them so as to suppport their species identity. According to him, chemical evidence supported the conclusion arrived at by conventional taxonomists.

In the present study reasonable close chemical (flavonoid) affinities were noted between the morphologically allied taxa.

For example:

P. galeatum - P. trichostachyon	- 87%
P. attenuatum - P. argyrophyllum	- 79%
P. argyrophyllum - P. hymenophyllum	- 78%
P. galeatum - P. sugandhi	- 82%
P. sugandhi - P. sugandhi var. leiospicata	- 88%
P. nigrum - P. nigrum var. hirtellosum	- 87%

A look at these chemcial relationships immediately suggests their validity in terms of their morphological relationships thereby lending support to the species delimitation arrived at by the earlier workers employing conventional tools. The three species that did not show much chemical similarity were P.longum P.mullesua and P.silentvalleyensis, all the three included under the section "Pipali" according to the new key proposed in this study. Their chemical relationship are as follows:

P. longum - P. mullesua - 69%

P. longum - P. silentvalleyensis - 35%

P. mullesua - P. silentvalleyensis - 57%

Their relationships with other species were also low; though P.silentvalleyensis showed 69% affinity with P.schmidtii. On the whole one may have to think that these three taxa are rather less interrelated among themselves and with other taxa occurring in the area. Probably their ancestry has been lost.

The chemotaxonomical study therefore is a useful supplement to the classical taxonomy in the genus Piper in understanding the inter-relationships among the various taxa. Similar results had been reported in the genus Cinnamomum also from the same Western Ghat forest areas - (Shylaja, 1984).

In Piperaceae the alkaloids form an important group of compounds especially in species like P.nigrum (where the pungent principle is due to the alkaloid piperine), P.longum, P.cubeba etc. One such important class of alkaloid is the isoquinoline group of alkaloids present in many families having a Magnolian-Ranalian ancestry including the Laurales and Aristolochiales, (Gottlieb, et al 1989) orders closely related to Piperales. Hence probably an investigation into the alkaloid patterns may be useful in understanding the phylogenetic sequences and relationships in Piperaceae than the other groups of compounds. Such investigations have paid rich dividents in Papavarales and Rutales, (Waterman, 1975; Cagrin et al 1977, Harborne and Turner, 1984). Gottlieb et al (1989) while discussing the chemical dichotomies of the Magnolian complex suggested that neolignans and benzyl-isoquinoline type of alkaloids are important in the taxonomic-phylogenetic consideration of Piperaceae. They suggested that the pyrones and amides form a link between Piperaceae and Lauraceae while the cinnamoyl amides could be related to Chloranthaceae. Thus further chemosystematic investigation could be useful in elucidating the phylogentic lines leading to the Piperaceae.

Numerical Taxonomy:

Many elegant studies existed demonstrating the usefulness of the numerical techniques in taxonomy. In *Pyrus* Challice and Westwood (1973) developed a computer generated classification based on chemical and botanical characters which supported the subdivision of the genus into four geographical races. Barrett and Rhodes (1976) established the relationships among the various cultivated *Citrus* species using numerical taxonomic studies. Small, Jui and Lefkovitch (1976) carried out a detailed numerical taxonomic analysis in *Cannabis* and established that all populations (non-intoxicant, intoxicant, semi-intoxicant and wild) fall under the same species

C.sativa. Small (1978, 1981) carried out similar studies in *Daucus* and *Humulus*. Numerotaxonomical studies were found useful in elucidating the taxonomic relationships in another tropical species namely *Cinnamomum* (Shylaja 1984).

In *Piper* there are no such studies except for that of Rahiman (1981) who by using a limited number of characters carried out a D^2 analysis of nine *Piper* spp. This study in general supported the existing species classification, though some abnormal groupings resulted during the D^2 analysis owing to the use of very few characters. Callejas (1986) carried out a cladistic analysis of the tribe Pipereae during the course of his revision of *Piper* subgenus *Ottonia*. His studies confirmed the earlier notions of Kunth (1839) and Miquel (1843-44) that *Piper sensu lato* is a highly hetrogenous assemblage from which segregate taxa should be recognised.

The present numerotaxonomical study using a wide range of characters resulted in the grouping of the *Piper* spp., which also in general, supported the existing classificatory scheme derived from classical taxonomy. In addition, the numerical taxonomic results helped to understand the interspecies variation in a much wider perspective by pinpointing the characters that are actually responsible for the divergence of the species.

At the cultivar level the numerical taxonomic analysis was found useful in relating the extent of divergence among the cultivated black pepper (*P.nigrum*). The underlying similarities among the majority of cultivars were brought to the focus by the analysis. At the same time the existence of distant groups also pointed out the fact that all the cultivars have not originated from a common stock but that their origins were separated in space and time. Based on this, supplemented by other evidences, it becomes necessary to arrive at certain concepts regarding the origins of P.nigrum, the details of which are dealt with in the following section.

The results therefore, indicate the usefulness of the chemical and numerical taxonomic techniques in elucidating the taxonomical relationships in Piper.

The origin of P.nigrum-the black pepper:

Black Pepper is known to have originated in the evergreen forests of the Western Ghats. Wild P.nigrum plants are growing luxuriantly in these forests at various elevations. No study has so far been carried out to find out the probable origin of P.nigrum. Cytological studies led workers like Mathew (1958, 1972), and Rahiman (1981) to suggest x = 13 as the basic chromosome number of the genus; and that P. nigrum with 2n = 52 can be considered a tetraploid . A study of the present South Indian species indicates that P.nigrum might have originated through hybridisation between species with or without polyploidisation of the hybrid.

The most probable candidates for the parentship of P.nigrum are *P.wightii*, *P.galeatum* and *P.trichostatchyon*. All the three are woody climbers, having more or less identical leaf morphology and texture. Their spikes and fruits are more similar to *P.nigrum* than the other species. The fruits of all the three have some amount of pungency, combined with bitterness.

A detailed study of the morphology has led to the conclusion tha *P.nigrum* might have originated as natural hybrid of *P.galeatum* and *P.wightii*.

The most compelling evidence for such a conclusion comes from the nature of the bracts. In *P.galeatum* the bracts are connate fleshy, boat shaped cups; in *P.wightii* the bracts are fully adnate to the rachis, the shape of the bract being more or less oblong. In *P.nigrum* the bracts form a shallow cup like structure below the ovary; this character being typically intermediate between the first two cases.

The somatic chromosome number of all these species are 2n = 52 (Rahiman, 1981; Rahiman and Nair, 1986; Bai and Subramanion, 1984). Based on the morphological and cytological evidence the following scheme is proposed for the origin of *P.nigrum*.

P.wightii	x ↓	P.galeatum
2n = 52	P. nigrum	2n = 52
	2n = 52	

P.wightii x P.trichostachyon

2n = 52 ↓ 2n = 52

P. nigrum var. hirtellosum

2n = 52

P.wightii is a threatened species, its distribution currently restricted to certain pockets at higher elevation (around 2000m). In the past, forests were in continuous stretches, which might have led to the overlapping of these species, and the population of these species might have been much richer. Most probably, as it happens even today, more than one species might have climbed up the same trees, thereby providing opportunity for natural crossing. The progenies once formed get effectively isolated from the parents and the rest of the progenies because of the absence of any active pollen transfer mechanism thereby preventing random mating and sebsequent gene flow (Ravindran et al 1989). At the same time the highly successful vegetative propagation ensures their survival and spread.

Such natural crossings might have happened a great many times at many locations, gradually leading to the building up of large populations of the hybrid, and also much variability in the population. Gradually the progenies that co-existed might have undergone sib-matings, back crossings and segregations producing fertile hybrids and also segregants. The seccessful progenies might have spread both vegetatively and through seeds, gradually becoming successful colonisers in the forest lands.

Natural hybridisation and the origin of Piper species: The case of P.sugandhi and P.sugandhi var. leiospicata

P.sugandhi and P.sugandhi var. leiospicata are the new taxa described from the Western Ghats. Morphologically these are very closely related except for one character, the spikes are minutely hairy in P.sugandhi and glabrous in P.sugandhi var. leiospicata. They occur together with species such as P.trichostachyon, P.galeatum and P.nigrum in the tropical evergreen forests in Wynad District. Analysis of the characters of the new species had shown that these are related to P.nigrum, P.trichostachyon and P.galeatum. The characters of P.sugandhi are intermediate or a combination of the characters of P.nigrum and P.trichostachyon. The bracts of P.sugandhi are intermediate between P.nigrum and P.trichostachyon. It retains the minutely hairy nature of P.trichostachyon, and also its fruit size and shape. Fruits are pungent as in P.nigrum. Table 7.1 gives certain characters of the three species (P.nigrum, P.trichostachyon and P.sugandhi) indicating the probable hybrid nature of P.sugandhi.

Table 7.1 Certain Characters of *P. sugandhi* and its putative parents (*P. nigrum* and *P. trichostachyon*)

Character	P.nigrum	P.tricho-stachyon	P.sugandhi
Habit	woody climber	Woody climber	Woody climber
Spike	Flowers closely arranged	Flowers spaced	Flowers less spaced (Intermediate)
Bract	cupular with decurrent base	Connate forming Fleshy cup	deeply cupular and somewhat fleshy, base decurrent
Texture	Glabrous	Minutely hairy	Minutely hairy
Stamens	2	2	2
Fruit shape	Round	Oblong	Oblong
Taste	pungent	Bitterly pungent	pungent
Chromosome number	2n = 52	2n = 52	2n = 52

Based on the various characters it seems that this new taxa might have originated as given below:

P. galeatum X	*P. nigrum* X	*P. trichostachyon*
2n = 52	2n = 52	2n = 52
Bracts connate, boat shaped, spike glabrous	Bract cupular with decurrent base-pungent	Bract boat shaped, spikes minutely hairy. Flowers sessile

↓ ↓

P. sugandhi var leiospicata	*P. sugandhi* 2n = 52
Bracts deeply cupular, decurrent base, pungent, spikes glabrous, flower shortly stipitate	Bract deeply cupular, base decurrent, pungent, spike minutely hairy, flowers shortly stipitate

A study of these species in their natural habitat had shown that they all co-exist, and often climb up the same trees thereby offering chances for crossing to occur. The breeding behaviour of *Piper* also might have played an important role in the evolution of the new species.

Phylogeny and Inter-relationships of Piper species

Phytogeographical distribution shows that *Piper* and the related genus *Peperomia* probably had originated in tropical America at a comparatively high altitude and dry conditions. *Peperomia* thrived later in drier and higher Andes zones, *Piper* in comparatively lower and damper Brazil and later spread to parts of Asia and other regions. Datta and Dasgupta (1979) after studying the anatomical features of Piperaceae concluded that the evolution of *Piper* and *Peperomia* are related to adaptation with two different conditions: *Piper* adapted gradually with damper low lands with elaboration of vascular arrangements, while *Peperomia* evolved in drier and higher lands (Andes zones) which required reduction of bundle surfaces or surface volume ratios-a xerophytic character.

Little is known about the evolutionary trends among Indian

Piper. Datta and Dasgupta (1977) after studying anatomical features of *Piper* species from north eastern region of India concluded that there is a definite sequence of advancement from *P.cubeba* to *P.longum* to *P.nigrum* and finally to *P.betle*. This sequence of advancement according to them is related to the gradual elaboration of the tracheary plates; the most primitive form is found in *P.cubeba*.

Coming to the South Indian *Piper* taxa it is clear from the studies presented here that certain definite groups can be identified among them, such that the members within each group have closer affinity compared to the others. The following groups can thus be made out:

1) P. longum, P. hapnium
2) P. galeatum, P. trichostachyon
3) P. attenuatum, P. argyrophyllum, P. hymenophyllum
4) P. mullesua, P. silentvalleyensis
5) P. wightii, P. schmidtii
6) P. nigrum, P. sugandhi

Cytological evidences have shown that most of the South Indian species have somatic chromosome number of 2n = 52 (Mathew, 1958; Rahiman 1981; Bai and Subramoniom, 1984, Rahiman and Nair 1986, Samuel, 1987). Deviations from this were reported in the case of *P.mullesua* and *P.hymenophyllum*.

The basic chromosome number of the South Indian *Piper* is believed to be x = 13. (Mathew, 1958, Rahiman 1981). Thus the 2n = 52 chromosomed taxa are tetraploids. Variations in chromosome number have been reported, specially in P.longum, ranging from 2n = 24 to 2n = 96 (Tjio, 1948; Sharma and Bhattacharya, 1959) . Diploid species have not been reported from South India. Higher ploidy occur in P.hymenophyllum as well as in P.mullesua (Rahiman and Nair, 1986). Polyploidy seems to have played an important role in the speciation in South Indian Piper (Mathew, 1958; Rahiman 1981)

From the ancestral forms more than one developmental lines can be visualised among the South Indian taxa of Piper; one of which leading to P.longum, P.mullesua etc.; a second line leading to P.galeatum and P.trichostachyon and then to P.wightii, P.nigrum etc., a third one leading to P.attenuatum and P.argyrophyllum and P.hymenophyllum. It is possible that the ancesters as well as the connecting links might have been lost during the course of evolution.

Origin of black pepper cultivars

It was mentioned in the previous section that P.nigrum might have originated as a hybrid. The overlapping of the parents at many locations could thus have given rise to hybrids on many occasions, separated in space and time. Much variability might have been accumulated in due course as a result of segregation, back crossing etc. Because of the successful vegetative propagation, and the absence of active pollen transfer, random mating and gene flow, an isolation barrier is built up around each individual plant. Chances of crossing is then limited to situations where more than one plant climbs up the same tree. This condition led to the establishment of a great many localised small populations, each one isolated from others. The present day cultivars might have originated from such localised populations (Ravindran and Babu, 1988, Ravindran et al 1989).

The cultivated black pepper has originated from the wild ones through the process of selection and domestication. Initially black pepper was a forest produce, people were collecting them from the plants growing in the forests. Gradually man has started cultivating them. For this the farmers selected vines having good fruit set, pungency, size, spike length etc. As a result of such selection process many cultivars came into existence in many localities. The present day cultivars had originated in this way. Because of the selection pressure for better fruit set the bisexual forms were selected as they give much better fruit set. This selection would have led to the directional evolution of bisexuality in the cultivated forms.

The new world Piper Vs. South Indian Piper:- an evolutionary dichotomy

When one looks at the New World and Old World (especially the South Indian) species of Piper one arrives at the inevitable conclusion that the evolutionary development in the genus represents a major case of dichotomy. The South and Central American species of Piper and their counter-parts in South India seem to have evolved along two distinct evolutionary

.ines. American *Piper* species (with very few exceptions) are)isexual forms and are shrubs or small trees. (Yuncker, .958). On the other hand the South Indian *Piper* species are iostly dioecious and are woody or scandent climbers (or :reepers). Of the eight species of climbing *Piper* lescribed by Tebbs (1989) from the New World all but one)ossess erect spikes. These major differences resulted)robably due to their evolution through two different lines :rom two different ancestral forms.

:he centre of diversity for the genus is Northern South and :entral America, which together account for more than 60% of :he species reported (Datta and Dasgupta, 1977).

:t becomes a moot question how the genus has spread to such liverse geographical areas from the centre of diversity. :he genus might have originated in the present day Central ınd Northern South America during the mid Cretaceous before :he splitting away of the ancient Gondwana land by the)late tectonic activity. The available fossil evidences .ndicate that the initial major diversification of ıngiosperms took place during the late Cretaceous (Friis, :haloner and Crane, 1987). Palynological data suggest that :he angiosperm radiation began at low paleolatitudes (Brenner, 1976; Hughes, 1978), but within a relatively short ;pan of time angiosperms became established world wide,)robably during the mid Cretaceous (Upchurch and Wolfe, 1987; :rane, 1987). The earliest well documented angiosperm fossil includes dispersed monosulcate pollen grains of the form genus _Clavatipollenites_, believed to be closely related to the extent Chloranthaceous genus _Ascarina_. This unequivocally indicates the early appearance of Piperales (Friis _et al_, 1987).

It is tempting to assume that some of the ancestors of the present day _Piper_ might have spread to various regions of the ancient Gondwana land. The plate tectonic activity and the opening up of the Atlantic and Indian oceans led to the splitting away of the Gondwana land mass into the present day South America, Africa, India and Australia. Many of the ancestors might have perished as a result of the drastic changes in climate that followed the movement of the continents. The survived ones might have undergone natural crossing, polyploidy etc. that led finally to the present day species.

Thus the present day forms might have originated from the ancestral forms that reached the Indian subcontinent during the mid Cretaceous before the plate tectonic activity shifted India. The South Indian species of _Piper_ are all either tetraploids or higher polyploids, while the 2n = 26 diploid forms are absent, indicating these ancestral forms might have become extinct; while in its original home in Central America and Brazil diploid forms have been reported. The descendants of the ancestral forms of South America and South India might have evolved independently in two lines in response to the needs of the habitats. As colonizers of the tropical rain forests the climbers along with vegetative propagation will have definite selective advantage in getting more sunlight than the undershrubs or small trees. A plant that can reach the forest canopy rapidly gains an advantage, enabling it to utilise the better light availability there (Gentry, 1985). This climbing habit has evolved independently several times over in many plant families (Tebbs, 1989). The predominance of vegetative propagation combined with the absence of free gene flow among the individuals and populations might have played a role in the evolution of dioecy and the particular growth habit of the South Indian taxa of Piper.

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A B S T R A C T

Black pepper is the most important of all spices used by man. The source of this spice is the dried mature fruits of the perennial climber, *Piper nigrum* L. (Piperaceae), native of the humid evergreen forests of the Western Ghats of South India. India is a major producer and exporter of black pepper, the annual export earning being over Rs.3000 million. In spite of its great economic importance, not much is known about black pepper and its related taxa occurring in the forests of Western Ghats. The present study is an attempt to fill the gap existng in our knowledge on this important genus.

Fourtyfour *P.nigrum* cultivars and 14 related taxa were included in the present study. The studies were confined to: (I) taxonomy (II) morphology (III) numerical taxonomy and (IV) Chemotaxonomy. In numerical analysis Average linkage analysis was used for the clustering of characters, centroid linkage analysis for the clustering of taxa and also factor analysis. Twentytwo characters from black pepper cultivars and 30 characters from the related taxa were recorded and the data were used in these numerical taxonomic analysis.

The numerical analysis was carried out at the Computer centre of Carneige-Mellon University, USA, using the BMDP 81 programme package developed by the University of California, Los Angelas.

The chemotaxonomical studies were restricted to the flavonoid patterns and were analysed by paper chromatography.

The major results and conclusions eminated from these studies are given below:

1. Two new taxa - *P.sugandhi* and *P.sugandhi*var.*leiospicata* were discovered and described.

2. Fourteen *Piper* taxa occurring in the Western Ghats were collected and described taxonomically. These taxa are:
   P.argyrophyllum, *P.attenuatum*, *P.galeatum*, *P.hymenophyllum*, *P.longum*, *P.mullesua*, *P.nigrum*, *P.nigrum* var. *hirtellosum*, *P.silentvalleyensis*, *P.schmidtii*, *P.sugandhi* (Sp.nov), *P.sugandhi* var. *leiospicate* (var.nov.), *P.trichostachyon*, and *P.wightii*.

3. A new key was formulated for the South Indian species of *Piper*.

4. Anatomical features of representative taxa were studied. They all shared the same basic anatomical features, though minor differences existed. The species differed in the number of peripheral and central bundles, the presence of continuous or discontinuous band of sclerenchyma, and by the presence or absence of a central mucilage canal.

5. The stomata of all Piper spp. studied were tetracytic, having a ring of four subsidary cells around the stomata. The stomatal development was found to be mesogenous or mesoperigenous.

6. The problem of character correlations in black pepper have been examined by the average linkage cluster analysis. This analysis led to the clustering of characters based on the correlations into six main groups:

   (1) Leaf length, leaf breadth, leaf size index.
   (2) Fruit shape, fruit size.
   (3) Spike length, L.L/Sp. length, Peduncle length.
   (4) L.L/L. breadth, guard cell length, guard cell breadth.
   (5) Leaf shape, leaf base
   (6) Leaf thickness, upper epidermal thickness, lower epidermal thickness.

7. Cluster analysis of 51 OTU's of P.nigrum (44 cultivars and seven wild ones) was carried out using

the centroid linkage analysis. The 51 OTUs were grouped in 11 clusters. As a result of the analysis 28 cvs were clustered into a single group. Four clusters consisted of only one cultivar each, four others had two cultivars each, one had seven cultivars each, one had seven cultivars while another cluster had four cultivars.

8. Factor analysis was carried out in order to learn the extent and nature of divergence among the cultivars. Eight factors were recognised during the analysis, that contributed practically to all the variability present among the cultivars.

9. The dispersion of cultivars (OTUs) in the dispersion plots indicated the divergence or closeness of the cultivars in relation to any two factors taken at a time. For eg. the distribution of cultivars between 1st and 2nd factors showed that OTU 29, (Panniyur 1) has large difference both with regards to x and y coordinates indicating that both factors 1 (leaf size index, leaf length, leaf breadth) and 2 (leaf thickness, lower epidermal thickness, upper epidermal thickness) are important in differentiating this cultivar from others. Similarly the dispersion plot showing the distribution of 1st and 3rd factors indicate that cv. Vokkalu differ from all the cultivars in relation to factor 3 (leaf length/spike

length, spike length, peduncle length).

In this way using factor analysis the characters that are critical in differentiating the various cultivars were established. The divergence of cultivars (or the cluster of cultivars) was mainly influenced by these factors.

10. The role of individual factors on the grouping of OTU was further studied by computing the intra and inter cluster D^2 values (Mahalanobis-D^2). As a result of this the original eleven clusters arrived at by the centroid linkage were further grouped into eight individual factors. These results indicated the cluster A, B, C and D are more or less closely related among themselves.

11. Centroid linkage cluster analysis of the *Piper* spp. led to six clusters. The first cluster consisted of *P. argyrophyllum* and *P. attenuatum*. Second cluster included *P. galeatum*, *P. trichostachyon* and *P. schmidtii*. The third cluster consisted of all the *P. nigrum* collections. *P. hymenophyllum* was included in the fourth cluster. *P. silentvalleyensis* and *P. mullesua* formed the fifth cluster , while *P. longum* was in the sixth cluster. In general the clustering pattern followed the taxonomic grouping of the species.

12. Factor analysis based on the thirty characters led to the recognition of seven factors. Analysis of the role played by these factors led to the following conclusions:

Factor 1 delineated P.nigrum from all other taxa.

Factor 2 was critical in differentiating P.silentvallevensis and P.mullesua from other species.

Factor 3 was mainly responsible for separating P.longum from the other species.

Factor 4 led to the differentiation of P.galetum, P.trichostachyon and P.schmidtii.

Factor 5 was most useful in delineating P.hymenophyllum.

13. Paper chromatographic analysis of flavonoids and related compounds were carried out. Based on the spot similarities paired affinity indices were computed.

Good flavonoid similarity was noticed between:

(1) P.galeatum and P.trichostachyon

(2) P.argyrophyllum and P.attenuatum

(3) P.galeatum and P.sugandhi var. leiospicata.

The results in general supported the conclusions arrived at by numerical taxonomy as well as by conventional taxonomy.

14. On the other hand, some species included in the same group by numerical analysis were found to show low chemical similarity, as in the case of *P. silentvalleyensis* and *P. mullesua*. These two species together with *P. longum* form the three taxa producing erect spikes (section "Pipali" in the new key). The chemical evidence tends to show that the three are closely related.

15. The flavonoid analysis of black pepper cultivars indicated the extent of infraspecific chemical similarity and variability with regard to flavonoids and related compounds. The chemical similarity was found to be useful in identifying closely related cultivars.

16. The present study had given the indication that *P. nigrum* was originated as a hybrid between *P. wightii* and *P. galeatum*. The wildly occurring *P. nigrum* are mostly dioecious, while the cultivated ones are bisexual, and this presents a case of directed evolution of bisexuality influenced by selection and domestication.

17. The role played by natural hybridisation in the origin of *Piper* spp. was further, strengthened by the discovery of *P. sugandhi* and *P. sugandhi* var. *leiospicata*. From morphological and ecological evidence these were thought to have originated as

hybrids between *P.nigrum* x *P.trichostachyon* and *P.nigrum* *P.galeatum* respectively.

18. The probable inter relationships among the South Indian *Piper* have been discussed.

19. This study also proved the usefulness of numerical and chemical methods in the taxonomy of *Piper*.

This study is also useful in identifying cultivars that are distinctly different and distantly related for use in crop improvement work.

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