CHARACTERIZATION AND QUALITY ANALYSIS OF BLACK PEPPER (*Piper nigrum* L.) GENOTYPES OF KERALA

by

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(2019-12-023)

THESIS

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DECLARATION

I, hereby declare that this thesis, entitled **"CHARACTERIZATION AND QUALITY ANALYSIS OF BLACK PEPPER (*Piper nigrum* L.) GENOTYPES OF KERALA"** is a bonafide record of research work done by me during the course of research and the thesis has not previously formed the basis for the award to me of any degree, diploma, associateship or other similar title, of any other University or Society.

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CERTIFICATE

Certified that this thesis, entitled **"CHARACTERIZATION AND QUALITY ANALYSIS OF BLACK PEPPER (*Piper nigrum* L.) GENOTYPES OF KERALA"** is a record of bonafide research work done independently by **Ms. Reshma, P. (2019-12-023)** under my guidance and supervision and that it has not previously formed the basis for the award of any degree, diploma, fellowship or associateship to her.

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RESHMA. P

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LIST OF ABBREVIATIONS

%	Per cent
AEU	Agro-Ecological Units
AFLP	Amplified Fragment Length Polymorphism
ANOVA	Analysis of Variance
AOAC	Association of Official Agricultural Chemists
CD	Critical Difference
cm	Centimeters
cm^2	Centimeter square
cm g^{-1}	Centimeter per gram
CRD	Completely Randomized Design
DUS	Distinctiveness, Uniformity and Stability
DW	Dry weight
FSSAI	Food Safety and Standards Authority of India
FW	Fresh weight
g	Gram
g/l	Gram per litre
GCMS	Gas Chromatography Mass Spectrometry
ha	Hectare
IISR	Indian Institute of Spices Research
IPGRI	International Plant Genetic Resource Institute
kg	Kilogram
m	Meter
mg	Milligram
ml	Milliliter
MT	Metric Tonnes
nm	Nanometer
NS	Non Significant

PPV & FRA	Protection of Plant Varieties and Farmers Right Act
RAPD	Random Amplified Polymorphic DNA
RHS	Royal Horticultural Society
RWC	Relative Water Content
TW	Turgid weight
UPGMA	Unweighted Pair Group Method with Arithmetic Mean

INTRODUCTION

1. INTRODUCTION

Black pepper (*Piper nigrum* L.) glorified as the 'King of Spices' or 'Black gold', belongs to the family Piperaceae, originated in India in the submountainous tracts of the Western Ghats (Rahiman *et al.*, 1979). Black pepper was one of the early and most commonly used spices in human history and is known for its characteristic pungency. Black pepper is commonly used as a table condiment and a culinary spice. It also has medicinal values and is used as ayurvedic medicine in India (Mathew *et al.*, 2005).

Black pepper production was once confined only to the western coastal region of India. Later, its cultivation spread to most tropical countries (Ravindran and Kallupurackal, 2001) and now it is chiefly cultivated in the rainy tropical regions of the world, such as Ethiopia, Vietnam, Indonesia, India and Brazil. India is ranked fourth in global production producing 61,004 MT with Karnataka being the highest producer, followed by Kerala and Tamil Nadu. Kerala contributes 30,000 MT from an area of 82,540 ha (Spices Board, 2020a). India exported 13,540 MT of black pepper per year, earning Rs 56 crore foreign exchange in 2018-19. The major importing countries of Indian pepper are USA, UK, Germany, Sweden and Japan (Spices Board, 2020b). The global production of black pepper is estimated to be 1,103,024 MT, with Ethiopia taking the lead (FAO, 2021).

India has a huge diversity of black pepper. Over seventy distinct landraces are under cultivation in Kerala (Mathai *et al.,* 1981), both as a mixed crop in homestead gardens and in semi plantation scale. Kerala, which encompasses a large portion of the Western Ghats has a diverse range of *Piper* species. This region is endowed with many landraces of black pepper besides the progenitors of cultivated ones (Mathew *et al.*, 2005).

All traditional pepper growing areas of Kerala have their own popular cultivar (Prasannakumari *et al.*, 2001). Many black pepper landraces have already vanished and others are on the verge of extinction. The genetic basis of black pepper has deteriorated over time owing to primarily gene attrition caused by the rapid displacement of many local cultivars by high yielding varieties (Mathew *et al.*, 2005). India's Southern most state, Kerala is a rich repository of wild relatives of black pepper (Joy *et al.*, 2007). Black pepper is largely cultivated by small and marginal farmers in Kerala and has a major impact on their lives (Sajitha, 2014).

Indian black pepper demands a premium price in international market due to its preference and intrinsic quality (Thomas, 2010). The Indian black pepper outperforms other countries in terms of taste, aroma and flavour. The key determining factors of black pepper in the trade are berries with high intrinsic values (Vinod, 2014). Black pepper is renowned for its innate quality and it is imparted by its two main components such as volatile oil and pungent compounds. The flavour, odour and pungency of black pepper are its most valuable assets. The local cultivars of Kerala have good quality attributes though the yield is comparatively low. Cultivars with high intrinsic quality must be identified to meet the industrial and global demand for high quality pepper. These high quality cultivars can also be combined in breeding for further improvement in black pepper. The major breeding goal of black pepper is to develop high yielding varieties that are resistant to biotic and abiotic stresses along with good quality parameters. Hence, an attempt was made to identify the black pepper genotypes from the main black pepper growing areas of Kerala by their quality.

It was in this background that the present study entitled 'Characterization and quality analysis of black pepper (*Piper nigrum* L.) genotypes of Kerala', was taken up with the objectives of survey, characterization and quality analysis of black pepper genotypes of Kerala based on morphological and biochemical parameters.

REVIEW OF LITERATURE

2. REVIEW OF LITERATURE

Black pepper is one of the most renowned and ancient spices in the world and a significant cash crop of Kerala. Black pepper (*Piper nigrum* L.) has its primary centre of origin in the Western Ghats of South India. The unique hot and pungent flavour of black pepper is highly valued by the whole world. The Western world was drawn to the Indian subcontinent by the insatiable desire for Indian 'black gold' because of its exquisite properties.

Kerala, occupying a considerable portion of the Western Ghats is a rich repository of wild forms and diversity of the genus *Piper*. Black pepper is cultivated mostly by small and marginal holders and their livelihood have a crucial bearing on this crop (Sajitha, 2014). India has a huge diversity for black pepper cultivars, the majority of which are of supreme quality. Over 75 cultivars of black pepper are being cultivated in India. 17 improved varieties of black pepper have also been released for cultivation (Prasath *et al.,* 2017). Majority of the black pepper landraces cultivated in Kerala are superior in quality though the yield is less. Much of the landraces are becoming extinct and hence a characterization of the quality aspects of landraces presently cultivated by the farmers need to be documented. Hence the present study on "Characterization and quality analysis of black pepper (*Piper nigrum* L.) genotypes of Kerala" was carried out at the College of Agriculture, Vellayani with the objective of survey, characterization and quality analysis of black pepper genotypes of Kerala based on morphological and biochemical parameters. The relevant literature on the morphological, biochemical and quality studies of black pepper was reviewed and summarised in this chapter under various subtitles.

2.1. DISTRIBUTION AND DIVERSITY OF GENUS PIPER

Royle (1839) observed that *Piper* plants grow from sea level to the Andes and Sub-Himalayan highlands. The Trans Gangetic and South Deccan regions of India have been identified as the two distinct origins of the genus *Piper* (Hooker, 1886). *Piper* is a significant structural component of the forest understorey since it is the most diverse genus among angiosperm basal lineages (Gentry, 1990). The phylogenetic analysis for the genus *Piper* showed three major clades such as the American tropics (700 species) followed by Southern Asia (300 species) and the South Pacific (100 species) with richest diversity of *Piper* species (Jaramillo and Manos, 2001). *P. nigrum, P. longum*, and *P. betle* are the most prevalent species of the Piperaceae family (Khan *et al.*, 2010) and *P. nigrum* L. is the most important one among these.

The black pepper of commerce is obtained from *Piper nigrum* L., which is thought to have originated in the sub mountain tracts of the Western Ghats (Rahiman *et al.*, 1979). The Western Ghats are largely comprised of the related species of *P. nigrum* with the Southern Western Ghats having the highest cultivar diversity (Ravindran, 2000).

The cultivation of black pepper commenced about 6000 years ago and now, aside from wild relatives there are many black pepper cultivars widespread in India. One of the most important aspects of black pepper diversity is cultivar diversity. More than a hundred black pepper cultivars are known to exist in India apart from its wild relatives and the main centres of variability are Kerala and Karnataka (Ravindran *et al.*, 1997a).

More than seventy distinct cultivars are being cultivated in the state of Kerala (Mathai *et al.*, 1981), both as a mixed crop in domestic gardens and on a semi plantation scale. Every traditional pepper growing tract of Kerala has its own popular cultivar (Prasannakumari *et al.*, 2001). In addition to the landraces and conventional cultivars grown by farmers, black pepper also harbours many wild species in forests (Mathew *et al.*, 2005).

Most of the improved varieties released for cultivation are clonal selections from the existing landraces. The majority of black pepper fields are grown mainly with landraces or the most popular hybrid Panniyurl (George *et al.*, 2005). The landraces are arbitrarily named in the Malayalam vernacular on several grounds, such as where the cultivars originated, startling morphological features etc. (Mathew *et al.*, 2005). They have been named for specific features of the vine such as a plant colour or appearance (Karimunda, Vellanamban), spike character (Kuthiravally and

Aimpirian), leaf shape (Vattamundi) or place of origin (Arakkulammunda, Perambramunda and Poonjaranmunda) or after an individual who has introduced a vine to a particular area (Yohannankodi and Thommankodi) etc. (Krishnamoorthy and Parthasarathy, 2009).

Screening of the germplasm identified cultivars that are rich in piperine, oleoresin and oil content. The cultivars Kottanadan, Kuthiravally, Kumbakodi and Nilgiri are high in piperine and oleoresin, while Balankotta, Kumbakodi and Kaniyakadan are high in essential oil (Parthasarathy *et al.*, 2007). Hussain *et al.* (2017a) reported that local genotypes available in farmer's fields have the potential to produce higher yields with higher quality characteristics. Some local cultivars have a high potential for higher quality performance (Pannaga *et al.*, 2021).

Cultivar diversity contributes to breeding and conservation programmes based on good berry sets, pungency etc (Joy *et al.*, 2007). The cultivars are descended straight from the wild *P. nigrum* and cultivar diversity is the result of both natural selection and conscious selection by humans for various traits (Krishnamoorthy and Parthasarathy, 2009).

High genetic variability was reported in *P. nigrum* cultivars (Ibrahim *et al.*, 1985). A few genetic studies have been conducted to investigate genetic variation among Indian black pepper cultivars using molecular markers such as random amplified polymorphic DNA (RAPD) and amplified fragment length polymorphism (AFLP) (Pradeep Kumar *et al.*, 2003; Nazeem *et al.*, 2005; Joy *et al.*, 2007). Microsatellite based analysis of genetic diversity of popular black pepper genotypes in South India emphasized the possibility of introduction of black pepper from South India to Malaysia from the observation of genetic similarity of Malaysian cultivar Kuching with other indigenous popular cultivars of South India (Joy *et al.*, 2011).

Cluster analysis is widely applied for the assessment of genetic distance of definite set of genotypes. The application of cluster analysis in taxonomic studies has previously been seen in *Piper* species (Ravindran *et al.*, 1992). In a study, cluster analysis of fourty four cultivars and seven wild black pepper accessions using twenty two morphological characters identified elevan clusters. Karimunda, Panniyur-1, Vadakkan and Kuthiravally were the cultivars that were unique and did not cluster with any other cultivars. The presence of 28 cultivars in one category further demonstrated that the majority of common cultivars closely mimic one another and most likely had a common origin (Ravindran *et al.*, 1997a).

The genetic resources of black pepper in India are a great strength for its improvement. The germplasm includes native cultivars, wild forms from the area of origin and related species that can be used in crop improvement. High yield, tolerance to biotic and abiotic stress and high quality are the primary breeding goals for black pepper (Krishnamoorthy and Parthasarathy, 2009).

Breeding activities begin with germplasm collection as a source of diversity (Carsono, 2008). Worldwide surveys in locations where black pepper is grown intensively may turn up unique gene sources that may be used for the improvement of black pepper or can be exploited directly (Saji *et al.*, 2013). Germplasm collection of local, native and wild black pepper can serve as a source of genetic diversity (Prayoga *et al.*, 2020).

The Indian Institute of Spices Research (IISR) at Kozhikode, Kerala has the world's largest collection of black pepper germplasm. This largest gene pool consists of landraces, natural mutants, improved varieties and even true seedlings of black pepper (Sasikumar *et al.*, 2007).

Germplasm collections are being maintained at IISR, Peruvannamuzhi, Kozhikode as well as in alternate sites (Appangala and Chettalli, Karnataka). Around 3467 black pepper accessions are being maintained at the IISR, Experimental Farm, Peruvannamuzhi. At present, field gene bank at Central Horticultural Experiment Station, Chettalli holds 627 accessions (IISR, 2020).

In addition to IISR, germplasm accessions are being conserved at All India Coordinated Research Project on Spices centers at Panniyur, Ambalavayal, Sirsi, Yercaud, Pechiparai, Pundibari, Chintapally and Dapoli (Saji *et al.*, 2019).

The Indian Institute of Spices Research has been collecting germplasm of black pepper and its wild relatives since 1976. The Western Ghats forests extending from Maharashtra to Kerala and are found in Goa, Karnataka, and Tamil Nadu as well as the Andaman and Nicobar Islands and the North Eastern regions of India were surveyed for germplasm collection. This germplasm includes cultivated kinds, wild relatives, commercially significant species, endangered species and alien species (IISR 2008). IISR explored Nagaland and the Andaman and Nicobar Islands for germplasm collection. Forty black pepper accessions were collected from the forests of Nagaland and seventeen from the Andaman and Nicobar Islands. Five new Piper species (*P. boehmeriaefolium, P. makruense, P. pothiforme, P. rhytidocarpum* and *P. diffusum*) from Nagaland and two new species (*P. pedicellatum* and *P. clypeatum*) from the Andaman and Nicobar Islands were introduced to the black pepper germplasm repository (IISR, 2018). A unique accession with long spike was collected from the estate of Tata Coffee, Madikeri, Karnataka. Nine accessions of *Piper* spp. were collected from Andaman and Nicobar Islands in an exploration programme (IISR, 2020).

A survey was undertaken by Prasannakumari *et al.* (2001) in the black pepper growing tracts of Thodupuzha and Meenachil taluks of Kerala. In each taluk, thirty holdings were selected and pepper cultivars grown in these homesteads were studied for yield and yield contributing attributes. The important cultivars identified in the holdings surveyed were Karimunda, Narayakody, Neelamundi, Kaniyakkadan, Mundi, Panniyur 1, Nedumchola, Perumkody and Jeerakamunda.

Saji *et al.* (2013) collected a unique black pepper accession with a very long spike, hitherto unreported in the world black pepper gene pool, from a coffee plantation in the Coorg district of Karnataka. Though it had loose settings, it has the potential to be a new source of genes for increasing spike length in black pepper. Sasikumar *et al.* (2013) reported a rare accession with high dry recovery and bulk density as well as round, solid, bold and attractive black corns. The modest quantities of piperine, oleoresin and essential oil suggested that the berries were of high quality. A trait specific survey conducted by Sasikumar *et al.* (2014) reported two unique black pepper accessions having very long spikes with poor setting from Coottanadu Estate, Wayanad, Kerala, bordering the evergreen forest of the Western Ghats.

Field surveys undertaken by Mathew *et al.* (2005) revealed that a significant proportion of *Piper nigrum* L. landraces and wild forms are under threat of extinction especially the low yielding ones are being replaced by farmers in their farms with improved cultivars. Due to overexploitation and habitat destruction intraspecific variants of the species are also becoming extinct. Even if the early migration of settlers across Kerala assisted in the spreading of landraces to new locations, the introduction of enhanced varieties of black pepper causes a danger to many of the older cultivars. These landraces may be lost forever unless collected and conserved (Saji *et al.,* 2019).

2.2. MORPHOLOGICAL CHARACTERIZATION

Morphological characterization is used to derive economic and breeding benefits from germplasm collection and associated family accessions (Bekele *et al.*, 2006). Observation and recording of morphological characteristics have been a standard method for identifying and describing distinct black pepper germplasm (Hussain *et al.*, 2017b; Bermawie *et al.*, 2019; Prayoga *et al.*, 2020).

Traditional classification of black pepper accessions and varieties has been based on plant characteristics such as leaf length and breadth, shoot tip colour, leaf shape and size, features of leaf tip and base, berry size, spike length, spike composition (bisexual, female and male), fruit set, number of fruits/spike, thousand fruit volume, thousand fruit weight, yield/vine and dry recovery and quality parameters such as piperine, oleoresin and essential oil (Sreedevi *et al.*, 2005).

Selection from the wild has resulted in cultivars with varying morphology and yield (Ibrahim *et al.*, 1985). Ratnambal *et al.* (1985) reported intracultivar or intervarietal variation for both morphological and qualitative characteristics. Ravindran and Nirmal Babu (1994) reported the nature and extent of variability in morphological characters in black pepper. In an analysis, both black pepper cultivars and their wild relatives showed a variation in morphological characters (Ravindran *et* *al.*, 1997a, b). Distinct morphological and anatomical features were identified in two interspecific hybrids of *Piper* while characterizing them based on morphology, anatomy, isozymes, cytology and function (Sasikumar *et al.*, 1999). There is significant variability among the black pepper landraces in terms of plant morphological characters, granting them the status of different plant types, each with its own distinctive traits. The morphological variations exhibited by the landraces are stable and determined genetically (Mathew *et al.*, 2005).

Black pepper is a perennial, glabrous woody climber that can reach a height of 10 metres or more. The mature vine is of columnar appearance and has a height of around 4.0 metres when its height is limited (Purseglove *et al.,* 1981). The vines have a dimorphic branching pattern with monopodial orthotropic branches and sympodial laterally spreading plagiotropic fruiting branches (Parthasarathy *et al.,* 2007).

Black pepper plants produce adventitious runner shoots from the base of the main shoot (Ravindran *et al.*, 2000b). According to Prakash *et al.* (2020) observed a few runner shoots production in more than half of the genotypes among fifty accessions they have studied.

The shape and size of the leaf lamina vary greatly in black pepper. The shape of the leaf lamina may be ovate, ovate elliptic, ovate lanceolate, elliptic lanceolate or cordate and the leaf size varied from 8 to 20 cm in length and 4 to 12 cm in width or longer. The leaf base may be round, cordate, acute or oblique. The leaf margins were either even or wavy. Leaf texture can be glabrous coriaceous, glabrous membraneous, glabrous sarcous, downy membraneous, downy coriaceous or downy along the veins (Ravindran *et al.*, 2000b). The lamina of the leaf is generally ovate, entire and coriaceous with a rounded, cordate, acute or oblique base and an acuminate tip (Parthasarathy *et al.,* 2007).

Preethy *et al.* (2018) reported variation in vegetative characters such as vine column height, leaf weight, leaf width and internodal length among the ten black pepper accessions and Karimunda had the shortest leaf length and width.

Morphological characterization of black pepper genotypes growing in the Morogoro District of Tanzania revealed three types of lateral branch patterns such as erect, horizontal and hanging. The leaf lamina forms of those were cordate, ovate, ovate lanceolate and ovate elliptic. The leaf base shapes seen were round, cordate and acute. All genotypes had even leaf margins and campylodromous leaf venation (Shango *et al.*, 2021).

The inflorescence of black pepper is a spike and its length ranged from 5 to 20 cm. Flowers are small and dioecious in the wild and some cultivated types, or completely perfect in many cultivated types. Fruits are botanically drupes but commonly known as berries and are ovoid or globose, dark green with shiny oranges and red when ripe with globose seeds (Govindarajan *et al.*, 1977). The spikes can be straight or twisted. Cultivars differ in their spike length. The leaf-spike relationship revealed that the spike length is nearly the same as the leaf length in the majority of cultivars (Ravindran *et al.*, 2000a). The number of berries in black pepper normally ranged from thirty to less than a hundred, depending on the variety or hybrid (Ravindran *et al.*, 2000b). The length of the spikes, the number of berries per spike and the fullness of the spikes vary with the cultivar. Spikes may be light yellow, white, or purple (Parthasarathy *et al.*, 2007).

Govindarajan *et al.* (1977) found high values for the hundred dried berry weight (3.10 to 8.57 g) and dry weight per litre (330 to 688 g) of Indian varieties, implying that Indian varieties had large berries and a high bulk density. Studies on five black pepper varieties revealed that bulk density increased with an increase in size, whereas it was found to decrease when the berry size was above 4.8 mm (Jayasree, 2009). Sruthi *et al.* (2013) reported the bulk density of dried berries of Panniyur 1 collected from eleven different locations and it ranged from 460.6 to 608.7 g/l.

Four black pepper varieties cultivated in the Morogoro district exhibited prostate or pendant spike orientation, filiform spikes and round berry shape. The genotypes differed significantly in terms of both spike length and berry size. All the four pepper varieties had berries that were large (> 4.26 mm) (Shango *et al.*, 2021).

Prakash *et al.* (2020) reported less variability for spike peduncle length, number of developed fruits per spike, hundred fruit weight and hundred fruit volume. They discovered a wide range of variation in the number of spikes per lateral, green spike yield, green berry yield and dry berry yield, indicating that these are the important traits that contribute to black pepper yield.

In black pepper, spike yield and spike number have been identified as important traits that contribute to yield and for which straight selection can be used to improve yield (Ibrahim *et al.*,1985; 1987). Spike length is a significant yield contributing characteristic in black pepper and thus amenable to selection (Sujatha and Namboodiri, 1995; Krishnamurthy *et al.*, 2010). Black pepper yield is affected by spike length, number of fruits per spikes and number of fruits/ vines (Bermawie *et al.*, 2019).

Pillai *et al.* (1987) observed a positive heterosis for spike length, number of developed fruits, bisexual flowers per spike and yield. Berries per spike was more susceptible to seasonal variation than spike length (Ibrahim *et al.*, 1988). Green berry yield per vine, spike number, spike length and angle of insertion of the fruiting branch were all quantitative traits that had a direct impact on yield (Sujatha and Namboodiri, 1995). Preethy *et al.* (2018) reported significant variation in yield and yield attributing characters among different accessions.

Fruit shape and size, although strongly associated, were less useful in cultivar delimitation, except in the case of cultivars with clearly defined characteristics, such as the oblong fruit shape of karivilanchy (Ravindran *et al.*, 1997a).

2.3. QUALITY CHARACTERIZATION AND SENSORY EVALUATION

Indian black pepper has the best quality and fetches a premium price in the major international markets (Thomas, 2010). Black pepper is mostly cultivated in India for export purposes (Nair, 2011). It is the intrinsic quality of Indian black pepper that draws customers from the United States, Canada and Europe (Kumar and Kulkarni, 2020).

Black pepper is renowned for its intrinsic quality and its two principal components are volatile oil and pungent compounds (Sruthi *et al.*, 2013). The quality parameters for black pepper that are valuable commercially are piperine, essential oil and oleoresin content.

Since the early nineteenth century, scientists have been studying the pungency of black pepper. The presence of piperine is mostly attributable to the pungency of black pepper. Piperine, the most common alkaloid in pepper, was isolated as a yellow crystalline material by Oersted in 1819 and its structure was eventually recognised as the trans form of piperyl piperidine (Narayanan, 2000). Piperine and its isomers are isomerized by light to form isopiperine, chavicine and isochavicine. On storage, piperine progressively converts to chavicine resulting in a loss of pungency (Kozukue *et al.*, 2007).

The aroma of black pepper comes from the volatile oil it produces. The essential oil cells are found inside the fruit wall (Mathai, 1981). Pepper oil obtained by steam distillation is a nearly colourless to slightly greenish liquid with a distinct pepper odour. Oil has a mild or non pungent taste (Risfaheri and Nurdjannah, 2000).

The essential oil is a mixture of a large number of volatile chemical compounds. The major compounds that have been identified in the volatile oil of black pepper are α- pinene, β-pinene, sabinene, limonene, β-caryophyllene, myrcene, p-cymene and caryophyllene oxide (Gopalakrishnan *et al.*, 1993; Menon *et al.*, 2000; 2002; 2003; Menon and Padmakumari, 2005).

The compounds germacrene, germacrene, D-lomonene, β-pinene, α-phellandrene, β-caryophyllene, α-pinene and cis-β-ocimene are responsible for the aroma of black pepper (Jirovetz *et al.*, 2002). Parthasarathy *et al.* (2007) described black pepper oil as a complex mixture of hydrocarbons, monoterpenes (70 to 80%), sesquiterpenes, and trace amounts of oxygenated compounds. The major sesquiterpene hydrocarbon, β-caryophyllene, was found in concentrations ranging from 10.3% to 22.4%. (Zachariah *et al.*, 2008). About 230 components were identified in the essential oil of black pepper (Jayatunga and Amarasinghe, 2019).

The commercial spice flavour of black pepper is oleoresin (Mathai, 1981). Oleoresin is a widely traded substance that contains both flavour and pungency components (Ravindran and Kallupurackal, 2001; Dhas and Korikanthimath, 2003).

Black pepper oleoresin is a viscous dark liquid with a pungent taste and strong flavour (Dhas and Korikanthimath, 2003). It is usually comprised of 25% volatile oil and 35% nonvolatile piperine (Zachariah and Parthasarathy, 2006). Oleoresins are economically essential due to their consistency in flavour, taste, antioxidant effects, longer shelf life and reduced storage space due to their high concentration (Zachariah, 2008).

Starch is a predominant component of black pepper, ranging from 35-40% of its weight. It is much higher in white pepper (53-58%) (Govindarajan, 1977). Starch is one-third of the weight of a mature berry and it is essential for powdered spice processing (Mathai, 1981). According to Farooqi *et al.* (2005), black pepper contains 34.85 per cent starch.

Starch and crude fibre levels are of minor relevance in terms of flavour (Mathai, 1981). The fibre measurement in a food sample is its crude fibre content (Mathai *et al.,* 1981). The non-volatile and uncombusted inorganic debris of a combusted substance is ash. Ash analysis of spices is beneficial because it can diagnose adulteration in powders to a degree (Pruthi, 1997). Total ash is an indicator of the amount of impurity of a substance and is generally used as a method to determine mineral component extent (AOAC, 2000). The high ash concentration reflects the mineral composition of samples (Antia *et al.*, 2006). The total ash content of black pepper berries collected from the local market was reported by Kolhe *et al.* (2011) as 1 per cent.

Raju *et al.* (1983) observed variability in quality characters such as volatile oil, piperine, oleoresin and starch content among 29 important traditional cultivars. Gopalam and Ravindran (1987) also observed qualitative characteristic variations in black pepper cultivars. Zachariah (1995) evaluated selected black pepper accessions and observed good variability for both flavour and quality. Variability of quality attributes is common among cultivars and even within the same cultivar (Ravindran and Kallupurackal, 2001). Bekele and Gedebo (2020) reported biochemical variability among thirteen genotypes of Ethiopia.

Kurian *et al.* (2002) reported a varietal variation of oleoresin and piperine in black pepper. Piperine concentrations ranged from 2.8 to 3.8 per cent in popular black pepper cultivars (Zachariah *et al.*, 2005). However, the piperine concentration of Panniyur 2 was found to be 6.6 per cent (Zachariah, 2008). Many popular cultivars of black pepper grown in Kerala have considerable variations in the percentage composition of major volatiles (Zachariah and Parthasarathy, 2008). Zachariah *et al.* (2010) reported that the starch content of berries of 26 black pepper cultivars from Panniyur and Peruvannamuzhi was in the range of 32.1% to 43.2%.

Certain cultivars with high piperine, oleoresin and oil content were discovered by germplasm screening. The indigenous cultivars Kottanadan, Kuthiravally, Kumbakodi and Nilgiri are high in piperine and oleoresin, whereas Kaniyakadan, Balankotta and Kumbakodi are rich in essential oil. The oil content of Sreekara and Subhakara was high (> 6%) (Krisnamoorthy and Parthasarathy, 2009).

Piperine, oleoresin and essential oil content were determined in seven black pepper cultivars namely Panniyur-2, Panniyur-3, Panniyur-4, Sreekara, Subhakara, KS-88 and Neelamundi. Although Panniyur-2 had a low yield, it had the highest piperine content (6.6%). The greatest oleoresin content was found in Neelamundi, KS-88 and Sreekara (13.9, 13.1 and 13.0%, respectively), whereas the greatest essential oil concentration was found in Sreekara and Subhakara (7.0 and 6.0%, respectively) (Radhakrishnan *et al.*, 2004).

Panniyur-1, Panniyur-2, Panniyur-5, Sreekara and Subhakara varieties of black pepper were graded in a hand-operated rotary sieve cleaner-cum-grader with pore sizes of 3.5, 3.8 and 4.8 mm. Primary metabolites such as starch increased as grade size increased but crude fibre showed no significant pattern. Secondary metabolites, such as oleoresin and piperine content, were higher in the lowest grade (3.5 mm), while essential oil content did not differ by grade in any varieties (Jayashree *et al.*, 2009).

Chemical evaluation of matured black pepper berries from eight different wild varieties revealed differences in commercially important constituents. The proportion of oleoresin varied from 6.4 to 25.7 per cent in the wild types. There were very promising oleoresin yielders in comparison with the cultivated varieties in this group. Two of the wild types were pungency free but had a black pepper aroma (Mathai *et al.,* 1981).

Zachariah *et al.* (2005) investigated the impact of grafting *P. nigrum* on *P. colubrinum.* Panniyur-1, 2, 3, 4 and 5, Malligesara, Pournami, Sreekara, Poonjaranmunda, Kuthiravally and Balankotta are among the cultivars utilised for grafting. Pinene, sabinene, and b-caryophyllene were the most abundant essential oil elements in pepper cultivars in grafts and nongrafts.

A few novel sesquiterpenes were also potentially found in black pepper oil that had previously been unidentified (Gopalakrishnan *et al.*, 1993). Menon and Padmakumar (2005) detected fifty-five compounds in the oils of black pepper cultivars from Kerala, viz. Karimunda, Kalluvally, Arakulammunda and Thommankody over three consecutive seasons using gas chromatography and mass spectrometry (GCMS). Several studies have found that the constituents of essential oils vary. This was due to factors such as cultivar, agroclimatic variation, raw material maturity, oil extraction method, and so on (Zachariah and Parthasarathy, 2008). The GCMS analysis of the essential oils obtained from Bangladesh and Indian cultivars showed a significant difference in chemical composition (Aziz *et al.*, 2012; Abukawsar *et al.*, 2018).

Chemical quality has been reported to vary even within a cultivar (Gopalam *et al.*, 1991). Pradeepkumar *et al.* (2003) reported a wide variation in oleoresin other than piperine. A significant location wise variation for both primary and secondary constituents of the Panniyur-1 hybrid of black pepper was reported by Sruthi *et al.* (2013). Profound variation was observed in essential oil, oleoresin, piperine, crude fibre and starch. According to Ahmad *et al.* (2019), samples taken from Vietnam and Pakistan contained significant higher levels of piperine than Indian black pepper, which might be linked to high yearly rainfall and ideal growing conditions for this crop.

When comparing the nutritional quality and safety of Kerala and Bangladesh cultivars, it was discovered that food value parameters such as crude fibre were higher in Bangladesh (14.33%) than in Kerala cultivars (12.94%). The Kerala cultivar (5.55%) had a greater total ash content than the Bangladesh cultivar (4.08%) (Abukawsar *et al.,* 2018).

The chemical quality is also said to be dependent on the maturity level (Sumathykutty *et al.,* 1989). The optimum stage of harvest of the Panniyur-1 hybrid with a maximum quantity of oleoresin was reported to be 7 months after flowering (Mathai, 1981).

A correlation analysis of black pepper chemical profiles revealed that starch was negatively correlated with piperine, oleoresin, essential oil and crude fibre, but positively correlated with bulk density. Essential oil, piperine and oleoresin showed a positive correlation with each other and also with crude fibre (Sruthi *et al.,* 2013).

The oleoresin content is high in high crude fibre yielders (Mathai *et al.,* 1981). Kurian *et al.* (2002) reported a positive correlation between oleoresin and essential oil. Quality analysis of twenty five genotypes indicated oleoresin was negatively correlated with bulk density but positively correlated with essential oil and piperine content (IISR, 2020).

Quality attributes of black pepper such as flavour, taste and pungency vary among cultivars (Mamatha *et al.*, 2008). People appreciate black pepper for its enticing aroma as well as the typical pungent and tingling orosensory impression. The appearance of black pepper is of significant importance to customers when it is intended for direct use as a spice in whole or ground form. However, the appearance of this spice is less important when it is being processed into oleoresin or essential oil (Hailemichael *et al.,* 2009). Wei *et al.* (2012) defined appearance as a direct attractive impact on consumers that cannot be quantified but can be evaluated using a sensory evaluation method.

The best shape for pepper berries was described as spherical (Mulyono *et al.*, 1994). The shape of pepper fruits is important because visual appeal influences consumer decision making in a competitive market (Parthasarathy *et al.*, 2007).

The colour of mature pepper is normally green due to chlorophyll. Pepper blackening during drying is a chemical reaction similar to browning (Mathew and Sankarikutty, 1977). For the usage of black pepper as a spice in whole or ground form, the appearance in terms of colour (brown or black) is important (Zachariah and Parthasarathy, 2008). The best price is paid for dried peppercorn that is uniformly dark brown to black in colour (Hailemichael *et al.*, 2009). Product colour has a direct tempting impact on the consumer and it aids in accepting or rejecting the product (Manera *et al.*, 2013).

According to Sharma *et al.* (1995), taste is the fundamental and most significant sensory property. They also discovered that colour scores were connected to acceptance in a significant way. The flavour is an extremely essential determinant in the economy, demand, acceptance or rejection of black pepper (Suhaj, 2006) and overall acceptability is a comparison of samples based on their colour, aroma, appearance and other related factors (Wei *et al.*, 2012).

Narasimhan *et al.* (1990) carried out a sensory evaluation of powdered black pepper for two important parameters such as odour and flavour. Liu *et al.* (2008) conducted sensory assessment to compare the effects of cryogenic grinding and hammer milling on the flavour attributes of black, white and green peppers. The sensory scores for odour, colour and pungent taste were all lower for hammer-milled samples than for cryogenically ground samples. Meghwal and Goswami (2014) conducted a sensory evaluation to assess the quality of stored black pepper powder and its deterioration with the storage time. Quality reduction in terms of colour, odour, flavour, aroma and acceptability was determined in this study.

2.4. PHYSIOLOGICAL PARAMETERS

Drought is recognised as one of the major production barriers in black pepper production (Ramadasan, 1987). Among the various abiotic stresses, drought was a severe stress (Anuradha, 2004). It severely reduced black pepper yield and resulted in significant economic losses (George *et al.*, 2017).

Kerala witnessed the drying up of thousands of black pepper vines in Kannur district, when India was experiencing severe droughts (Sadanandan, 2000). Because of their large leaf area and high stomatal conductance, pepper plants are sensitive to water scarcity (Campos *et al.*, 2014). According to Vijayakumari et al. (2014), different biochemical and physiological responses were operated by plants in response to compact drought stress.

Even a very short period of drought after the onset of flowering reduced berry production in black pepper (Pillai *et al.*, 1987). The flowering phase, which begins in May-June, was the most critical developmental phase of black pepper that was disrupted by moisture stress (Vasantha, 1996).

The only way to minimise yield decline during water stress was to cultivate drought resistant varieties (Rajagopal and Balasimha, 1994). The Indian Institute of Spices Research examined over a thousand germplasm accessions of black pepper and discovered twenty drought tolerant accessions. Only a few of the reported accessions were being used to create drought tolerant black pepper varieties (George *et al.*, 2007).

Many physiological and biochemical parameters, including relative water content (RWC), cell membrane leakage, catalase, peroxidase and superoxide dismutase activity, etc were employed for the assessment of drought in black pepper (Krishnamurthy *et al.*, 2000). Physiological parameters were potential markers for drought tolerance since they had significant mechanistic connections to water stress responses (Bartlett *et al.*, 2014).

Moisture loss from excised leaves was positively linked to relative water content. The accessions that lost less moisture had higher relative water content (Vasantha *et al.*, 1990). The relative water content of tolerant accessions was higher (Krishnamurthy *et al.* 1998). Relative water content was regarded as one of the indicators for screening black pepper for tolerant types (Thankamani and Asokan, 2004). According to Krishnamurthy and Saji (2006), relative water content lowered in the entire *Piper* species when subjected to drought stress and the rate of decline varied between species.

Epicuticular wax was made up of a complex mixture of very long chain aliphatic compounds of fatty acids, alkanes, alcohols, esters, aldehydes, ketones and triterpenes (Kolattukudy, 1996). Wax is known to play a key role in regulating gas exchange, reducing non-stomatal water loss and shielding plants from ultraviolet radiation and high temperature damage (Wang et al., 2016).

Thankamani and Ashokan (2002) discovered that water stress increased epicuticular wax content on black pepper leaves. Epicuticular wax in leaf tissues served as a protective barrier against a number of biotic and abiotic stresses (Sharma *et al.*, 2019)

Drought tolerance was associated with an increase in leaf thickness and a decrease in specific leaf area (Cunningham *et al.*, 1999). The reduction in specific leaf area in plants under water stress suggested increased leaf thickness, which aided in the retention of water in the leaf tissue, allowing for a more positive response to drought (Trujillo *et al.*, 2013).

The first black pepper hybrid, Panniyur 1, was reported to be a drought susceptible variety (Thankamani et al., 2003; Vijayakumar and Puthur, 2012).

MATERIALS AND METHODS

3. MATERIALS AND METHODS

The study entitled "Characterization and quality analysis of black pepper (*Piper nigrum* L.) genotypes of Kerala" was carried out at the Department of Plantation Crops and Spices, College of Agriculture, Vellayani, Thiruvananthapuram during the period from 2020 to 2021. The experiment was performed by carrying out survey, characterization and quality analysis of black pepper genotypes of Kerala based on morphological and biochemical parameters. The experimental details such as materials used and methods followed during the study are presented in this chapter.

3.1. SURVEY

The study was carried out by surveying black pepper plantations and homestead gardens of different locations of Agro-Ecological Units of Kerala especially AEU 3 (Onattukara Sandy Plains), AEU 4 (Kuttanad), AEU 8 (Southern Laterites), AEU 12 (Southern and Central Foothills), AEU 14 (Southern High Hills) and AEU 21 (Wayanad Eastern Plateau) for identification of genotypes with better quality. Fifty plants were surveyed and from that twenty one genotypes were selected. Survey details of the selected genotypes such as location, village, taluk, district, latitude, longitude, altitude, age of plant, habitat, ethnobotanical information, resistance/ susceptibility/ tolerance to pest, diseases, and drought, local name, ethnic group growing plant if any, cropping system, irrigation, fertilizer application, regular bearing, genetic erosion, site topography and special characters, if any were documented.

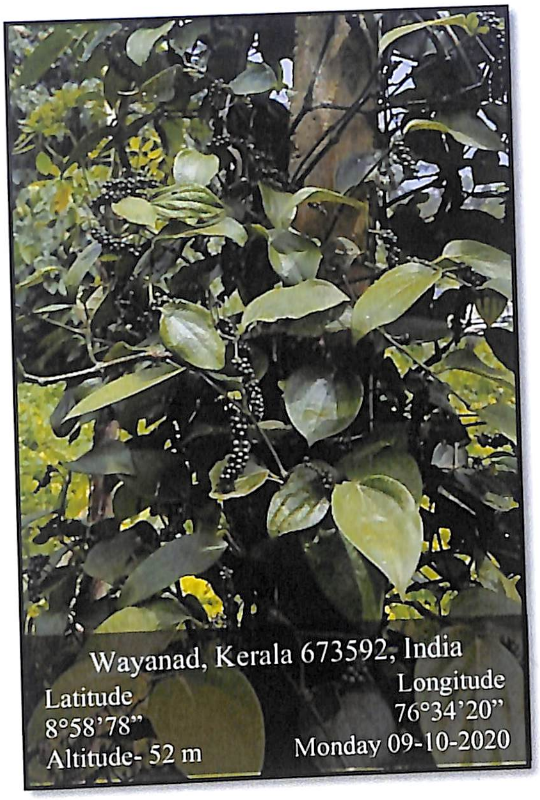
3.2. CHARACTERIZATION AND QUALITY ANALYSIS OF SELECTED BLACK PEPPER GENOTYPES

From the fifty plants surveyed twenty one genotypes were selected based on survey data. The location of the selected genotypes is presented in Table 1.

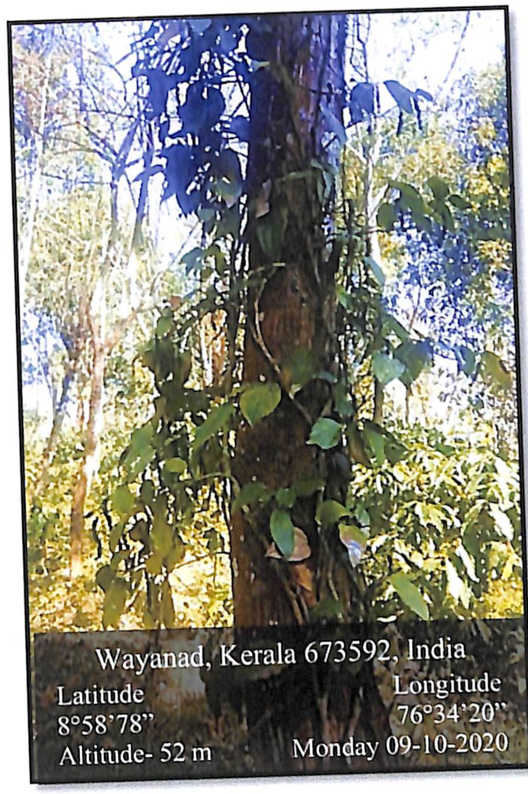
Genotypes were morphologically characterized using the descriptor for black pepper published by International Plant Genetic Resource Institute (IPGRI, 1995) and DUS guidelines for the conduct of test for Distinctiveness, Uniformity and Stability on black pepper by Protection of Plant Varieties and Farmers Right Act (2009).

Table 1. Selected black pepper genotypes and their location details

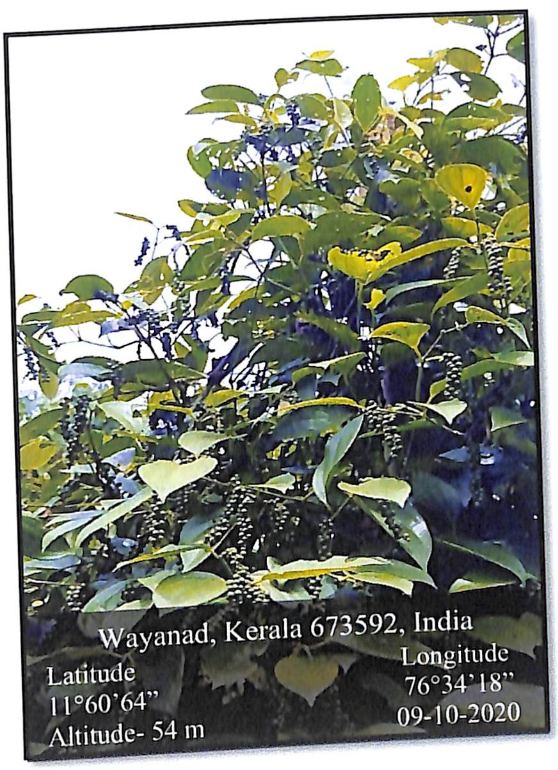
Sl. no.	Genotypes	Location
1	G_1	AEU 21, Noolpuzha, Sulthan Bathery, Wayanad
2	G_2	AEU 21, Noolpuzha, Sulthan Bathery, Wayanad
3	G_3	AEU 21, Noolpuzha, Sulthan Bathery, Wayanad
4	G_4	AEU 21, Nenmani, Sulthan Bathery, Wayanad
5	G_5	AEU 21, Nenmani, Sulthan Bathery, Wayanad
6	G_6	AEU 12, Cheppukulam, Thodupuzha, Idukki
7	G_7	AEU 12, Cheppukulam, Thodupuzha, Idukki
8	G_8	AEU 12, Cheppukulam, Thodupuzha, Idukki
9	G_9	AEU 12, Peringassery, Thodupuzha, Idukki
10	G_{10}	AEU 12, Peringassery, Thodupuzha, Idukki
11	G_{11}	AEU 12, Uppukunnu, Thodupuzha, Idukki
12	G_{12}	AEU 14, Senapathy, Udumbanchola, Idukki
13	G_{13}	AEU 14, Senapathy, Udumbanchola, Idukki
14	G_{14}	AEU 14, Senapathy, Udumbanchola, Idukki
15	G_{15}	AEU 3, Vallikunnam, Mavelikkara, Alappuzha
16	G_{16}	AEU 3, Vallikunnam, Mavelikkara, Alappuzha
17	G_{17}	AEU 3, Vallikunnam, Mavelikkara, Alappuzha
18	G_{18}	AEU 8, Kalliyoor, Trivandrum
19	G_{19}	AEU 8, Vellayani,Trivandrum
20	G_{20}	AEU 4, Vakathanam, Changanaseri, Kottayam
21	G_{21}	AEU 4, Vakathanam, Changanaseri, Kottayam



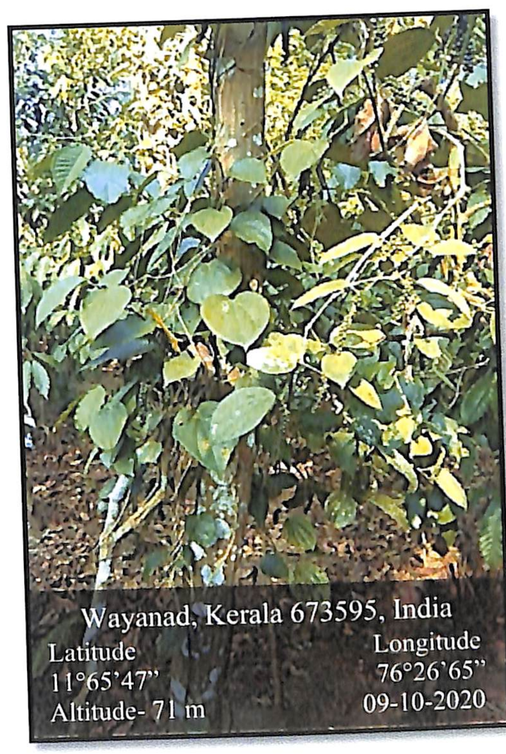
G_1 (Wayanadan)



G_2 (Chumala)

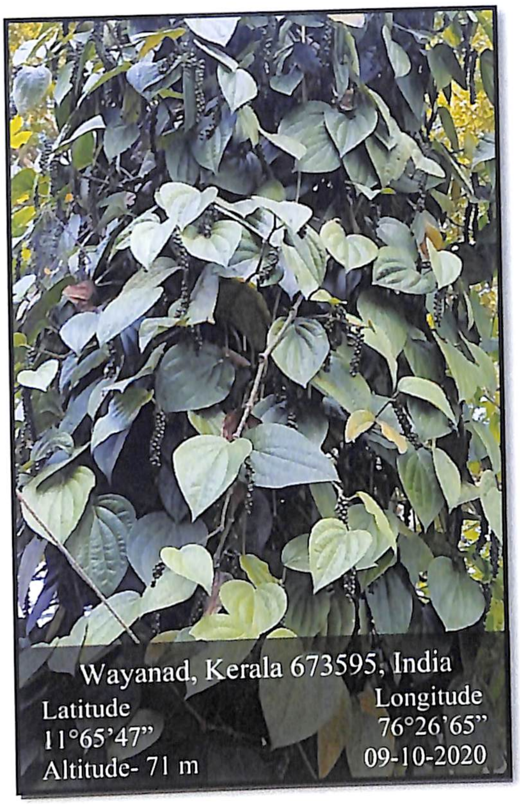


G_3 (Vellayaranmunda)



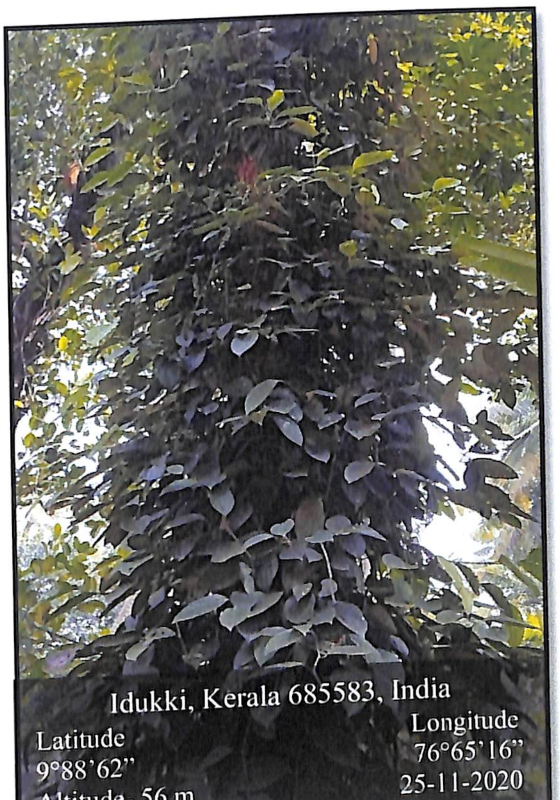
G_4 (Nadeshan)

Plate 1a. Selected genotypes with geotagging

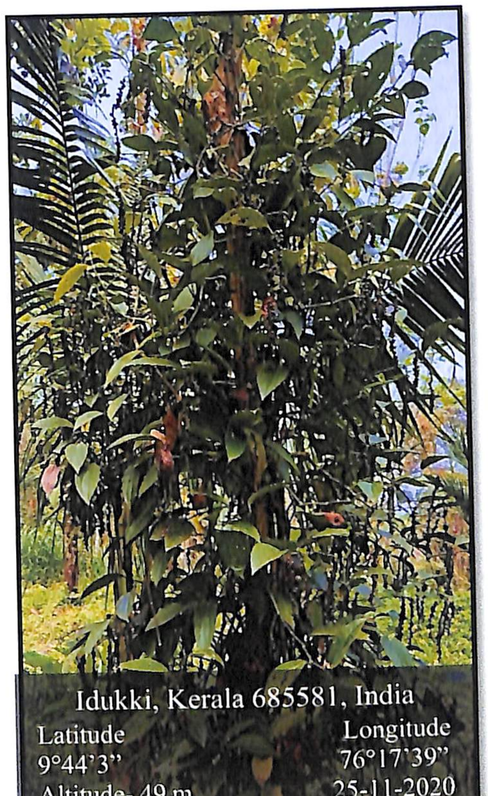


G_5 (Nadan)

G_6 (Karimunda)



G_7 (Neelamundi)



G_8 (Cheppukulamundi)

Plate 1b. Selected genotypes with geotagging

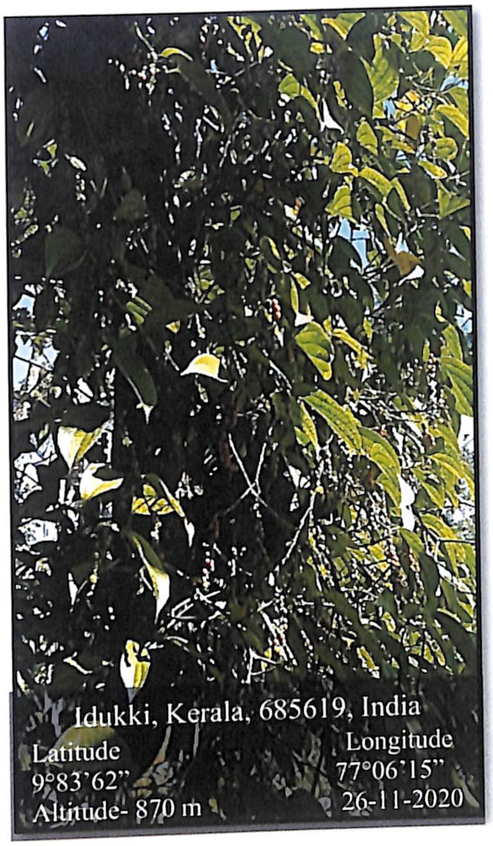
G_9 (Vattamundi)

G_{10} (Thulamundi)

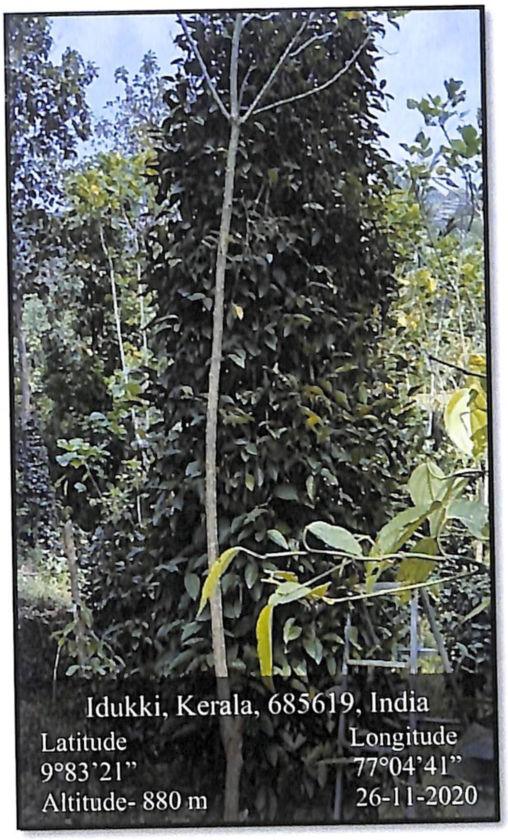
G_{11} (Manjamunda)

G_{12} (Chengannurkodi)

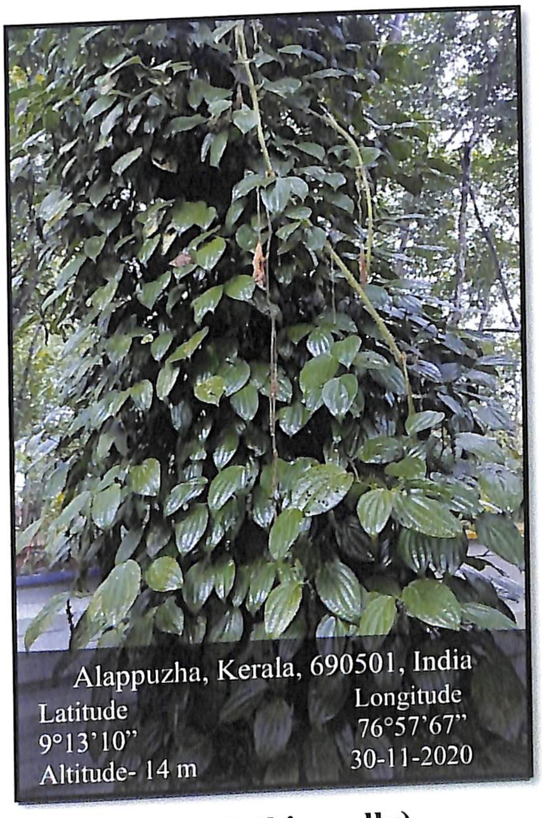
Plate 1c. Selected genotypes with geotagging



G_{13} (Vellanamban)



G_{14} (Jeerakamunda)



G_{15} (Kuthiravally)

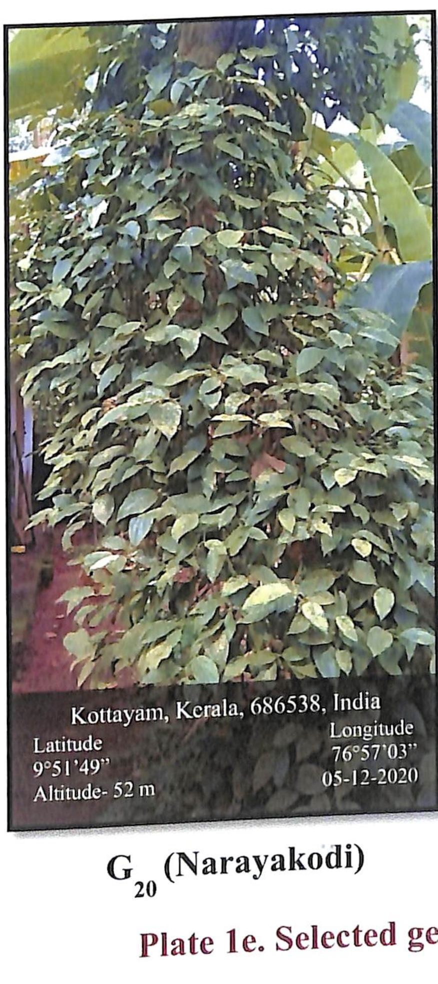
G_{16} (Kottanadan)

Plate 1d. Selected genotypes with geotagging

G_{17} (Arimulak)

G_{18} (Padappan)

G_{19} (Karivilanchy)



G_{20} (Narayakodi)

G_{21} (Panniyur 1)

Plate 1e. Selected genotypes with geotagging

Morphological characterization and quality analysis of twenty one selected genotypes were performed based on descriptor and DUS characterization. For the morphological characterization, observations on qualitative and quantitative characters of plant, leaf, inflorescence, fruit and seed of the selected genotypes were recorded. The same genotypes were physiologically characterized and the fruits were analysed for quality parameters.

3.2.1 Qualitative Characters for Morphological Characterization

Qualitative parameters on plant, leaf, inflorescence, fruit and seed of selected twenty one genotypes were recorded. The latest Royal Horticultural Society (RHS) colour chart was used for the assessment of colour characteristics.

3.2.1.1 Plant Characters

Plant characters like shoot tip colour, runner shoot production, presence or absence of pubescence on the stem, lateral branch pattern, lateral branch length and number of nodes per lateral branch were recorded for twenty one genotypes.

3.2.1.1.1 Shoot tip colour

The shoot tip colour of black pepper genotypes was observed from the shoot tips of runner shoots and recorded as light green (149B/149C), light purple (N77C/ N77D) or dark purple (N79A/ N79B) per the RHS colour chart (PPV & FRA, 2009).

3.2.1.1.2 Runner shoot production

The genotypes were examined for the number of runner shoots produced and were classified as few or many (IPGRI, 1995).

3.2.1.1.3 Absence/ presence of pubescence on stem

The presence or absence of pubescence on the stem was assessed in each of the genotypes and noted as absent or present (IPGRI, 1995).

3.2.1.1.4 Lateral branch pattern

The black pepper genotypes were evaluated visually for lateral branch pattern appearance and were categorized into semi erect, horizontal and hanging (PPV & FRA, 2009).

3.2.1.1.5 Lateral branch length

Based on the lateral branch length the selected genotypes were classified as short (<30), medium (30 - 40) and long (40) (PPV & FRA, 2009).

3.2.2.1.6 Number of nodes per lateral branch

The genotypes were grouped into few (<20), medium (20-40) and many (>40) based on the number of nodes per lateral branch (PPV & FRA, 2009).

3.2.1.2 Leaf Characters

The recorded leaf characters include leaf lamina shape, leaf base shape, leaf margin, type of veining, leaf texture, juvenile leaf length, leaf petiole length, leaf length and leaf width.

3.2.1.2.1 Leaf lamina shape

The leaf lamina shape of each genotype was observed from matured leaves of the plagiotropic branches and the genotypes were classified as ovate, ovate lanceolate, ovate elliptic and cordate (PPV & FRA, 2009).

3.2.1.2.2 Leaf base shape

The leaf base shape was observed from the matured leaves of the plagiotropic branches and the genotypes were grouped into round, cordate and acute (PPV & FRA, 2009).

3.2.1.2.3 Leaf margin

The leaf margin was observed visually on matured leaves of plagiotropic branches of the middle of the vine and the genotypes were classified as even and wavy (PPV & FRA, 2009).

3.2.1.2.4 Type of veining

The leaf venation of the matured leaves of a plagiotropic branches was examined to determine whether it was acrodromous, campylodromous and eucamptodromous (IPGRI, 1995).

3.2.1.2.5 Leaf texture

The leaf texture was recorded after visual observation of matured leaves of plagiotropic branches and noted whether it was glabrous coriaceous, glabrous membranous, glabrous sarcous, downy membranous and downy along the veins (IPGRI, 1995).

3.2.1.2.6 Juvenile leaf length

The genotypes were categorized into short (<3 cm), intermediate (3 - 7 cm) and long (7 cm) based on juvenile leaf length (IPGRI, 1995).

3.2.1.2.7 Leaf petiole length

Based on leaf petiole length the genotypes were classified as short (<2cm), medium (2-3cm) and long (>3cm) (PPV & FRA, 2009).

3.2.1.2.8 Leaf length

The leaf having a length of less than 10 cm was classified as short, 10 to 16 cm as medium and more than 16 cm as long (PPV & FRA, 2009).

3.2.1.2.9 Leaf width

Based on width of leaf, the genotypes were included under three categories such as narrow (<7), medium (7-10) and broad (>10) (PPV & FRA, 2009).

3.2.1.3 Inflorescence, Fruit and Seed characters

3.2.1.3.1 Spike colour

As per DUS guidelines the colour of spike should be noted within 2-3 weeks after the emergence of the spikes. The colour of the spike was visually observed seven days after the emergence and was characterized as light brown (177A/ 177B) or greenish yellow (1B/ 1D) using the RHS colour chart (PPV & FRA, 2009).

3.2.1.3.2 Spike twisting

A visual inspection of the plagiotropic branches was performed to determine whether spike twisting was present or absent (PPV & FRA, 2009).

3.2.1.3.3 Spike orientation

Visual assessment of the plagiotropic branches was done to observe the spike orientation and noted as erect and prostrate (IPGRI, 1995).

3.2.1.3.4 Spike shape

Visual assessment of the plagiotropic branches was done to observe spike shape and noted as filiform, cylindrical, globular and conical (IPGRI, 1995).

3.2.1.3.5 Spike fragrance

Fragrance of spike was noted at seven days after emergence of the spikes and was recorded as fragrant or nonfragrant (IPGRI, 1995).

3.2.1.3.6 Spike proliferation

Visual assessment of the plagiotropic branches was done to observe branching of spikes and noted as present or absent (PPV & FRA, 2009).

3.2.1.3.7 Spike setting

Visual assessment of the extent of compactness of the berries was done and the genotypes were grouped into loose and compact (PPV & FRA, 2009).

3.2.1.3.8 Berry shape

The shape of fruits was observed visually and the genotypes were categorized as round and oval (PPV & FRA, 2009).

3.2.1.3.9 Berry size

Based on berry size, the selected genotypes were classified as small (< 3cm), medium (3-4.25 cm) and bold (> 4.25cm) (PPV & FRA, 2009).

3.2.1.3.10 Colour change while fruit ripening

The colour change of the fruit while ripening was noticed and categorized as green to black and green to yellow, orange and then to red (IPGRI, 1995).

3.2.1.3.11 Fruit taste

Fruits of each genotype were tasted and the results were noted as bitter, pungent or spicy (IPGRI, 1995).

3.2.1.3.12 Seed shape

After extraction of seeds from the ripened fruits, the shape of the seeds was observed visually and classified as round, ovate and elliptical (IPGRI, 1995).

3.2.1.3.13 Seed texture

The seeds of ripened fruits were extracted, visually observed and classified as smooth and sculptured (IPGRI, 1995).

3.2.1.3.14 Spike peduncle length

Spike peduncle length was determined from the base of the spike to the base of the first pedicel and categorized as short (<1), medium (1 to 2 cm) and long (>2 cm) (PPV & FRA, 2009).

3.2.1.3.15 Spike length

Spike length was categorized as short (<1 cm), medium (10 to 15 cm) and long (>15 cm) (PPV & FRA, 2009).

3.2.1.3.16 Number of berries per spike

Number of berries were counted from matured spikes from the middle of the vine and noted as few (<25), medium (25-50) and many (>50) (PPV & FRA, 2009).

3.2.1.3.17 Number of spikes per lateral branch

Number of spikes were counted from 10 randomly selected branches of the middle of the vine and the genotypes were classified as few (<4), medium (4-7) and many (>7) (PPV & FRA, 2009).

3.2.1.3.18 Bulk density

The genotypes with bulk density less than 500 g were classified as low, 500 to 600 g as medium and more than 600 g as high (PPV & FRA, 2009).

3.2.1.3.19 Time of harvest maturity

Number of days from flowering to maximum maturity of berries were recorded and categorized into early (<7 months), medium (7 to 8 months) and late (>8 months) (PPV & FRA, 2009).

3.2.2 Sensory Parameters

Sensory evaluation of the selected genotypes was carried out for the parameters like appearance, colour, odour, taste and flavour. Sensory parameters were scored by a semi trained panel of 25 members using nine point Hedonic scale (Rangana, 1986). Score card for the sensory analysis is shown in Appendix I.

Samples for sensory evaluation

Judging panel

Plate 2. Sensory evaluation

3.2.3 Quantitative Characters for Morphological Characterization

Quantitative parameters on morphology such as plant, leaf, inflorescence, fruit and seed were recorded.

3.2.3.1 Plant Characters

3.2.3.1.1 Vine column height

The height of the chosen genotypes was measured from the base to the tip of the vine (IPGRI, 1995) using the Smart measure android application (Smart measure 1.6.7 for android) and expressed in meters (m).

3.2.3.1.2 Vine column diameter

The diameter of the vine column was measured as a mean of three separate positions on the vine, each taken from the bottom, center and upper portion of the vine and mean values were expressed in centimeters (cm) (IPGRI, 1995).

3.2.3.1.3 Support height

The effective total height of the support available for the vine to climb was measured (IPGRI, 1995) with the help of the Smart measure android application (Smart measure 1.6.7 for android) and expressed in meters (m).

3.2.3.1.4 Support diameter

The diameter of the support was recorded with the help of measuring tape and values expressed in centimeters (cm) (IPGRI, 1995).

3.2.3.1.5 Lateral branch length

The mean length of 50 randomly selected lateral branches of the vine was taken (IPGRI, 1995).

3.2.3.1.6 Number of nodes per lateral branch

The number of nodes was counted from 10 lateral branches of the vine and the mean number was recorded (PPV & FRA, 2009).

3.2.3.2 Leaf Characters

3.2.3.2.1 Juvenile leaf length

Length of the juvenile leaves were taken (IPGRI, 1995) from the base of midrib to the tip and the mean was recorded.

3.2.3.2.2 Leaf petiole length

Leaf petiole length was measured from the base to the insertion with the leaf lamina on an average of randomly selected 10 matured leaves of plagiotropic branches and mean was expressed in centimeters (cm) (PPV & FRA, 2009).

3.2.3.2.3 Leaf length

Leaf length was measured from the base of midrib to the tip, on an average from the randomly selected 10 matured leaves of plagiotropic branches of each genotype and the mean was noted in centimeters (cm) (PPV & FRA, 2009).

3.2.3.2.4 Leaf width

Leaf width was measured at the maximum width, on an average from the randomly selected 10 matured leaves of the plagiotropic branches and the mean was recorded in centimeters (cm) (PPV & FRA, 2009).

3.2.3.3 Inflorescence, Fruit and Seed characters

3.2.3.3.1 Spike peduncle length

Spike peduncle length was determined from the base of the spike to the base of the first pedicel, on an average from10 randomly chosen spikes from the middle of the vine and the mean was recorded in centimeters (cm) (PPV & FRA, 2009).

3.2.3.3.2 Spike length

Spike length was determined using a scale from the base of the pedicel to the tip of the spike, on an average of 10 randomly chosen spikes and the mean was recorded in centimeters (cm) (PPV & FRA, 2009).

3.2.3.3.3 Number of well developed and underdeveloped berries per spike

The number of fully developed berries as well as under developed berries of spikes were counted from 10 randomly selected spikes and the mean was worked out and recorded.

3.2.3.3.4 Number of spikes per lateral branch

The number of spikes was taken from 10 randomly selected lateral branches of the middle of the vine, six months after the emergence of spikes and the mean was recorded (PPV & FRA, 2009).

3.2.3.3.5 Number of spikes per 30 cm²

The number of spikes/30 cm^2 was taken by counting the number of spikes per 30 cm^2 area on all four sides of the vine and the mean was recorded.

3.2.3.3.6 Number of spikes per vine

The total number of spikes per vine before main harvest was recorded.

3.2.3.3.7 Spike yield per vine

Fresh spike yield per vine of selected genotypes was taken using electronic balance and recorded in kilogram per vine (kg $vine^{-1}$).

3.2.3.3.8 Berry yield per vine

The berries were separated from the spikes and the fresh weight was recorded in kilogram using an electronic balance and expressed in kilogram per vine (kg $vine^{-1}$).

3.2.3.3.9 Hundred berry weight

The net weight of hundred fresh berries were recorded using an electronic weighing balance and expressed in grams (g).

3.2.3.3.10 Hundred berry volume

The volume of the water displaced when hundred fresh berries were immersed in a measurement cylinder filled with known volume of water, was used to measure the hundred berry volume and expressed in milliliter (ml).

3.2.3.3.11 Bulk density

Dried black pepper berries of each genotype were filled in one liter measuring cylinder and their weight was recorded in grams (g) (PPV & FRA, 2009).

3.2.3.3.12 Berry diameter

The average diameter of 25 randomly selected mature berries of each genotype was determined with a digital vernier caliper (HA WK HT0472) and measured value was expressed in millimeters (mm).

3.2.4 Physiological Parameters

Physiological parameters like leaf thickness, relative water content, epicuticular wax, specific leaf area and stomatal density were recorded.

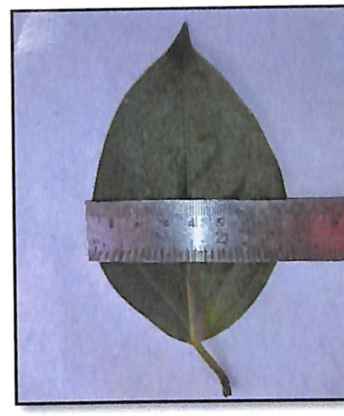
3.2.4.1 Leaf thickness

Leaf thickness of ten leaves of each genotype was measured using digital Vernier Caliper (HAWK HT0472) and the mean leaf thickness was expressed in millimeters (mm).

3.2.4.2 Relative water content

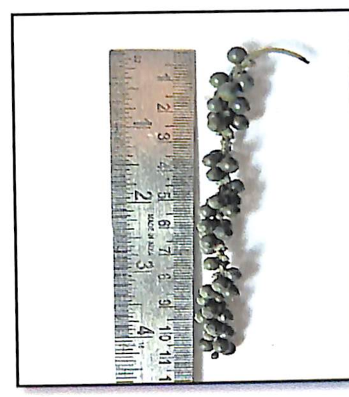
The relative water content of leaves was measured based on the method described by Turner (1981). Ten leaf discs of about 1 cm diameter were punched from

Leaf length



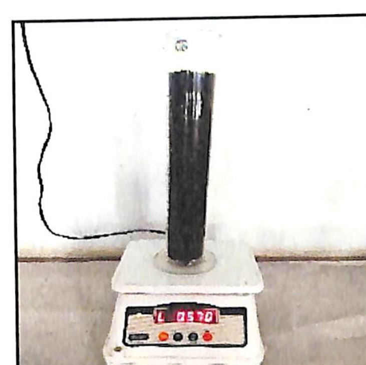
Leaf width

Juvenile leaf length



Spike length

Diameter of berry



Bulk density

Plate 3. Measurement of leaf, spike and berry characters in black pepper

leaves of every genotype and recorded the fresh weight (FW). The turgid weight (TW) was measured after the leaf discs were floated for 3 hours on distilled water in covered petri dishes until the discs become fully turgid. The discs were oven dried at 80ºC for 24 hours and the dry weight (DW) was determined. The relative water content was calculated using the following formula

$$RWC (\%) = \frac{(FW-DW) \times 100}{(TW - DW)}$$

3.2.4.3 Epicuticular wax

The epicuticular wax was calculated based on the method described by Galeano (1986) with slight modifications. A sample of 10 cm^2 leaf bites was taken from the middle portion of the leaf avoiding the midrib and noted the initial weight. The leaf bites were dipped in 10 ml of chloroform for 30 seconds. The test tubes were kept undisturbed until chloroform gets evaporated. The final weight of leaf bites was measured. The differences indicated the wax content. ECW was expressed as milligram per centimeter square (mg cm^{-2}).

3.2.4.4 Specific leaf area

The specific leaf area was calculated by a method suggested by Wolf (1972), following slight modification. The leaf is taken and traced over graph paper to calculate leaf area (LA). The leaf sample was oven dried at 70°C for around 2 days until a constant weight was obtained. The dry weight of leaf (DW) was measured. The following equation was used to measure specific leaf area:

$$SLA\ (cm\ g^{-1}) = \frac{LA}{DW}$$

3.2.4.5 Stomatal density

Number of stomata per cm^2 of leaf was observed under a compound microscope.

3.2.5 Quality Attributes

The selected genotypes were analyzed for quality. The quality was determined after oven drying the fruits with fruit coat for 48 hours at 45^{0}C. Content of piperine, essential oil, oleoresin, starch, crude fibre and total ash were determined by following standard procedures.

3.2.5.1 Piperine

The piperine content was measured using the spectrophotometric method (Sowbhagya *et al.,* 1990). 100 mg of dried berries was powdered and taken in a 100 ml volumetric flask. 100 per cent acetone was used to make up the volume. The flask was well shaken and placed 2 hours in dark condition. The solution was then pipetted out of the volumetric flask in 0.5 ml increments and made up to 5 ml with acetone. The absorbance of the solution was measured at 337 nm against acetone as blank. The standard values for pure piperine at various concentrations were calculated using the same method and a piperine standard curve was plotted between absorbance and concentration.

3.2.5.2 Oleoresin

Oleoresin was extracted using the solvent extraction process with the Soxhlet apparatus (Pruthi, 1999) and acetone as the solvent. Three gram of dried black pepper berries were crushed and loaded into the thimble, which is positioned inside the Soxhlet extractor. 250 ml of acetone was added to the round bottom flask. The extraction was completed when the solvent in the extraction tube showed no colour. The thimble was removed at the final stage of extraction and the solvent remained in the round bottom flask along with the oleoresin was allowed to evaporate. Oleoresin obtained was expressed in percentage.

$$\text{Oleoresin (\%)} = \frac{\text{Weight of the oleoresin collected (g)}}{\text{Initial weight of the sample (g)}} \times 100$$

3.2.5.3 Essential oil

The essential oil in dried berries was extracted using a modified Clevenger apparatus by hydro distillation method (Pruthi, 1999). Twenty gram of dried black pepper corns was grounded and taken in a round bottom flask. 200 ml of distilled water was then added to it. This mixture was subjected to hydrodistillation to separate the volatile oil. The process was continued for 3 hours. The oil was made free from water by adding a pinch of anhydrous sodium sulphate into it.

$$\text{Percentage of volatile oil (v/w)} = \frac{\text{Volume of the volatile oil collected (ml)}}{\text{Total weight of the sample (g)}} \times 100$$

3.2.5.4 Starch

A colorimetric method using anthrone reagent was performed for analyzing the starch content (Sadasivam and Manickam, 2008). 0.5 g of powdered sample was homogenized with hot 80% ethanol to eliminate the sugars found in the sample, centrifuged, and the resulting residue was continuously washed with 80% ethanol until no colour was produced with anthrone reagent. The residue was then dried over a water bath. 5 ml water and 6.5 ml 52 per cent perchloric acid were added to this residue and extracted at 0°C for 20 minutes. It was centrifuged and the supernatant was separated. 0.2 ml of supernatant was pipetted out from this and diluted to 1 ml with water. Working standards were prepared by diluting 0.2, 0.4, 0.6, 0.8 and 1 ml of standard with water to make up to 1 ml. 4 ml of anthrone reagent was added to this and heated for 8 minutes, cooled and absorbance was read at 630 nm against water as blank. A standard graph from which the starch value calculated, was drawn by plotting the concentration of the standard against the absorbance.

3.2.5.5 Crude fibre

The acid alkali digestion method was used to estimate the crude fibre content of dried black pepper berries (Sadasivam and Manickam, 2008). Two grams of dried black pepper were grounded and boiled for 30 minutes with 200 ml of 1.25 per cent sulphuric acid. The flask was removed at the end of the boiling period and given rest. This was then filtered through muslin cloth carefully and washed with boiling water. The residue was transferred to the flask containing 200 ml of 1.25 per cent sodium hydroxide solution and boiled for 30 minutes. This was again filtered through muslin cloth and washed with 1.25 per cent of 25 ml boiled sulphuric acid, 50 ml portion of water and 25 ml of sodium hydroxide. The residue is removed and transferred to a preweighed ashing dish (W_1) and this was oven dried at 130^0C for 2 hours. The ashing dish was weighed (W_2) again after cooling in a desiccator and the residue was ignited in muffle furnace at 600^0C for 30 minutes. The ashing dish was reweighed (W_3) after cooling in a desiccator. The percentage of crude fibre was noted as

$$\text{Crude fibre (\%)} = \frac{(W_2 - W_1) - (W_3 - W_1) \times 100}{\text{Weight of sample}}$$

3.2.5.6 Total ash

Total ash content of ground sample was determined by the method suggested by FSSAI (2015). Two grams of freshly powdered sample was taken in a preweighed (W_1) silica crucible and weighed accurately (W_2). This was placed in a muffle furnace at 550±25°C and slowly ignited until the sample turned into grey ash. The crucible with ash was placed in a desiccator to cool and the weight (W3) was noted. The percentage of total ash was estimated as

$$\text{Total ash (\%)} = \frac{(W_3 - W_1)}{(W_2 - W_1)} \times 100$$

3.3. STATISTICAL ANALYSIS

Statistical analysis like NTSYS package for clustering of qualitative characters, multivariate analysis for quantitative clustering, one way ANOVA for completely randomized design with yield characters and Kruskal Wallis test for analysis of sensory parameters were carried out.

RESULTS

RESULTS

The present study entitled "Characterization and quality analysis of black pepper (*Piper nigrum* L.) genotypes of Kerala" was carried out in the Department of Plantation Crops and Spices, College of Agriculture, Kerala Agricultural University, Thiruvananthapuram, during the period from 2020 to 2021.

A survey was carried out in black pepper plantations and homesteads in AEU 3 (Alappuzha), AEU 4 (Kottayam), AEU 12 (Idukki), AEU 14 (Idukki), AEU 21 (Wayanad) and AEU 8 (Thiruvananthapuram) of Kerala and twenty one genotypes were selected for carrying out the research work with the conceived objectives. The results of the present investigation on characterization and quality analysis of the selected genotypes are presented in this chapter.

4.1. SURVEY

The survey was carried out in fourteen locations from the black pepper growing areas of Idukki, Wayanad, Kottayam, Alappuzha and Thiruvananthapuram districts of Kerala and genotypes selected from those regions were utilized for this study. The details of the fifty black pepper genotypes surveyed is presented in Appendix II. From the fifty black pepper genotypes surveyed, twenty one genotypes were selected based on the vigorous nature of the vine, good fruit set, high spiking intensity, close setting of berries, long spikes, regular yield, early maturity, high yield, staggered flowering, bold berries, suitability in higher elevations, open and shade conditions and good sensory characters.

Brief passport data of twenty one selected genotypes of black pepper is presented in Table 2. The selected genotypes were G_1 (Wayanadan), G_2 (Chumala), G_3 (Vellayaranmunda), G_4 (Nadeshan), G_5 (Nadan), G_6 (Karimunda), G_7 (Neelamundi), G_8 (Cheppukulamundi), G_9 (Vattamundi), G_{10} (Thulamundi), G_{11} (Manjamunda), G_{12} (Chengannurkodi), G_{13} (Vellanamban), G_{14} (Jeerakamunda), G_{15} (Kuthiravally), G_{16} (Kottanadan), G_{17} (Arimulak), G_{18} (Padappan), G_{19} (Karivilanchy), G_{20} (Narayakodi) and G_{21} (Panniyur 1).

Table 2a. Brief passport data of the selected black pepper genotypes

Sl. No.	Genotypes	Location	Village	Taluk	District
1	G_1	AEU 21	Noolpuzha	SulthanBathery	Wayanad
2	G_2	AEU 21	Noolpuzha	SulthanBathery	Wayanad
3	G_3	AEU 21	Noolpuzha	SulthanBathery	Wayanad
4	G_4	AEU 21	Nenmeni	SulthanBathery	Wayanad
5	G_5	AEU 21	Nenmeni	SulthanBathery	Wayanad
6	G_6	AEU 12	Vazhithala	Thodupuzha	Idukki
7	G_7	AEU 12	Vazhithala	Thodupuzha	Idukki
8	G_8	AEU 12	Cheppukulam	Thodupuzha	Idukki
9	G_9	AEU 12	Peringassery	Thodupuzha	Idukki
10	G_{10}	AEU 12	Peringassery	Thodupuzha	Idukki
11	G_{11}	AEU 12	Uppukunnu	Thodupuzha	Idukki
12	G_{12}	AEU 14	Senapathy	Udumbanchola	Idukki
13	G_{13}	AEU 14	Senapathy	Udumbanchola	Idukki
14	G_{14}	AEU 14	Senapathy	Udumbanchola	Idukki
15	G_{15}	AEU 3	Vallikunnam	Mavelikkara	Idukki
16	G_{16}	AEU 3	Vallikunnam	Mavelikkara	Alappuzha
17	G_{17}	AEU 3	Vallikunnam	Mavelikkara	Alappuzha
18	G_{18}	AEU 8	Kalliyoor	Thiruvananthapuram	Alappuzha
19	G_{19}	AEU 8	Vellayani	Thiruvananthapuram	Thiruvananthapuram
20	G_{20}	AEU 4	Vakathanam	Changanaseri	Thiruvananthapuram
21	G_{21}	AEU 4	Vakathanam	Changanaseri	Kottayam
					Kottayam

Table 2b. Brief passport data of the selected black pepper genotypes

Sl. No.	Genotypes	Latitude	Longitude	Altitude (m)	Age of the plant (Years)
1	G_1	8°58'78"	76°34'20"	52 m	7
2	G_2	8°58'78"	76°34'20"	52 m	5-7
3	G_3	11°60'64"	76°34'18"	54 m	10
4	G_4	11°65'47"	76°26'65"	71 m	10-12
5	G_5	11°65'47"	76°26'65"	71 m	7
6	G_6	9°88'62"	76°65'16"	56 m	8
7	G_7	9°88'62"	76°65'16"	56 m	10
8	G_8	9°44'39"	76°17'39"	49 m	9-10
9	G_9	9°86'56"	76°83'48"	39 m	10-12
10	G_{10}	9°86'56"	76°83'48"	39 m	5-7
11	G_{11}	9°84'97"	76°87'67"	28 m	10
12	G_{12}	9°83'23"	77°06'24"	878 m	12
13	G_{13}	9°83'62"	77°06'15"	870 m	7-10
14	G_{14}	9°83'21"	77°04'41"	880 m	8-10
15	G_{15}	9°13'10"	76°57'67"	14 m	12
16	G_{16}	9°12'14"	76°52'61"	13 m	10-12
17	G_{17}	9°14'29"	76°58'37"	20 m	10
18	G_{18}	8°43'15"	77°01'44"	32 m	6-8
19	G_{19}	8°42'96"	76°98'77"	30 m	12
20	G_{20}	9°51'49"	76°57'03"	52 m	10
21	G_{21}	9°51'76"	76°57'51"	51 m	7-8

Table 2c. Brief passport data of the selected black pepper genotypes

Sl. No.	Genotypes	Habitat	Ethnobotanical information	Pest, diseases and drought (Resistance/ Susceptibility/ Tolerance)
1	G_1	Cultivated	Used in culinary preparation and helps against throat infection	Susceptible pests and diseases
2	G_2	Cultivated		Susceptible to drought
3	G_3	Cultivated		Susceptible to drought
4	G_4	Cultivated		Susceptible pests and diseases
5	G_5	Cultivated		Susceptible pests and diseases
6	G_6	Cultivated	Used against digestion problems and used in culinary preparation	Tolerant to pollu beetle, tolerant to drought
7	G_7	Cultivated		Tolerant to Phytophthora foot rot
8	G_8	Cultivated		Susceptible to drought, diseases
9	G_9	Cultivated		Tolerant to diseases and pest
10	G_{10}	Cultivated		Tolerant to diseases and pest
11	G_{11}	Cultivated	Used in culinary preparation and against asthma and whooping cough	Tolerant to diseases, pest and drought
12	G_{12}	Cultivated		Tolerant to diseases and pest
13	G_{13}	Cultivated		Tolerant to drought
14	G_{14}	Cultivated		Tolerant to pollu beetle
15	G_{15}	Cultivated	Used in culinary preparation and helps against stomach upset	Susceptible to anthracnose
16	G_{16}	Cultivated		Tolerant to diseases and pest
17	G_{17}	Cultivated	Used in culinary preparation and to treat throat infection	Tolerant to drought
18	G_{18}	Cultivated		Less susceptible to drought
19	G_{19}	Cultivated		Susceptible to pollu beetle
20	G_{20}	Cultivated		Tolerant to Phytophthora foot rot, Tolerant to pollu beetle
21	G_{21}	Cultivated	Used in culinary preparation	Susceptible to diseases and pests

Table 2d. Brief passport data of the selected black pepper genotypes

Sl. No.	Genotypes	Local name	Ethnic group growing the plant, if any	Cropping system
1	G_1	Wayanadan	No	Monocropping
2	G_2	Chumala	No	Monocropping
3	G_3	Vellayaranmunda	No	Mixed with coconut
4	G_4	Nadeshan	No	Mixed with coconut
5	G_5	Nadan	No	Mixed with coconut
6	G_6	Karimunda	No	Ancillary cropping with tea
7	G_7	Neelamundi	No	Monocropping
8	G_8	Cheppukulamundi	No	Monocropping
9	G_9	Vattamundi	No	Monocropping
10	G_{10}	Thulamundi	No	Ancillary cropping with rubber
11	G_{11}	Manjamunda	No	Monocropping
12	G_{12}	Chengannurkodi	No	Monocropping
13	G_{13}	Vellanamban	No	Monocropping
14	G_{14}	Jeerakamunda	No	Monocropping
15	G_{15}	Kuthiravally	No	Monocropping
16	G_{16}	Arimulak	No	Monocropping
17	G_{17}	Kottanadan	No	Monocropping
18	G_{18}	Padappan	No	Monocropping
19	G_{19}	Karivilanchy	No	Monocropping
20	G_{20}	Narayakodi	No	Monocropping
21	G_{21}	Panniyur 1	No	Monocropping

Table 2e. Brief passport data of the selected black pepper genotypes

Sl. No.	Genotypes	Irrigation	Fertilizer application	Regular bearing	Genetic erosion
1	G_1	Yes	Yes	Yes	Slow
2	G_2	Yes	Yes	Yes	Intermediate
3	G_3	Yes	Yes	Yes	Intermediate
4	G_4	Yes	Yes	Yes	Slow
5	G_5	Yes	Yes	Yes	Slow
6	G_6	Yes	Yes	Yes	Slow
7	G_7	Yes	Yes	Yes	Slow
8	G_8	Yes	Yes	Yes	Slow
9	G_9	Yes	Yes	Yes	Slow
10	G_{10}	Yes	Yes	No	Intermediate
11	G_{11}	Yes	Yes	Yes	Slow
12	G_{12}	Yes	Yes	Yes	Slow
13	G_{13}	Yes	Yes	Yes	Intermediate
14	G_{14}	Yes	Yes	Yes	Intermediate
15	G_{15}	Yes	Yes	No	Intermediate
16	G_{16}	Yes	Yes	Yes	Fast
17	G_{17}	Yes	Yes	Yes	Intermediate
18	G_{18}	Yes	Yes	Yes	Fast
19	G_{19}	Yes	Yes	Yes	Fast
20	G_{20}	Yes	Yes	Yes	Intermediate
21	G_{21}	Yes	Yes	Yes	Slow

Table 2f. Brief passport data of the selected black pepper genotypes

Sl. No.	Genotypes	Site topography	Special characters if any
1	G_1	Undulating	Vigorous vine, close setting of berries, bold berries
2	G_2	Undulating	Good fruit set, bold berries
3	G_3	Undulating	High spiking intensity
4	G_4	Rolling	Close setting of berries
5	G_5	Rolling	Vigorous vine, close setting of berries, long spikes
6	G_6	Hilly	High spiking intensity, performs well under both open and shade conditions
7	G_7	Hilly	Suitable for higher elevation
8	G_8	Hilly	Regular yield
9	G_9	Hilly	Vigorous vine, good setting
10	G_{10}	Hilly	Regular yielder
11	G_{11}	Hilly	Early maturity
12	G_{12}	Mountainous	High yield
13	G_{13}	Mountainous	High yield
14	G_{14}	Mountainous	High spiking intensity
15	G_{15}	Flat	Vigorous vine, long spikes
16	G_{16}	Flat	Early maturity
17	G_{17}	Flat	High yield
18	G_{18}	Almost flat	Stable yield
19	G_{19}	Almost flat	Staggered flowering, bold berries
20	G_{20}	Hilly	Stable yield
21	G_{21}	Hilly	Vigorous vine, bold berries, performs well under open condition, high fruit set

4.2. CHARACTERIZATION AND QUALITY ANALYSIS OF SELECTED BLACK PEPPER GENOTYPES

The selected twenty one genotypes were characterized morphologically. The yield, physiological and quality parameters of the selected twenty one genotypes were evaluated. The data was subjected to statistical analysis and the results were interpreted. For the morphological characterization, observations on qualitative and quantitative parameters were recorded. The dried fruits were also subjected to sensory evaluation.

4.2.1 Qualitative Characters

The qualitative characters observed in the selected genotypes included plant, leaf, inflorescence, fruit and seed characters. Thirty four qualitative characters were observed for morphological characterization. Of the thirty four qualitative characters only twenty two characters showed variability among twenty one selected black pepper genotypes. Characters such as runner shoot production, pubescence on stem, type of veining, leaf texture, spike colour, spike orientation, spike shape, spike fragrance, spike proliferation, colour change while fruit ripening, fruit taste and seed texture were uniform in all the selected genotypes and hence these non variable characters were not used in cluster analysis.

4.2.1.1 Plant Characters

4.2.1.1.1 Shoot tip colour

The runner shoot tip colour observed in the selected black pepper genotypes were light green, light purple and dark purple (Table 3a). Among the twenty one genotypes, three genotypes (14.29%) had light green as in G_1 (Wayandan), G_{15} (Kuthiravally) and G_{21} (Panniyur 1), sixteen genotypes (76.19%) had light purple colour and two genotypes (9.52%) had dark purple colour as in G_9 (Vattamundi) and G_{10} (Thulamundi). Expression of runner shoot tip colour is presented in Plate 4.

4.2.1.1.2 Lateral branch pattern

The lateral branch pattern observed in the selected black pepper genotypes included semi-erect, horizontal and hanging (Table 3a). Among the selected genotypes, fourteen genotypes (66.67%) had horizontal lateral branch pattern, five genotypes (23.81%) had hanging lateral branch pattern and two genotypes (9.52%) had semi-erect lateral branch pattern. Semi-erect lateral branch pattern was exhibited by G_9 (Vattamundi) and G_4 (Nadeshan). Expression of lateral branch pattern is presented in Plate 5.

4.2.1.1.3 Lateral branch length

Variations in lateral branch length observed among the selected black pepper genotypes were short, medium and long (Table 3b). Eleven genotypes (52.38%) had long lateral branches, five genotypes (23.81%) had medium and the remaining five genotypes (23.81%) also had short lateral branches.

4.2.1.1.4 Number of nodes per lateral branch

The selected black pepper genotypes showed variability in number of nodes per lateral branch (Table 3b). Among the twenty one genotypes, fourteen genotypes (66.67%) had few nodes per lateral branch and seven genotypes (33.33%) had medium nodes per lateral branch.

4.2.1.2 Leaf Characters

4.2.1.2.1 Leaf lamina shape

The shape of the leaf was categorized into ovate, ovate lanceolate, ovate elliptic and cordate (Table 5a). Among the twenty one genotypes studied, six genotypes (28.57%) had ovate lanceolate, six genotypes (28.57%) had cordate, five genotypes (23.81%) had ovate and four genotypes (19.05%) had ovate elliptic leaf lamina shape. Ovate elliptic leaf lamina was noticed in G_2 (Chumala), G_8 (Cheppukulamundi), G_{13} (Vellanamban) and G_{18} (Padappan). Expression of leaf lamina shape is presented in the Plate 6.

Table 3a. Plant characters of selected black pepper genotypes

Sl. No.	Genotypes	Shoot tip colour	RHS Colour chart code	Lateral branch pattern
1	G_1	Light green	149B	Horizontal
2	G_2	Light purple	N77D	Horizontal
3	G_3	Light purple	N77D	Horizontal
4	G_4	Light purple	N77D	Semi erect
5	G_5	Light purple	N77D	Hanging
6	G_6	Light purple	N77D	Horizontal
7	G_7	Light purple	N77D	Horizontal
8	G_8	Light purple	N77D	Horizontal
9	G_9	Dark purple	N79B	Semi erect
10	G_{10}	Dark purple	N79B	Horizontal
11	G_{11}	Light purple	N77D	Horizontal
12	G_{12}	Light purple	N77D	Horizontal
13	G_{13}	Light purple	N77D	Hanging
14	G_{14}	Light purple	N77D	Hanging
15	G_{15}	Light green	149B	Horizontal
16	G_{16}	Light purple	N77D	Horizontal
17	G_{17}	Light purple	N77D	Horizontal
18	G_{18}	Light purple	N77D	Horizontal
19	G_{19}	Light purple	N77D	Horizontal
20	G_{20}	Light purple	N77D	Hanging
21	G_{21}	Light green	149B	Hanging

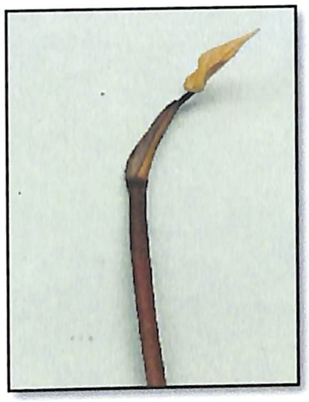
Table 3b. Plant characters of selected black pepper genotypes

Sl. No.	Genotypes	Lateral branch length	Number of nodes per lateral branch
1	G_1	Short	Few
2	G_2	Medium	Few
3	G_3	Long	Medium
4	G_4	Short	Few
5	G_5	Medium	Few
6	G_6	Medium	Few
7	G_7	Long	Few
8	G_8	Long	Medium
9	G_9	Long	Few
10	G_{10}	Short	Few
11	G_{11}	Long	Few
12	G_{12}	Long	Medium
13	G_{13}	Long	Medium
14	G_{14}	Long	Medium
15	G_{15}	Long	Medium
16	G_{16}	Medium	Few
17	G_{17}	Medium	Few
18	G_{18}	Short	Few
19	G_{19}	Long	Few
20	G_{20}	Long	Medium
21	G_{21}	Short	Few

Table 4. Distribution of plant character among the black pepper genotypes

Sl. No.	Character	Expression	Frequency (%)
1	Shoot tip colour	Light green	14.29
		Light purple	76.19
		Dark purple	9.52
2	Lateral branch pattern	Semi-Erect	9.52
		Horizontal	66.67
		Hanging	23.81
3	Lateral branch length	Short	23.81
		Medium	23.81
		Long	52.38
4	Number of nodes per lateral branch	Few	66.67
		Medium	33.33

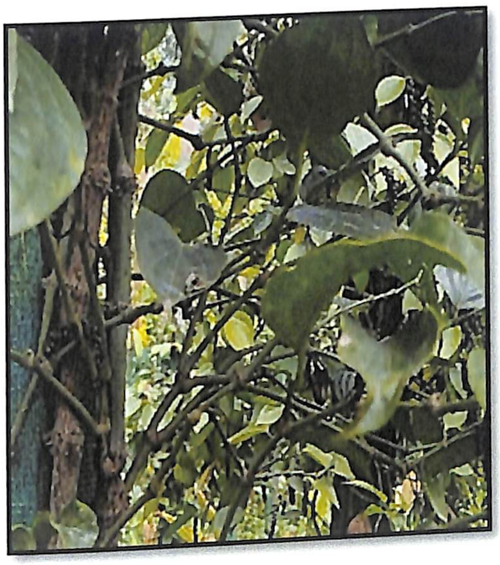
Light green



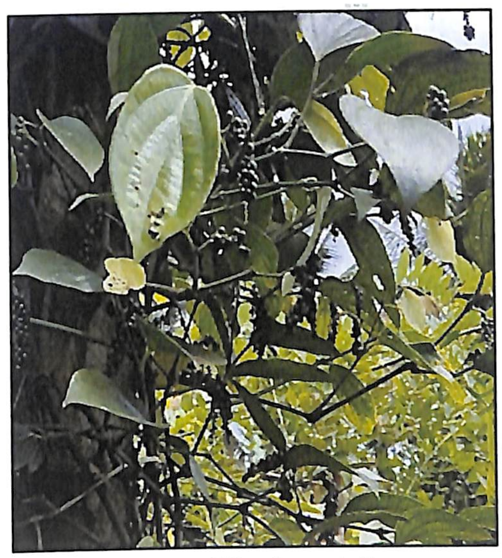
Light purple

Dark purple

Plate 4. Variation in shoot tip colour of runner shoot



Semi erect



Horizontal

Hanging

Plate 5. Variation in lateral branch pattern

4.2.1.2.3 Leaf margin

The margin of the leaf was categorized into even and wavy (Table 5a). Even leaf margin was common compared to wavy leaf margin. Among the twenty one genotypes, nineteen genotypes (90.48%) possessed even leaf margin and two genotypes (9.52%) showed wavy leaf margins. Wavy leaf margin was observed in G_{20} (Narayakodi) and G_{12} (Chengannurkodi). Expression of leaf margin is presented in Plate 8.

4.2.1.2.4 Juvenile leaf length

The genotypes were categorized into short, intermediate and long based on juvenile leaf length (Table 5b). Among the selected twenty one genotypes, eleven genotypes (52.38%) showed medium juvenile leaf, five genotypes (23.81%) showed short juvenile leaf and another five (23.81%) showed long juvenile leaf.

4.2.1.2.5 Leaf petiole length

Based on the leaf petiole length the genotypes were classified into short, medium and long (Table 5b). Among the selected genotypes, fourteen genotypes (66.67%) possessed medium leaf petiole, four genotypes (19.04%) had short petiole and three genotypes (14.29%) had long petiole. Leaf petiole length was medium in G_4 (Nadeshan), G_6 (Karimunda), G_{10} (Thulamundi) and G_{17} (Arimulak). Genotypes such as G_7 (Neelamundi), G_{15} (Kuthiravally) and G_{21} (Panniyur 1) possessed long petioles.

4.2.1.2.6 Leaf length

The selected genotypes were categorized into short, medium and long based on leaf length (Table 5b). Among the selected twenty one genotypes, eleven (52.38%) showed medium leaves, five (23.81%) showed short leaves and another five (23.81%) showed long leaves.

4.2.1.2.7 Leaf width

Based on leaf width, the genotypes were classified into narrow medium and broad (Table 5b). Among the twenty one genotypes, six (28.57%) were narrow, nine (42.86%) were medium and six (28.57%) were broad.

Table 5a. Leaf characters of selected black pepper genotypes

Sl. No.	Genotypes	Leaf lamina shape	Leaf base shape	Leaf margin
1	G_1	Cordate	Cordate	Even
2	G_2	Ovate- elliptic	Round	Even
3	G_3	Ovate	Acute	Even
4	G_4	Cordate	Cordate	Even
5	G_5	Cordate	Cordate	Even
6	G_6	Ovate	Acute	Even
7	G_7	Ovate- lanceolate	Round	Even
8	G_8	Ovate- elliptic	Acute	Even
9	G_9	Cordate	Cordate	Even
10	G_{10}	Ovate	Round	Even
11	G_{11}	Ovate- lanceolate	Round	Even
12	G_{12}	Ovate- lanceolate	Acute	Wavy
13	G_{13}	Ovate- elliptic	Round	Even
14	G_{14}	Ovate- lanceolate	Acute	Even
15	G_{15}	Cordate	Cordate	Even
16	G_{16}	Ovate- lanceolate	Round	Even
17	G_{17}	Ovate	Round	Even
18	G_{18}	Ovate- elliptic	Round	Even
19	G_{19}	Ovate	Acute	Even
20	G_{20}	Ovate- lanceolate	Round	Wavy
21	G_{21}	Cordate	Cordate	Even

Table 5b. Leaf characters of selected black pepper genotypes

Sl. No.	Genotypes	Juvenile leaf length	Leaf petiole length	Leaf length	Leaf width
1	G_1	Long	Medium	Long	Broad
2	G_2	Medium	Medium	Medium	Medium
3	G_3	Medium	Medium	Medium	Medium
4	G_4	Long	Short	Long	Broad
5	G_5	Long	Medium	Long	Broad
6	G_6	Short	Short	Short	Narrow
7	G_7	Medium	Long	Medium	Medium
8	G_8	Short	Medium	Short	Medium
9	G_9	Medium	Medium	Medium	Broad
10	G_{10}	Short	Short	Short	Medium
11	G_{11}	Long	Medium	Long	Narrow
12	G_{12}	Medium	Medium	Medium	Medium
13	G_{13}	Medium	Medium	Medium	Medium
14	G_{14}	Short	Medium	Short	Narrow
15	G_{15}	Medium	Long	Medium	Broad
16	G_{16}	Medium	Medium	Medium	Medium
17	G_{17}	Short	Short	Short	Narrow
18	G_{18}	Medium	Medium	Medium	Medium
19	G_{19}	Medium	Medium	Medium	Narrow
20	G_{20}	Medium	Medium	Medium	Narrow
21	G_{21}	Long	Long	Long	Broad

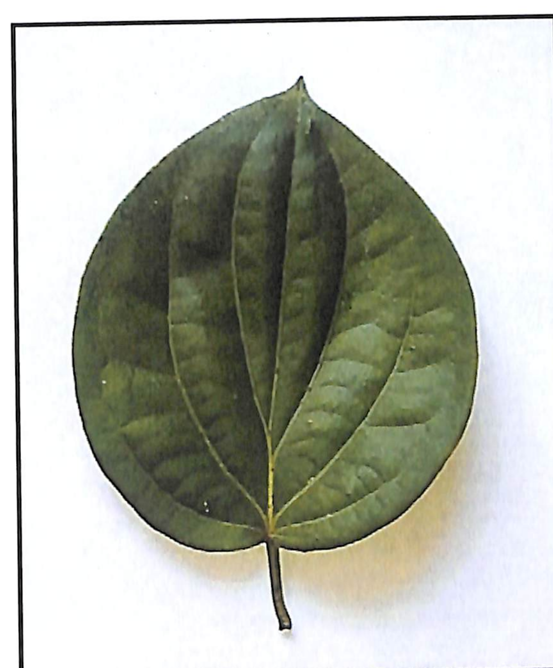
Table 6. Distribution of leaf characters among the black pepper genotypes

Sl. No.	Character	Expression	Frequency (%)
1	Leaf lamina shape	Ovate	23.81
		Ovate- lanceolate	28.57
		Ovate- elliptic	19.05
		Cordate	28.57
2	Leaf base shape	Round	42.86
		Cordate	28.57
		Acute	28.57
3	Leaf margin	Even	90.48
		Wavy	9.52
4	Juvenile leaf length	Short	23.81
		Medium	52.38
		Long	23.81
5	Leaf petiole length	Short	19.04
		Medium	66.67
		Long	14.29
6	Leaf length	Short	23.81
		Medium	52.38
		Long	23.81
7	Leaf width	Narrow	28.57
		Medium	42.86
		Broad	28.57

Ovate

Ovate lanceolate

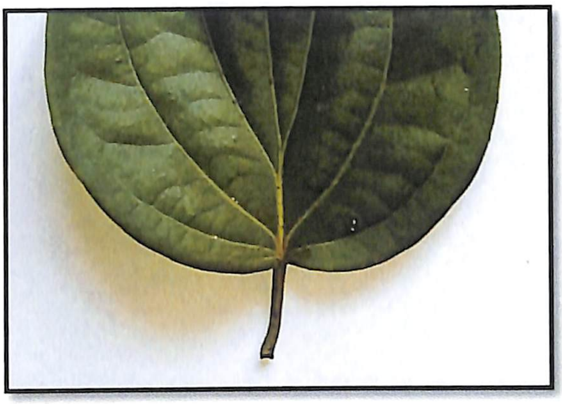
Ovate elliptic



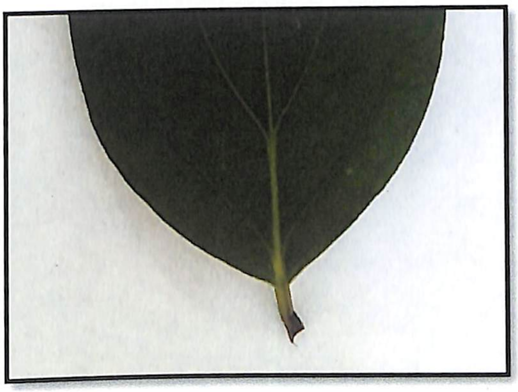
Cordate

Plate 6. Expression of leaf lamina shape

Round



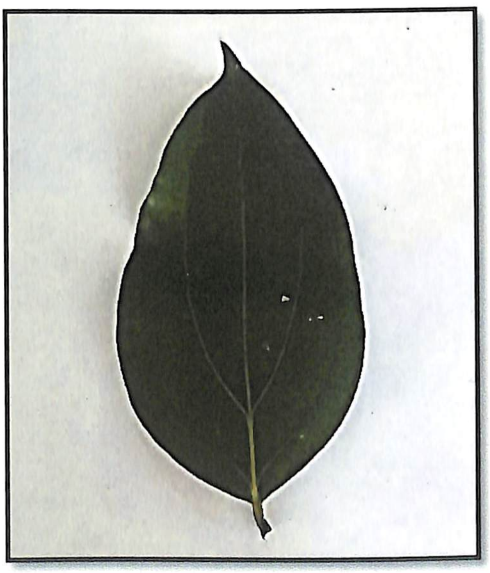
Cordate



Acute

Plate 7. Expression of leaf base shape

Even



Wavy

Plate 8. Expression of leaf margin

4.2.1.3 Inflorescence, Fruit and Seed characters

4.2.1.3.1 Spike twisting

Among the studied genotypes, spike twisting was absent (Table 7a) in nineteen genotypes (90.48%). Two genotypes (9.52%) showed twisted spikes. Spike twisting was present in G_{16} (Kottanadan) and G_{20} (Narayakodi). Expressions of spike twisting is given in plate 9.

4.2.1.3.2 Spike setting

The genotypes were grouped into loose and compact based on the extent of compactness of the berries (Table 7a). Among the selected genotypes, eighteen genotypes (85.71%) had compact spike setting and three genotypes (14.29%) had loose setting. G8 (Cheppukulamundi), G10 (Thulamundi) and G14 (Jeerakamundi) genotypes had loose spike setting. Variation in spike setting is given in plate 10.

4.2.1.3.3 Berry shape

Based on the shape of the fruits, the genotypes were categorized as round and oval (Table 7a). Nineteen genotypes (90.48%) possessed round shaped fruits while oval shaped fruit was observed only in two genotypes (9.52%). Oval shaped berries were seen in G_{20} (Narayakodi) and G_{19} (Karivilanchy). Variations in berry shape is given in plate 11.

4.2.1.3.4 Berry size

The selected genotypes were classified as small, medium and bold based on berry size (Table 7a). Among the selected genotypes, four genotypes (19.05%) were small, ten genotypes (47.62%) were medium and seven genotypes (33.33%) were bold. Bold berries were seen in G_1 (Wayanadan), G_7 (Neelamundi), G_9 (Vattamundi), G_{13} (Vellanamban), G_{18} (Padappan), G_{19} (Karivilanchy) and G_{21} (Panniyur 1).

4.2.1.3.5 Seed shape

The shape of the seed was classified as round and ovate (Table 7b). Among the selected genotypes, nineteen genotypes (90.48%) possessed round shaped seed and two genotypes (9.52%) exhibited ovate seed shape. Ovate shaped seeds were observed in G_{20} (Narayakodi) and G_{19} (Karivilanchy). Variation in shape of the seed is given in plate 12.

4.2.1.3.6 Spike peduncle length

Expression of spike peduncle length is depicted in Table 7b. Among the selected genotypes, seven genotypes (33.33%) had short peduncle length, thirteen genotypes (61.91%) had medium peduncle length and only one genotype (4.76%) exhibited long peduncle length. Long spike peduncle length was observed in G_9 (Vattamundi).

4.2.1.3.7 Spike length

Among the twenty one genotypes, medium spike length was found to be common, followed by short and long (Table 7b). Nine genotypes (42.86%) had short spike length, ten genotypes had medium spike length (47.62%) and two genotypes (9.52%) such as G_{15} (Kuthiravally) and G_{21} (Panniyur 1) exhibited long spike length. Variation in spike length is given in plate 13.

4.2.1.3.8 Number of berries per spike

The number of berries per spikes varied from medium to many (Table 7b). Among the twenty one genotypes, fifteen genotypes (71.43%) exhibited medium number of berries per spikes and six genotypes (28.57%) had many number of berries per spikes. Genotypes such as G_4 (Nadeshan), G_5 (Nadan), G_9 (Vattamundi), G_{11} (Manjamunda), G_{15} (Kuthiravally) and G_{21} (Panniyur 1) showed many number of berries per spikes.

4.2.2.3.9 Number of spikes per lateral branch

The number of spikes per lateral branches were recorded (Table 7c) and the selected genotypes were grouped into few, medium and many. Thirteen genotypes (61.91%) had many spikes per lateral branch followed by medium in six genotypes (28.57%) and few in two genotypes (9.52%). Few spikes per lateral branch were recorded in G_4 (Nadeshan) and G_{10} (Thulamundi). Expression of genotypes showing the number of spikes per lateral branch is given in Plate 14.

4.2.2.3.10 Bulk density

The genotypes were grouped into low, medium and high based on bulk density (Table 7c). Medium was common in eleven genotypes (52.38%), followed by low in eight genotypes (38.10%) and high (9.52%) in two genotypes. Genotypes such as G_{15} (Kuthiravally) and G_{17} (Arimulak) had high bulk density.

4.2.1.3.11 Time of harvest maturity

The genotypes were classified into early, medium and late (Table 7c) based on the number of days from flowering to harvest maturity. Among the selected genotypes, eighteen genotypes (85.72%) were medium, two genotypes (9.52%) were early and one genotype was late (4.76%). Genotypes such as G_{11} (Manjamunda) and G_{17} (Arimulak) exhibited early harvest maturity and G_9 (Vattamundi) showed late harvest maturity.

4.2.1.4 Non Variable Characters Observed Among the Selected Black Pepper Genotypes

Characters such as runner shoot production, pubescence on stem, type of veining, leaf texture, spike colour, spike orientation, spike shape, spike fragrance, spike proliferation, colour change while fruit ripening, fruit taste and seed texture were uniform in all the selected genotypes (Table 9).

4.2.3 Clustering of Selected Genotypes Based on Qualitative Characters

Cluster analysis was carried out for twenty two qualitative characters of the 21 genotypes using NTSYS (Numerical Taxonomy System) package 2.2.

The qualitative characters namely, shoot tip colour, lateral branch pattern, lateral branch length, number of nodes per lateral branch, leaf lamina shape, leaf base shape, leaf margin, juvenile leaf length, leaf petiole length, leaf length, leaf width, spike twisting, spike setting, berry shape, berry size, seed shape, spike peduncle length, spike length, number of berries per spike, number of spikes per lateral, bulk density and time of harvest maturity were considered for cluster analysis.

Table 7a. Inflorescence, fruit and seed characters of selected black pepper genotypes

Sl. No.	Genotypes	Spike twisting	Spike setting	Berry shape	Berry size
1	G_1	Absent	Compact	Round	Bold
2	G_2	Absent	Compact	Round	Medium
3	G_3	Absent	Compact	Round	Small
4	G_4	Absent	Compact	Round	Medium
5	G_5	Absent	Compact	Round	Medium
6	G_6	Absent	Compact	Round	Medium
7	G_7	Absent	Compact	Round	Bold
8	G_8	Absent	Loose	Round	Medium
9	G_9	Absent	Compact	Round	Bold
10	G_{10}	Absent	Loose	Round	Medium
11	G_{11}	Absent	Compact	Round	Medium
12	G_{12}	Absent	Compact	Round	Medium
13	G_{13}	Absent	Compact	Round	Bold
14	G_{14}	Absent	Loose	Round	Small
15	G_{15}	Absent	Compact	Round	Small
16	G_{16}	Present	Compact	Round	Medium
17	G_{17}	Absent	Compact	Round	Small
18	G_{18}	Absent	Compact	Round	Bold
19	G_{19}	Absent	Compact	Oval	Bold
20	G_{20}	Present	Compact	Oval	Medium
21	G_{21}	Absent	Compact	Round	Bold

Table 7b. Inflorescence, fruit and seed characters of selected black pepper genotypes

Sl. No.	Genotypes	Seed shape	Spike length	Spike peduncle length	Number of berries per spike
1	G_1	Round	Short	Medium	Medium
2	G_2	Round	Short	Medium	Medium
3	G_3	Round	Short	Short	Medium
4	G_4	Round	Medium	Short	Many
5	G_5	Round	Medium	Medium	Many
6	G_6	Round	Short	Medium	Medium
7	G_7	Round	Short	Medium	Medium
8	G_8	Round	Medium	Medium	Medium
9	G_9	Round	Short	Long	Many
10	G_{10}	Round	Medium	Medium	Medium
11	G_{11}	Round	Medium	Medium	Many
12	G_{12}	Round	Medium	Medium	Medium
13	G_{13}	Round	Medium	Short	Medium
14	G_{14}	Round	Medium	Short	Medium
15	G_{15}	Round	Long	Medium	Many
16	G_{16}	Round	Medium	Short	Medium
17	G_{17}	Round	Short	Medium	Medium
18	G_{18}	Round	Short	Short	Medium
19	G_{19}	Ovate	Medium	Medium	Medium
20	G_{20}	Ovate	Short	Medium	Medium
21	G_{21}	Round	Long	Short	Many

Table 7c. Inflorescence, fruit and seed characters of selected black pepper genotypes

Sl. No.	Genotypes	Number of spikes per lateral branch	Bulk density	Time of harvest maturity
1	G_1	Many	Low	Medium
2	G_2	Many	Medium	Medium
3	G_3	Many	Medium	Medium
4	G_4	Few	Low	Medium
5	G_5	Many	Low	Medium
6	G_6	Many	Medium	Medium
7	G_7	Many	Low	Medium
8	G_8	Many	Medium	Medium
9	G_9	Many	Low	Late
10	G_{10}	Few	Medium	Medium
11	G_{11}	Many	Low	Early
12	G_{12}	Many	Medium	Medium
13	G_{13}	Medium	Low	Medium
14	G_{14}	Many	Medium	Medium
15	G_{15}	Many	High	Medium
16	G_{16}	Many	Medium	Medium
17	G_{17}	Medium	High	Early
18	G_{18}	Medium	Medium	Medium
19	G_{19}	Medium	Low	Medium
20	G_{20}	Medium	Medium	Medium
21	G_{21}	Medium	Medium	Medium

Present

Absent

Plate 9. Expression of spike twisting

Compact

Loose

Plate 10. Variation in spike setting

Round

Oval

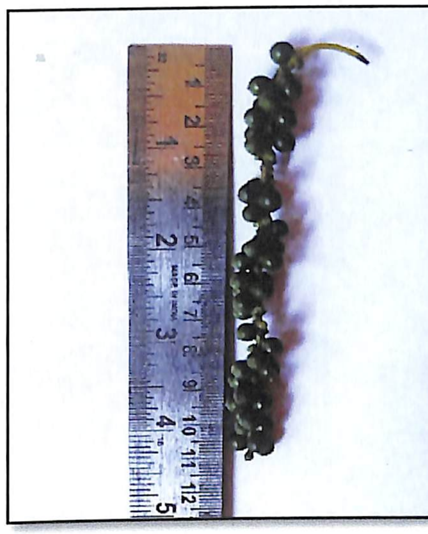
Plate 11. Variation in berry shape

Round

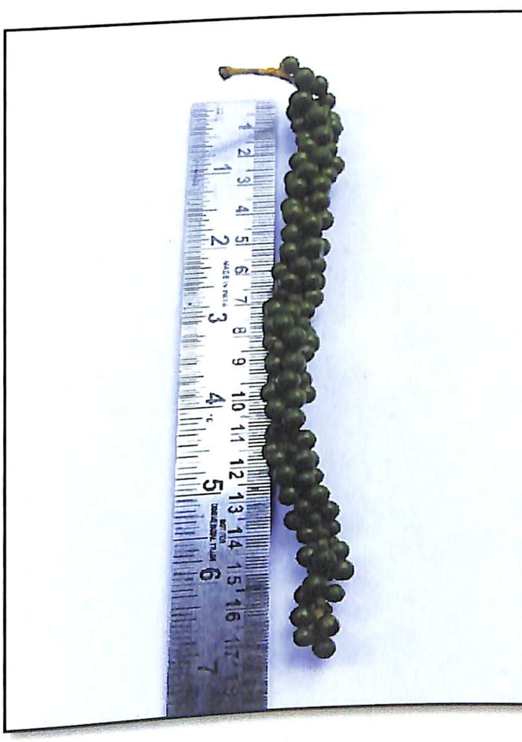
Ovate

Plate 12. Variation in seed shape

Short



Medium



Long

Plate 13. Variation in spike length

Few

Medium

Many

Plate 14. Expression of the genotypes showing number of spikes per lateral branch

Table 8. Distribution of spike, fruit and seed characters

Sl. No.	Character	Expression	Frequency (%)
1	Spike twisting	Absent	90.48
		Present	9.52
2	Spike setting	Loose	85.71
		Compact	14.29
3	Berry shape	Round	90.48
		Oval	9.52
4	Berry size	Small	19.05
		Medium	47.62
		Bold	33.33
5	Seed shape	Round	90.48
		Ovate	9.52
6	Spike peduncle length	Short	33.33
		Medium	61.91
		Long	4.76
7	Spike length	Short	42.86
		Medium	47.62
		Long	9.52
8	Number of berries per spike	Medium	71.43
		Many	28.57
9	Number of spikes per lateral branch	Few	9.52
		Medium	28.57
		Many	61.91
10	Bulk density	Low	38.10
		Medium	52.38
		High	9.52
11	Time of harvest maturity	Early	9.52
		Medium	85.72
		Late	4.76

Table 9. Non variable qualitative characters among the selected black pepper genotypes

Sl. No.	Non variable character	Expression
1	Runner shoot production	Few
2	Pubescence on stem	Absent
3	Type of veining	Campylodromous
4	Leaf texture	Glabrous coriaceous
5	Spike colour	Greenish yellow
6	Spike orientation	Prostrate
7	Spike shape	Filiform
8	Spike fragrance	Present
9	Spike proliferation	Absent
10	Colour change while fruit ripening	Green to yellow, orange and then to red
11	Fruit taste	Spicy
12	Seed texture	Smooth

The genotypes were grouped based on morphological similarity of qualitative characters. The dendrogram grouped the genotypes into 15 clusters at 73% similarity (Fig. 1). A detailed list of qualitative characters of the selected genotypes and the summary of the qualitative characters based on qualitative clustering are given in Table 11. Cluster III and VI has maximum genotypes (3 each) followed by cluster V and XI (2 each) while cluster I, II, IV, VII, VIII, IX, X, XII, XIII, XIV and XV had only one genotype each. In the fifteen clusters identified, Cluster III and Cluster VI had two subclusters each. The subcluster in Cluster III were IIIA and IIIB. Subcluster IIIA included genotypes G_2 (Chumala) and G_6 (Karimunda). Subcluster III B included G_{16} (Kottanadan) alone. Cluster VI consisted of two sub clusters VIA and VIB. G_8 (Cheppukulamundi) and G_{12} (Chengannurkodi) belonged to subcluster VIA and G_{14} (Jeerakamunda) belonged to subcluster VIB. The genotype G_9 (Vattamundi) in cluster XV showed maximum diversity due to dark purple colour for runner shoot tip, semi erect branching pattern, broad and cordate leaf, bold berries, low bulk density and late maturity.

4.2.4 Sensory Parameters

Sensory evaluation of the selected black pepper genotypes was carried out for parameters such as appearance, colour, odour, taste and flavour using a nine point hedonic scale. The sensory scores obtained with respect to the appearance of the dried berries, colour, odour, taste and flavour of the powdered samples are presented in Table 12.

Dried berries of genotype G_{13} (Vellanamban) recorded the highest mean score for appearance (8.30) followed by G_{15} (Kuthiravally) (8.0) and G_6 (Karimunda) (7.90). The lowest mean score (7.10) for appearance was recorded for G_{17} (Arimulak). There was no significant difference among the selected black pepper genotypes for the appearance of the dried berries.

There was a significant variation for colour, odour, taste and flavour among the selected twenty one genotypes. The genotype G_6 (Karimunda) recorded the highest mean (7.8) for colour followed by G_{13} (Vellanamban), G_{14} (Jeerakamunda), G_{16} (Kottanadan) and G_{19} (Karivilanchy) (7.67). The lowest mean score (5.67) for colour

Table 10. Clustering based on qualitative characters in black pepper genotypes

Cluster	Number of genotypes	Cluster members
I	1	G_1 (Wayanadan)
II	1	G_7 (Neelamundi)
III	3	G_2 (Chumala) G_6 (Karimunda) G_{16} (Kottanadan)
IV	1	G_3 (Vellayaranmunda)
V	2	G_{13} (Vellanamban) G_{18} (Padappan)
VI	3	G_8 (Cheppukulamundi) G_{12} (Chengannurkodi) G_{14} (Jeerakamunda)
VII	1	G_{19} (Karivilanchy)
VIII	1	G_{20} (Narayakodi)
IX	1	G_{10} (Thulamundi)
X	1	G_{17} (Arimulak)
XI	2	G_4 (Nadeshan) G_5 (Nadan)
XII	1	G_{11} (Manjamunda)
XIII	1	G_{15} (Kuthiravally)
XIV	1	G_{21} (Panniyur 1)
XV	1	G_9 (Vattamundi)

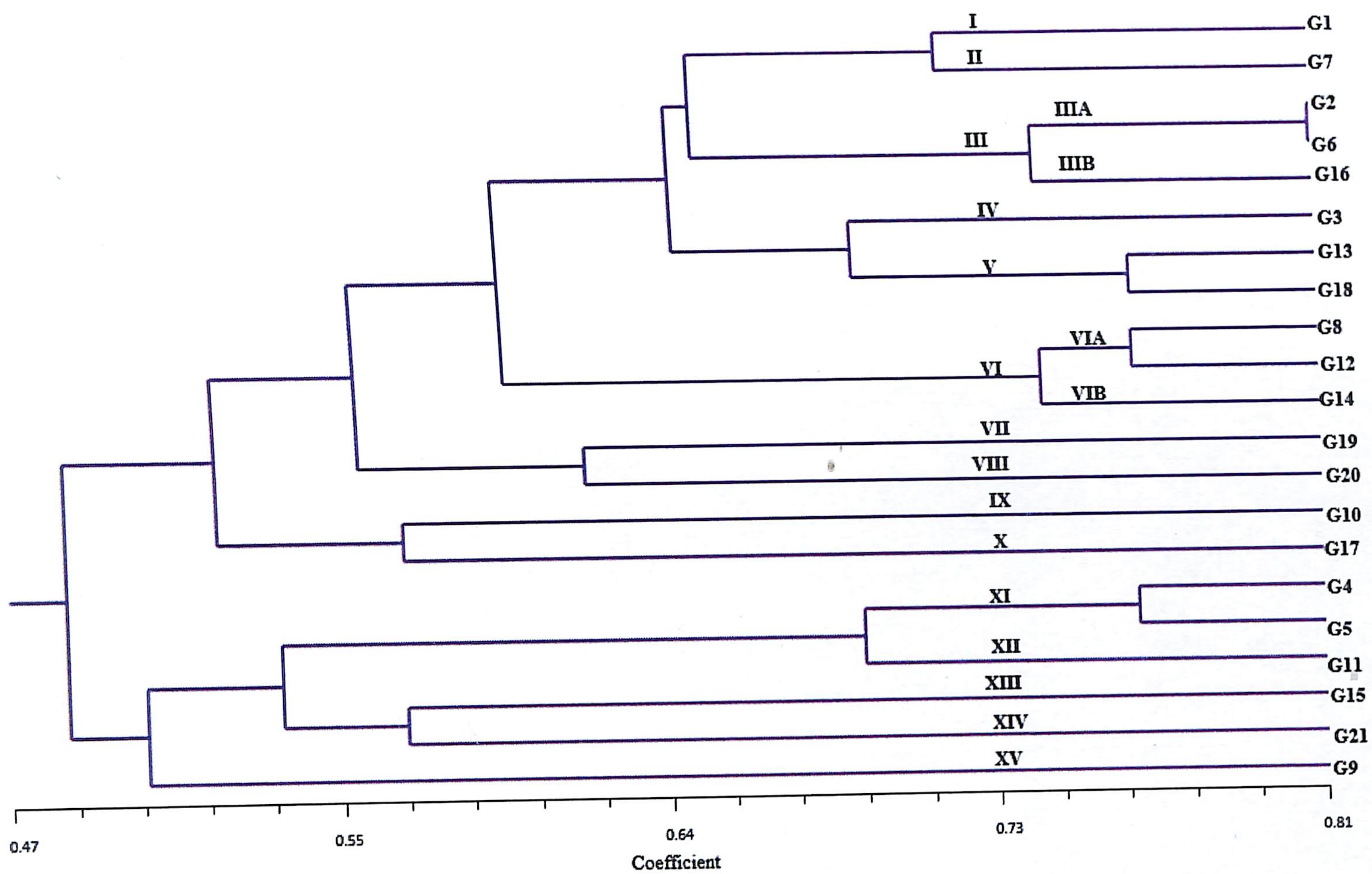


Fig. 1. UPGMA dendrogram of qualitative characteristics of black pepper genotypes

Table 11a. Summary of qualitative characters based on qualitative clustering

Qualitative cluster	Cluster members	Shoot tip colour	Lateral branch pattern	Lateral branch length	No. of nodes per laterals	Leaf lamina shape	Leaf base shape	Leaf margin
I	G_1 (Wayanadan)	Light green	Horizontal	Short	Few	Cordate	Cordate	Even
II	G_7 (Neelamundi)	Light purple	Horizontal	Long	Few	Ovate lanceolate	Round	Even
III	G_8 (Cheppukulamundi) G_{12} (Chengannurkodi) G_{14} (Jeerakamunda)	Light purple	Horizontal	Medium	Few	Ovate elliptic	Round/ acute	Even
IV	G_3 (Vellayaranmunda)	Light purple	Horizontal	Long	Medium	Ovate	Acute	Even
V	G_{13} (Vellanamban) G_{18} (Padappan)	Light purple	Hanging/ Horizontal	Long/Short	Medium /Few	Ovate elliptic	Round	Even
VI	G_8 (Cheppukulamundi) G_{12} (Chengannurkodi) G_{14} (Jeerakamunda)	Light purple	Horizontal/ Hanging	Long	Medium	Ovate elliptic/ Ovate lanceolate	Acute	Even/Wavy
VII	G_{19} (Karivilanchy)	Light purple	Horizontal	Long	Few	Ovate	Acute	Even
VIII	G_{20} (Narayakodi)	Light purple	Hanging	Long	Few	Ovate lanceolate	Round	Wavy
IX	G_{10} (Thulamundi)	Dark purple	Horizontal	Short	Few	Ovate	Round	Even
X	G_{17} (Arimulak)	Light purple	Horizontal	Medium	Few	Ovate	Round	Even
XI	G_4 (Nadeshan) G_5 (Nadan)	Light purple	Semi-erect/ Hanging	Short	Few	Cordate	Cordate	Even
XII	G_{11} (Manjamunda)	Light purple	Horizontal	Long	Few	Ovate lanceolate	Round	Even
XIII	G_{15} (Kuthiravally)	Light green	Horizontal	Long	Few	Cordate	Cordate	Even
XIV	G_{21} (Panniyur 1)	Light green	Hanging	Short	Few	Cordate	Cordate	Even
XV	G_9 (Vattamundi)	Dark purple	Semi-erect	Long	Few	Cordate	Cordate	Even

Table 11b. Summary of qualitative characters based on qualitative clustering

Qualitative cluster	Cluster members	Juvenile leaf length	Leaf length	Leaf width	Leaf petiole length	Spike twisting	Spike setting	Berry shape
I	G_1 (Wayanadan)	Medium	Medium	Broad	Medium	Absent	Compact	Round
II	G_7 (Neelamundi)	Medium	Medium	Medium	Long	Absent	Compact	Round
III	G_8(Cheppukulamundi) G_{12} (Chengannurkodi) G_{14} (Jeerakamunda)	Medium/Short	Medium/Short	Medium/ Short	Medium/ Short	Absent/Present	Compact	Round
IV	G_3 (Vellayaranmunda)	Medium	Medium	Medium	Medium	Absent	Compact	Round
V	G_{13} (Vellanamban) G_{18} (Padappan)	Medium	Medium	Medium	Medium	Absent	Compact	Round
VI	G_8(Cheppukulamundi) G_{12} (Chengannurkodi) G_{14} (Jeerakamunda)	Short/Medium	Short/Medium	Medium/Narrow	Medium	Absent	Compact/Loose	Round
VII	G_{19} (Karivilanchy)	Medium	Medium	Narrow	Medium	Absent	Compact	Oval
VIII	G_{20} (Narayakodi)	Medium	Medium	Narrow	Medium	Present	Compact	Oval
IX	G_{10} (Thulamundi)	Short	Short	Narrow	Short	Absent	Loose	Round
X	G_{17} (Arimulak)	Short	Short	Narrow	Short	Absent	Compact	Round
XI	G_4 (Nadeshan) G_5 (Nadan)	Medium	Medium	Broad	Short/ Medium	Absent	Compact	Round
XII	G_{11} (Manjamunda)	Long	Long	Narrow	Medium	Absent	Compact	Round
XIII	G_{15} (Kuthiravally)	Medium	Medium	Broad	Long	Absent	Compact	Round
XIV	G_{21} (Panniyur 1)	Long	Long	Broad	Long	Absent	Compact	Round
XV	G_9 (Vattamundi)	Medium	Medium	Broad	Medium	Absent	Compact	Round

Table 11c. Summary of qualitative characters based on qualitative clustering

Qualitative cluster	Cluster members	Berry size	Seed shape	Spike peduncle length	Spike length	Number of berries per spike	Number of spikes per lateral branch	Time of harvest maturity	Bulk density
I	G_1 (Wayanadan)	Bold	Round	Medium	Short	Medium	Many	Medium	Medium
II	G_7 (Neelamundi)	Bold	Round	Medium	Medium	Medium	Many	Medium	Low
III	G_8(Cheppukulamundi) G_{12} (Chengannurkodi) G_{14} (Jeerakamunda)	Medium	Round	Short/ Medium	Short/ Medium	Medium	Many	Medium	Medium
IV	G_3 (Vellayaranmunda)	Small	Round	Short	Short	Medium	Many	Medium	Medium
V	G_{13} (Vellanamban) G_{18} (Padappan)	Bold	Round	Short	Short/Medium	Medium	Medium	Medium	Low/ Medium
VI	G_8(Cheppukulamundi) G_{12} (Chengannurkodi) G_{14} (Jeerakamunda)	Small/Medium	Round	Medium	Medium	Medium	Many	Medium	Medium
VII	G_{19} (Karivilanchy)	Bold	Round	Medium	Medium	Medium	Medium	Medium	Low
VIII	G_{20} (Narayakodi)	Medium	Round	Medium	Short	Medium	Medium	Medium	Medium
IX	G_{10} (Thulamundi)	Medium	Round	Long	Medium	Medium	Few	Medium	Medium
X	G_{17} (Arimulak)	Small	Round	Medium	Short	Medium	Medium	Early	High
XI	G_4 (Nadeshan) G_5 (Nadan)	Medium	Round	Medium	Medium	Many	Few/Many	Medium	Low
XII	G_{11} (Manjamunda)	Medium	Round	Medium	Medium	Many	Many	Early	Low
XIII	G_{15} (Kuthiravally)	Small	Round	Short	Medium	Many	Many	Medium	High
XIV	G_{21} (Panniyur 1)	Bold	Round	Short	Long	Many	Medium	Medium	Medium
XV	G_9 (Vattamundi)	Bold	Round	Medium	Short	Many	Many	Late	Low

was recorded for G_9 (Vattamundi). Powder sample of G_{15} (Kuthiravally) recorded the highest mean score (8.46) for odour followed by G_1 (Wayanadan) and G_7 (Neelamundi) (7.8). The lowest mean score (7.0) for odour was recorded for G_3 (Vellayaranmunda), G_{10} (Thulamundi) and G_{13} (Vellanamban). Among the selected genotypes, G_{16} (Kottanadan) recorded the highest mean score (8.47) for taste (pungency) followed by G_{21} (Panniyur 1) (8.01). The lowest mean score (6.2) for taste was recorded for G_2 (Chumala). The highest mean score (8.93) value for flavour was noted in G_{15} (Kuthiravally) followed by G_{16} (Kottanadan) (7.87). The lowest mean score (7.07) for flavour was recorded in G_9 (Vattamundi).

4.2.5 Quantitative Characters

4.2.5.1 Plant Characters

The plant characters recorded include vine column height, vine column diameter, support height, support diameter, lateral branch length and number of nodes per lateral branch (Table 13).

The vine height ranged from 4.10 m to 6.10 m. G_9 (Vattamundi) had the lowest height (4.10m) followed by G_4 (Nadeshan). The highest plant among the genotypes was G_{18} (Padappan). The vine column diameter ranged from 0.53 cm to 0.94 cm. The highest diameter was recorded for G_1 (Wayanadan) and the lowest for G_{12} (Chengannurkodi).

The height of the support trees ranged from 12 m to 19.7 m. Height was highest for the support tree of G_{18} (Padappan) and lowest for the support tree of G_6 (Karimunda). The diameter of the support ranged from 16.70 m to 30.12 m. The diameter was highest in the support tree of G_{17} (Arimulak) and lowest in the support tree of G_{13} (Vellanamban).

The lateral branch length varied from 27.25 cm to 65.20 cm. The highest value for lateral branch length was recorded in G_{14} (Jeerakamunda) (65.20cm) and lowest was in G_{10} (Thulamundi) (27.25cm). The number of nodes per lateral branch was observed to range from 5.2 to 24.2. The highest number of nodes per lateral was recorded in G_{14} (Jeerakamunda) and the lowest was in G_1 (Wayanadan).

Table 12. Sensory parameters

Genotypes	Appearance		Colour		Odour		Taste		Flavour	
	Mean score	Rank	Mean score	Rank	Mean score	Rank	Mean score	Rank	Mean score	Rank
G_1	7.50	97.45	7.26	119.63	7.8	195.93	7.0	112.70	7.26	119.63
G_2	7.50	97.45	7.13	138.53	7.67	201.83	6.2	117.33	7.40	172.50
G_3	7.50	97.45	7.0	126.60	7.0	112.70	7.47	216.30	7.60	162.73
G_4	7.82	124.75	7.4	166.30	7.4	102.63	7.67	109.60	7.13	72.17
G_5	7.60	96.95	7.47	162.78	7.47	216.30	6.4	134.43	7.26	119.63
G_6	7.9	130.90	7.8	196.70	7.26	169.20	7.67	230.90	7.67	191.50
G_7	7.37	93.33	7.40	145.80	7.8	113.00	7.8	195.93	7.26	119.63
G_8	7.54	97.45	7.3	123.67	7.67	109.60	7.67	201.83	7.47	148.87
G_9	7.61	106.55	5.67	178.23	7.26	169.20	7.0	112.70	7.07	77.70
G_{10}	7.64	106.55	7.0	178.23	7.0	.39.40	7.27	205.27	7.33	159.03
G_{11}	7.62	106.55	7.33	159.03	7.4	195.93	6.47	140.23	7.23	154.67
G_{12}	7.51	101.50	7.23	154.67	7.6	125.40	7.13	191.60	7.67	185.07
G_{13}	8.30	154.05	7.67	185.07	7.0	112.70	7.27	205.27	7.23	154.67
G_{14}	7.61	106.55	7.67	185.07	7.67	109.60	7.0	112.70	7.6	183.00
G_{15}	8.0	138.90	7.07	160.33	8.46	247.10	7.53	218.43	8.93	310.50
G_{16}	7.52	97.45	7.67	185.07	7.67	201.83	8.47	283.40	7.87	206.50
G_{17}	7.10	68.85	7.2	146.10	7.26	169.20	7.67	109.60	7.13	201.50
G_{18}	7.52	101.50	7.27	155.97	7.26	169.20	7.26	169.20	7.67	190.00
G_{19}	7.11	68.85	7.67	192.77	7.6	125.40	7.4	211.1.	7.73	206.50
G_{20}	7.61	106.55	7.40	163.70	7.67	201.83	7.67	109.60	7.83	209.50
G_{21}	7.61	106.55	7.60	185.50	7.33	122.90	8.01	252.20	7.6	184.50
K value	27.26 Non Significant		57.29 Significant		72.43 Significant		62.39 Significant		75.64 Significant	
χ^2			31.41							

Table 13a. Plant characters of selected black pepper genotypes

Sl. No.	Genotypes	Vine column height (m)	Vine column diameter (cm)	Support height (m)	Support diameter (cm)
1	G_1	4.70	0.94	10.21	24.1
2	G_2	5.2	0.82	15.1	25.4
3	G_3	5.7	0.73	14.0	18.23
4	G_4	4.5	0.64	8.5	26.14
5	G_5	5.1	0.73	17.1	29.14
6	G_6	4.8	0.61	12	27.1
7	G_7	5.4	0.85	18	30.01
8	G_8	5.7	0.62	14.2	26.24
9	G_9	4.1	0.61	15	30.11
10	G_{10}	5.2	0.76	18.2	18.25
11	G_{11}	4.89	0.55	14.2	26.7
12	G_{12}	4.8	0.53	19	26.78
13	G_{13}	5	0.74	15	16.7
14	G_{14}	5.6	0.65	16.1	25.2
15	G_{15}	5	0.61	18.47	18.4
16	G_{16}	5.8	0.74	13.4	29.74
17	G_{17}	5.24	0.55	14	30.12
18	G_{18}	6.1	0.65	19.7	19.78
19	G_{19}	5.6	0.72	15.4	26.7
20	G_{20}	5.1	0.55	18.2	22.1
21	G_{21}	5.2	0.82	18.7	30.1

Table 13b. Plant characters of selected black pepper genotypes

Sl. No.	Genotypes	Lateral branch length	Number of nodes per lateral branch
1	G_1	27.45	5.2
2	G_2	32.56	7.15
3	G_3	41.26	22.85
4	G_4	29.12	8.96
5	G_5	36.02	12.74
6	G_6	31.2	7.5
7	G_7	48.20	12.5
8	G_8	45.25	20.2
9	G_9	45.4	8.26
10	G_{10}	27.25	6.4
11	G_{11}	45.25	10.23
12	G_{12}	42.25	20.78
13	G_{13}	48.52	22.23
14	G_{14}	65.20	24.2
15	G_{15}	51.12	20.14
16	G_{16}	36.15	15.41
17	G_{17}	37.41	11.4
18	G_{18}	28.12	12.10
19	G_{19}	50.25	8.25
20	G_{20}	60.52	23.14
21	G_{21}	28.85	12.01

4.2.5.2 Leaf Characters

The leaf characters recorded include juvenile leaf length, leaf petiole length, leaf length and leaf width (Table 14).

The length of the juvenile leaf ranged from 4.1 cm to 7.5 cm. The length of the petiole varied from 1.52 cm to 3.51 cm. The length of the leaves ranged from 8.5 cm to 17.25 cm. The leaf width ranged from 5.2 cm to 15.5 cm. Juvenile leaf length, leaf length and leaf width were found to be highest in G_{21} (Panniyur 1) and lowest in G_6 (Karimunda). Leaf width was highest in G_{21} (Panniyur 1) whereas it was lowest in G_2 (Chumala).

4.2.5.3 Inflorescence, Fruit and Seed characters

Spike characters taken for observation were spike peduncle length, spike length, number of well developed and underdeveloped berries per spike, number of spikes per lateral branch, number of spikes per 30 cm^2, number of spikes per vine, spike yield per vine, berry yield per vine, hundred fresh berry weight, hundred fresh berry volume, bulk density and berry diameter (Table 15).

The spike peduncle length ranged from 0.58 cm in G_{13} (Vellanamban) to 2.08 cm in G_9 (Vattamundi). Spike length varied from 6.5 cm in G_3 (Vellayaranmunda) to 17.5 cm in G_{15} (Kuthiravally). The number of well developed berries per spike varied from 30.12 in G_8 (Cheppukulamundi) to 88.25 in G_{21} (Panniyur 1). The number of underdeveloped berries ranged from 3.26 in G_{21} (Panniyur 1) to 21.4 in G_8 (Cheppukulamundi). The number of spikes per lateral branch ranged from 3.24 in G_4 (Nadeshan) to 15.7 in G_{14} (Jeerakamunda). The number of spikes per 30 cm^2 was the lowest in G_{19} (Karivilanchy) (18.69) and the highest in G_{14} (Jeerakamunda) (57.12). The number of spikes per vine ranged from 303 in G_{17} (Arimulak) to 542 in G_{14} (Jeerakamunda).

Hundred fresh berry weight ranged from 10.03 g in G_{16} (Kottanadan) to 20.10 g in G_{13} (Vellanamban). Hundred fresh berry volume ranged from 9.2 ml in G_2 (Chumala) to 18.74 ml in G_7 (Neelamundi). Bulk density ranged from 481.6 g in G_1 (Wayanadan) to

640 g in G_{15} (Kuthiravally). G_1 (Wayanadan), G_7 (Neelamundi), G_9 (Vattamundi), G_{13} (Vellanamban), G_{18} (Padappan), G_{19} (Karivilachy) and G_{21} (Panniyur 1) were bold and recorded a bulk density of 481.6 g, 488 g, 496.2 g, 497.2 g, 596.1 g, 489.5 g and 506.2 g respectively. The berry diameter ranged from 2.8 mm in G_3 (Vellayaranmunda) to 5.11 mm in G_{21} (Panniyur 1).

Analysis of variance using completely randomized design (CRD) was carried out for yield characters such as fresh spike yield per vine (kg) and fresh berry yield per vine (kg) for the twenty one selected black pepper genotypes based on data collected during two years (2019-2020) and (2020-2021). Both the characters were non significant among the genotypes studied (Table 16).

4.2.6 Physiological Parameters

Physiological parameters like leaf thickness, relative water content, epicuticular wax, specific leaf area and stomatal density were recorded from the leaves of selected black pepper genotypes (Table 17).

Leaf thickness of the selected black pepper genotypes ranged from 0.21 mm in G_8 (Cheppukulamundi) and G_{10} (Thulamundi) to 0.35 in G_{16} (Kottanadan). Relative water content ranged from 91.54% to 98.41%. The relative water content was highest in G_{16} (Kottanadan) and lowest in G_2 (Chumala). The relative water content of G_{13} (Vellanamban) was 97.7 per cent followed by G_6 (Karimunda) with 97.11 per cent. Epicuticular wax of the selected genotypes ranged from 1.50 mg cm^{-2} in G_4 (Nadeshan) to 1.82 mg cm^{-2} in G_{16} (Kottanadan). The epicuticular wax recorded in G_{13} (Vellanamban) was 1.79 mg cm^{-2}, G_{20} (Narayakodi) was 1.78 mg cm^{-2} and G_6 (Karimunda) was 1.75 mg cm^{-2}. Specific leaf area of the selected twenty one genotypes ranged from 160.25 cm^2 g^{-1} in G_{16} (Kottanadan) to 243.12 cm^2 g^{-1} in G_{14} (Jeerakamunda). The specific leaf area of G_6 (Karimunda) was 167.56 cm^2 g^{-1} and that for G_{18} (Padappan) was 168.4 cm^2 g^{-1}. The mean stomatal density of the leaf was the lowest in G_{16} (Kottanadan) (8.01 per cm^2) followed by G_{13} (Vellanamban) (8.2 per cm^2) and G_6 (Karimunda) (9.5 per cm^2). The mean stomatal density of the leaf was highest in G_3 (Vellayaranmunda) (13.5 per cm^2).

Table 14. Leaf characters of selected black pepper genotypes

Sl. No.	Genotypes	Juvenile leaf length(cm)	Leaf petiole length (cm)	Leaf length (cm)	Leaf width (cm)
1	G_1	6.5	2.5	16.01	14.63
2	G_2	4.25	2.51	9.4	5.2
3	G_3	5.15	2.01	14.4	8.28
4	G_4	7.4	1.84	17.01	12.42
5	G_5	6.8	2.74	16.2	14.3
6	G_6	4.1	1.52	8.74	7.07
7	G_7	5.6	3.2	15.25	8.5
8	G_8	4.5	2.91	9.41	8.1
9	G_9	5.9	2.52	15.33	10.5
10	G_{10}	4.25	1.94	8.5	7.0
11	G_{11}	5.8	2.7	15.23	7.4
12	G_{12}	6.01	2.9	12.3	7.6
13	G_{13}	5.7	2.71	15.2	7.31
14	G_{14}	3.5	2.02	9.52	6.54
15	G_{15}	5.78	3.14	15.4	11.5
16	G_{16}	5.01	2.5	13.2	7.5
17	G_{17}	4.2	1.7	9.1	6.5
18	G_{18}	5.3	2.4	12.14	7.5
19	G_{19}	5.01	2.2	14.14	6.8
20	G_{20}	4.9	2.0	14.4	6.4
21	G_{21}	7.5	3.51	17.25	15.5

Table 15a. Inflorescence, fruit and seed of selected black pepper genotypes

Sl. No.	Genotypes	Spike peduncle length (cm)	Spike length (cm)	Number of well developed berries per spikes	Number of under developed berries per spikes
1	G_1	1.1	9.5	35.47	12.15
2	G_2	1.7	7.25	50.5	6.7
3	G_3	0.85	6.5	30.31	8.10
4	G_4	0.78	11.4	60.21	5.24
5	G_5	1.6	14.8	72.47	6.41
6	G_6	2.0	8.56	42.5	5.44
7	G_7	1.0	9.87	35.5	13.1
8	G_8	1.9	12.5	30.12	21.4
9	G_9	2.08	9.85	60.52	7.12
10	G_{10}	1.02	10.54	37.1	17.5
11	G_{11}	1.2	14.2	52.18	11.5
12	G_{12}	1.0	12.1	38.4	10.47
13	G_{13}	0.58	10.45	37.5	10.4
14	G_{14}	0.96	9.34	35.23	10.20
15	G_{15}	1.01	17.5	67.45	8.14
16	G_{16}	0.94	10.45	35.77	15.1
17	G_{17}	1.25	8.1	45.21	8.45
18	G_{18}	0.61	9.5	34.5	13.1
19	G_{19}	1.00	10.45	35.74	7.5
20	G_{20}	1.1	9.02	48.5	10.1
21	G_{21}	0.98	16.85	88.25	3.26

Table 15b. Inflorescence, fruit and seed of selected black pepper genotypes

Sl. No.	Genotypes	Number of spikes per lateral branch	Number of spikes per 30 cm^2	Number of spikes per vine
1	G_1	8.50	40.75	449
2	G_2	8.20	42.86	373
3	G_3	10.50	50.15	480
4	G_4	3.24	24.74	345
5	G_5	9.25	40.34	452
6	G_6	12.12	50.12	500
7	G_7	9.14	31.02	414
8	G_8	11.01	45.18	420
9	G_9	10.10	40.25	440
10	G_{10}	3.85	19.15	320
11	G_{11}	10.54	40.14	345
12	G_{12}	8.45	26.14	387
13	G_{13}	5.14	34.78	375
14	G_{14}	15.70	57.12	542
15	G_{15}	10.25	44.44	423
16	G_{16}	8.26	36.10	507
17	G_{17}	4.62	29.41	303
18	G_{18}	6.25	40.14	375
19	G_{19}	5.01	18.69	398
20	G_{20}	6.71	40.07	476
21	G_{21}	5.14	38.17	478

Table 15c. Inflorescence, fruit and seed of selected black pepper genotypes

Sl. No.	Genotypes	Hundred fresh berry weight (g)	Hundred fresh 100 berry volume (ml)	Bulk density (g)	Berry diameter (mm)
1	G_1	19.5	18.7	481.6	5.10
2	G_2	10.7	9.2	590	4.20
3	G_3	10.2	9.4	520.2	2.80
4	G_4	16.2	14.25	497.6	4.14
5	G_5	17.5	16.1	498.7	3.01
6	G_6	10.2	9.82	526	3.05
7	G_7	20.0	18.74	488	4.51
8	G_8	19.1	18.2	595.3	4.10
9	G_9	12.14	11.25	496.2	5.1
10	G_{10}	10.4	9.6	514.2	4.11
11	G_{11}	17.2	16.56	496.9	3.85
12	G_{12}	16.2	15.4	541.3	3.96
13	G_{13}	20.1	18.5	497.2	4.89
14	G_{14}	10.08	9.5	584	2.85
15	G_{15}	10.2	9.8	640	2.98
16	G_{16}	10.03	9.5	583.2	3.98
17	G_{17}	10.5	9.5	612.4	2.97
18	G_{18}	10.58	9.5	596.1	4.35
19	G_{19}	12.4	11.4	489.5	5.01
20	G_{20}	11.5	10.9	560	3.01
21	G_{21}	14.52	13.2	506.2	5.11

Table 16a. Variability in yield among the selected black pepper genotypes

Sl. No.	Genotypes	Fresh spike yield per vine (kg)			Fresh berry yield per vine (kg)		
		2019-20	2020-21	Pooled mean	2019-20	2020-21	Pooled mean
1	G_1	4.1	3.2	3.65	3.5	2.4	2.95
2	G_2	2.8	3.5	3.15	2.0	2.8	2.4
3	G_3	3.2	3.5	3.35	2.5	2.8	2.25
4	G_4	2.8	3.9	3.35	2.0	3.1	2.55
5	G_5	3.3	4.1	3.7	2.8	3.4	3.1
6	G_6	3.6	3.8	3.7	3.1	3.0	3.05
7	G_7	3.7	3.1	3.4	3.0	2.65	2.83
8	G_8	3.1	3.4	3.25	2.2	2.8	2.5
9	G_9	3.7	3.1	3.4	3.1	2.4	2.75
10	G_{10}	1.8	2.5	2.3	1.0	1.9	1.45
11	G_{11}	3.5	3.8	3.65	2.9	3.2	3.05
12	G_{12}	3.4	4.1	3.75	2.7	3.5	3.1
13	G_{13}	2.8	3.5	3.15	2.1	2.9	2.5
14	G_{14}	3.3	3.1	3.2	2.7	2.5	2.6
15	G_{15}	3.1	4.6	3.85	2.3	3.9	3.1
16	G_{16}	3.3	3.2	3.25	3.0	2.9	2.95
17	G_{17}	2.4	2.5	2.45	1.7	2.1	1.9
18	G_{18}	3.1	3.8	3.45	2.5	3.2	2.85
19	G_{19}	3.1	2.9	3	2.5	2.4	2.25
20	G_{20}	3.1	3.4	3.25	2.5	2.8	2.65
21	G_{21}	3.5	4.1	3.8	2.8	3.5	3.15

Table 16b. Variability in yield among the selected black pepper genotypes

Genotype	Fresh spike yield per vine (kg)	Fresh berry yield per vine (kg)
G1	3.65±0.64	2.95±0.78
G2	3.15±0.50	2.40±0.57
G3	3.35±0.21	2.65±0.21
G4	3.35±0.78	2.55±0.78
G5	3.70±0.57	3.10±0.42
G6	3.70±0.28	3.05±0.21
G7	3.40±0.42	2.83±0.25
G8	3.25±0.21	2.50±0.42
G9	3.40±0.42	2.75±0.50
G10	2.15±0.50	1.45±0.64
G11	3.65±0.21	3.05±0.21
G12	3.75±0.50	3.10±0.57
G13	3.15±0.50	2.50±0.57
G14	3.20±0.14	2.60±0.14
G15	3.85±1.06	3.10±1.13
G16	3.30±0.28	2.95±0.21
G17	2.45±0.07	1.90±0.28
G18	3.45±0.50	2.85±0.50
G19	3.00±0.14	2.45±0.07
G20	3.25±0.21	2.65±0.21
G21	3.80±0.42	3.15±0.50
SE(m)	0.331	0.357
CD	NS	NS

Table 17. Physiological parameters of selected black pepper genotypes

Sl. No	Genotypes	Leaf thickness (mm)	Relative Water Content (%)	Epicuticular wax ($mgcm^{-2}$)	Specific Leaf Area (cm^2g^{-1})	Stomatal density (No./ cm^2)
1	G_1	0.28	92.23	1.52	210.45	11.2
2	G_2	0.26	91.54	1.51	198.52	12.4
3	G_3	0.24	92.10	1.61	200.3	13.5
4	G_4	0.29	93.5	1.50	242.14	10.58
5	G_5	0.28	92.2	1.7	213.25	11.6
6	G_6	0.31	97.11	1.75	167.56	9.5
7	G_7	0.30	94.0	1.68	190.14	10.2
8	G_8	0.21	93.52	1.64	216.89	11.6
9	G_9	0.26	92.79	1.61	240.13	12.5
10	G_{10}	0.21	94.7	1.54	227.3	11.6
11	G_{11}	0.26	93.8	1.57	218.6	11.4
12	G_{12}	0.27	92.6	1.60	230.78	12.4
13	G_{13}	0.34	97.7	1.79	165.78	8.2
14	G_{14}	0.25	94.8	1.51	243.12	13.1
15	G_{15}	0.32	93.69	1.57	231.12	12.4
16	G_{16}	0.35	98.41	1.82	160.25	8.01
17	G_{17}	0.25	92.8	1.72	200.12	12.4
18	G_{18}	0.33	96.4	1.70	168.4	10.05
19	G_{19}	0.29	94.6	1.52	230.2	12.4
20	G_{20}	0.31	95.4	1.78	190.56	10.1
21	G_{21}	0.24	93.2	1.67	230.41	10.80

4.2.7 Quality Attributes

The selected twenty one genotypes were subjected to analysis of quality parameters such as piperine, oleoresin, essential oil, starch, crude fibre and total ash (Table 18).

Piperine content was highest in G_{16} (Kottanadan) (5.6%) followed by G_{21} (Panniyur 1) (5.2%). The lowest piperine content was observed in G_2 (Chumala) (3%). Oleoresin content ranged from 6.3 per cent in G_3 (Vellayaranmunda) to 13.2 per cent in G_{16} (Kottanadan). The oleoresin content of G_{15} (Kuthiravally) was 10.9 per cent and that of G_{19} (Karivilanchy) and G_{17} (Arimulak) was 10.5 per cent and 10.3 per cent respectively. The oleoresin content recorded from G_{21} (Panniyur 1) was also 10.3 per cent. The essential oil content of selected genotypes ranged from 3.0 per cent in G_3 (Vellayaranmunda) and G_8 (Cheppukulamundi) to 4.5 per cent in G_{15} (Kuthiravally). The genotypes G_4 (Nadeshan) and G_9 (Vattamundi) recorded 3.9 per cent essential oil content. The content of starch ranged from 33 per cent in G_3 (Vellayaranmunda) to 38.4 per cent in G_{21} (Panniyur 1). The starch content of G_{19} (Karivilanchy) was 38% and that of G_1 (Wayanadan) was 37.7%. The crude fibre content ranged from 9.01 percent in G14 (Jeerakamunda) to 14.2 percent in Kottanadan. The crude fibre content of G_{12} (Chengannurkodi) and G_{19} (Karivilanchy) was 12.8 per cent and 12.5 per cent respectively. The total ash content of the dried berries ranged from 4.1 per cent to 5.5 per cent. It was highest in G_{21} (Panniyur 1) (5.5%) and lowest in G_{19} (Karivilanchy) (4.1%). Total ash of G_{13} (Vellanamban) was 5.4 per cent.

4.2.8 Descriptive Statistics of Observed Quantitative Characters

Descriptive statistics were done to summarize the data in a sensible way (Table 19). The mean spike peduncle length of selected twenty one black pepper genotypes was 1.17 cm and it varied from 0.58 to 2.08 cm with a standard deviation of 0.43. The spike length ranged from 6.5 to 17.5 with a mean spike length of 10.89 and a standard deviation of 2.89. The mean number of well developed fruits per spike was 46.35 with a standard deviation of 15.53. The mean number of underdeveloped fruits

Table 18. Quality attributes of selected black pepper genotypes

Sl. No	Genotypes	Piperine (%)	Oleoresin (%)	Essential oil (%)	Starch (%)	Crude fibre (%)	Total ash (%)
1	G_1	3.7	7.50	3.2	37.70	11.40	5.10
2	G_2	3.00	6.80	3.80	35.10	10.50	4.20
3	G_3	3.9	6.30	3.00	33.00	10.20	5.40
4	G_4	3.06	9.10	3.90	35.50	11.50	5.10
5	G_5	3.9	8.50	3.10	35.10	11.20	5.10
6	G_6	4.20	9.30	3.10	33.10	11.70	4.40
7	G_7	4.50	7.90	3.30	36.40	10.00	5.20
8	G_8	3.75	6.40	3.00	33.20	9.20	4.90
9	G_9	3.40	8.40	3.90	37.00	11.40	5.20
10	G_{10}	3.20	7.80	3.10	34.00	10.90	4.50
11	G_{11}	3.85	6.70	3.60	34.30	10.20	4.50
12	G_{12}	3.90	7.40	3.80	34.00	12.80	4.20
13	G_{13}	3.40	7.80	3.80	37.40	10.60	5.40
14	G_{14}	3.11	6.50	3.60	34.30	9.01	4.90
15	G_{15}	3.90	10.90	4.50	33.20	12.40	4.70
16	G_{16}	5.60	13.20	3.80	34.40	14.20	4.50
17	G_{17}	4.21	10.30	3.70	33.60	12.10	4.60
18	G_{18}	3.90	7.10	3.80	36.40	10.50	4.80
19	G_{19}	4.50	10.50	3.70	38.00	12.50	4.10
20	G_{20}	3.60	8.90	3.20	34.00	10.10	4.20
21	G_{21}	5.20	10.30	3.40	38.40	11.60	5.50

standard deviation of 10.34. The higher the standard deviation, the higher the variability and it is revealed from the wide range of spikes/vines (303 to 542). The mean number of spikes per vine was 419.14, with a standard deviation of 64.82. The fresh spike yield per vine showed a standard deviation of 0.41 and it ranged from 2.3 kg to 3.85 kg. The fresh berry yield per vine showed a standard deviation of 0.43 with a mean value of 2.69 kg. The standard deviation for hundred fresh berry weight and hundred berry volume was 3.84 and 3.67 respectively. The bulk density of dried berries ranged from 481 to 640 g with a mean of 520.2 g. Bulk density was also a highly variable character with a standard deviation of 49.4. The berry diameter ranged from 2.8 to 5.11 with a standard deviation of 0.83.

The mean leaf thickness among the selected genotypes was 0.28 mm with a standard deviation of 0.044. The relative water content of the genotypes varied from 91.54 to 98.41% with a mean of 94.18% and standard deviation of 1.92. Epicuticular wax content ranged from 1.5 to 1.82 mg cm^{-2}. The mean epicuticular wax content was 1.63 mg cm^{-2} and the standard deviation noted was 0.10. The standard deviation with respect to the specific leaf area was 28.24 and the values ranged between 160.25 to 263.25 cm^2 g^{-1}. Stomatal density of the selected genotypes ranged from 8.01 to 13.5 per cm^2 area with a mean of 11.24 and a standard deviation of 1.49. Among the physiological parameters, specific leaf area was the most variable character among the genotypes, which showed a higher standard deviation of 28.24.

The piperine content of the dried berries ranged from 3.0 per cent to 5.6 per cent. The mean piperine content among the selected genotypes was 3.896% with a standard deviation of 0.662. The mean oleoresin content was found to be 8.448% with a standard deviation of 1.805. The essential oil content of the genotypes ranged from 3.0 to 4.5%. The mean value for essential oil was 3.538 with a standard deviation of 0.39. The percentage of starch ranged from 33.0 to 38.4%. The mean starch content was found to be 35.095% with a standard deviation of 1.66. The crude fibre content of the selected genotypes ranged from 9.01 to 14.2% with a mean of 11.229 per cent and standard deviation of 1.115. Total ash content ranged from 4.1 to 5.6 % with a mean of 4.795 and a standard deviation of 0.46.

Table 19. Descriptive statistics for inflorescence, fruit and seed characters

Characters	Mean	Standard Deviation	Minimum	Maximum
Spike peduncle length (cm)	1.17	0.43	0.58	2.08
Spike length (cm)	10.89	2.89	6.5	17.5
No. of well developed fruits per spike	46.35	15.53	30.31	88.25
No. of underdeveloped fruits per spike	10.07	4.32	3.26	21.4
No. of spikes per lateral branch	8.19	3.09	3.24	15.7
No. of spikes per 30 cm^2	37.13	10.34	18.69	57.12
No. of spikes per vine	419.14	64.82	303	542
Fresh spike yield per vine (kg)	3.35	0.41	2.3	3.85
Fresh berry yield per vine (kg)	2.69	0.43	1.45	3.15
Hundred fresh berry weight (g)	13.77	3.84	10.03	20.1
Hundred fresh berry volume (ml)	12.81	3.67	9.2	18.74
Bulk density (g)	520.2	49.14	481	640
Berry diameter (mm)	4.1	0.83	2.8	5.11
Leaf thickness (mm)	0.28	0.044	0.21	0.3
Relative Water Content (%)	94.18	1.92	91.54	98.41
Epicuticular wax (mg cm^{-2})	1.63	0.10	1.5	1.82
Specific Leaf Area (cm^2 g^{-1})	209.33	28.24	160.25	263.25
Stomatal density (No/cm^2)	11.24	1.49	8.01	13.5
Piperine (%)	3.896	0.662	3	5.6
Oleoresin (%)	8.448	1.805	6.3	13.2
Essential oil (%)	3.538	0.39	3	4.5
Starch (%)	35.095	1.662	33	38.4
Crude fibre (%)	11.229	1.115	9.01	14.2
Total ash (%)	4.795	0.455	4.1	5.6

4.2.9 Quantitative Characterization of Selected Black Pepper Genotypes

Multivariate analysis using Principal Component Analysis was carried to summarize the variation among the selected genotypes for quantitative characters. Three separate Principal Component Analysis were done using quantitative, physiological and quality parameters. The PCA results revealed the relation among the selected black pepper genotypes and relative contribution of various traits on those genotypes.

4.2.9.1 Principal Component Analysis of Yield and Yield Related Traits

Quantitative characters such as vine column height, vine column diameter, support height, support diameter, lateral branch length, number of nodes per lateral branch, juvenile leaf length, leaf petiole length, leaf length, leaf width, spike peduncle length, spike length, number of well developed berries per spike, number of underdeveloped berries per spike, number of spikes per lateral branch, number of spikes per 30 cm^2, number of spikes per vine, fresh spike yield per vine, fresh berry yield per vine, hundred fresh berry weight, hundred fresh berry volume, bulk density and berry diameter were statistically analyzed using PCA.

Component features that contribute to the greatest variability for yield have been derived from loading values (Table 20). Seven principal components (eigenvalue >1) contributed to 85.53% of the variance as revealed from PCA (Appendix III). The first seven principal component axes explained 85.53 per cent of the variability for yield among the genotypes under study. The remaining 12 axes contributed 14.47 per cent of the variability. Percentage contribution of variables on principal components is given in the Table 21. PC1 accounted for the highest variance (27.05%) followed by PC2 (18.26%) while PC3, PC4, PC5, PC6 and PC7 accounted for 11.75%, 9.97%, 7.16%, 6.69% and 4.67% variance, respectively. The yield related contribution was greater in PC1. Variables such as juvenile leaf length (13.22%), leaf length (13.39%), leaf width (13.44%) and number of spikes/30 cm^2 (16.54%) contributed high variability for yield in PC1. The two yield related traits in PC2 were number of spikes/lateral branch (14.76%) and number of spikes/vine (13.09%). The overall contribution of number of nodes/lateral branch (14.99% in PC3), number of well developed berries/spike (15.49% in PC4),

Table 20. Component loadings of each variable on PCs

Sl. No.	Variables	PC1	PC2	PC3	PC4	PC5	PC6	PC7
1	Vine column height (m)	-0.09	-0.03	0.28	0.17	-0.34	0.32	-0.28
2	Vine column diameter (cm)	0.14	-0.16	-0.04	-0.18	-0.12	**0.37**	0.36
3	Support height (m)	-0.02	0.09	0.34	0.28	**-0.38**	-0.09	0.36
4	Support diameter (cm)	0.12	0.04	-0.28	-0.1	-0.27	-0.32	0.09
5	Lateral branch length	-0.09	0.24	0.22	-0.13	0.30	-0.34	0.3
6	Number of nodes per lateral branch	-0.08	0.27	**0.39**	-0.00	0.25	-0.01	-0.07
7	Juvenile leaf length (cm)	**0.37**	-0.05	0.02	0.14	0.09	0.04	-0.17
8	Leaf petiole length (cm)	0.26	0.09	0.31	0.01	-0.30	-0.06	0.25
9	Leaf length (cm)	**0.38**	0.02	0.06	0.08	0.29	0.08	-0.02
10	Leaf width (cm)	**0.38**	0.03	-0.10	0.09	-0.04	0.13	-0.08
11	Spike peduncle length (cm)	-0.03	0.12	-0.34	-0.18	-0.38	-0.31	-0.01
12	Spike length (cm)	0.25	0.11	0.17	0.24	-0.17	-0.24	-0.04
13	No. of well developed berries per spike	0.25	0.09	-0.17	**0.39**	-0.07	-0.18	0.06
14	No. of underdeveloped berries per spike	-0.14	-0.09	0.34	-0.29	-0.29	0.01	-0.11
15	No. of spikes per lateral branch	-0.06	**0.38**	-0.06	-0.30	-0.07	-0.02	0.05
16	No. of spikes per 30 cm^2	**0.41**	-0.05	-0.13	-0.11	-0.12	0.21	-0.08
17	No. of spikes per vine	0.03	**0.36**	-0.09	-0.15	0.07	0.29	0.27
18	Fresh spike yield per vine (kg)	0.26	0.31	-0.00	-0.02	-0.01	0.15	-0.16
19	Fresh berry yield per vine (kg)	0.25	0.31	0.00	-0.03	-0.03	0.09	-0.09
20	Hundred fresh berry weight (g)	0.26	-0.11	0.19	-0.31	-0.06	-0.16	-0.19
21	Hundred fresh berry volume (ml)	0.25	-0.09	0.21	-0.31	-0.08	-0.17	-0.19
22	Bulk density (g)	-0.23	0.18	0.13	0.24	-0.26	-0.02	-0.14
23	Berry diameter (mm)	0.19	-0.27	0.03	-0.15	-0.11	0.04	**0.39**

Table 21. Percentage contribution of variables on PCs

Sl. No.	Variables	PC1	PC2	PC3	PC4	PC5	PC6	PC7
1	Vine column height (m)	0.85	0.06	7.94	2.73	11.14	9.95	7.99
2	Vine column diameter (cm)	2.02	4.46	0.13	3.11	7.82	**13.18**	10.48
3	Support height (m)	0.05	0.89	10.52	7.67	**13.13**	0.89	9.43
4	Support diameter (cm)	1.35	0.16	7.74	0.92	7.39	10.19	0.91
5	Lateral branch length	0.84	5.84	4.92	3.76	11.91	11.34	8.44
6	Number of nodes per lateral branch	0.69	7.43	**14.99**	0.00	6.42	0.02	0.43
7	Juvenile leaf length (cm)	**13.22**	0.28	0.03	1.89	0.94	0.17	2.71
8	Leaf petiole length (cm)	6.95	0.77	9.59	0.01	9.17	0.32	6.06
9	Leaf length (cm)	**13.39**	0.04	0.36	0.58	6.49	0.63	0.05
10	Leaf width (cm)	**13.44**	0.12	1.08	0.04	0.13	1.79	0.61
11	Spike peduncle length (cm)	0.07	1.54	11.40	6.09	11.19	9.71	0.01
12	Spike length (cm)	6.47	1.19	2.93	5.75	2.77	5.96	0.14
13	No. of well developed berries per spike	5.98	0.91	2.74	**15.49**	0.55	3.33	0.39
14	No. of underdeveloped berries per spike	1.88	0.89	11.71	8.59	8.79	0.02	1.12
15	No. of spikes per lateral branch	0.34	**14.76**	0.32	9.07	0.62	0.03	0.22
16	No. of spikes per 30 cm^2	**16.54**	0.29	1.55	1.28	1.44	4.53	0.56
17	No. of spikes per vine	0.09	**13.09**	0.91	2.18	0.44	8.13	7.20
18	Fresh spike yield per vine (kg)	6.78	9.61	0.00	0.05	0.01	2.12	2.63
19	Fresh berry yield per vine (kg)	6.34	9.86	0	0.09	0.10	0.94	0.96
20	Hundred fresh berry weight (g)	6.74	1.21	3.96	12.75	0.01	2.45	3.73
21	Hundred fresh 100 berry volume (ml)	6.42	0.75	4.33	12.44	0.02	2.73	3.77
22	Bulk density (g)	5.16	3.32	1.75	5.54	6.56	0.03	2.02
23	Berry diameter (mm)	3.96	7.09	0.07	2.22	1.17	0.15	**14.83**

support height (13.13% in PC5), vine column diameter (13.58 % in PC6) and berry diameter (14.83% in PC7) was high on yield variability.

To illustrate the relationship between PC1 and PC2, a loading plot (Fig. 2) was generated using the variability of all 23 variables under investigation. The traits observed away from the origin had a higher loading and a great influence on this variability. The first quadrant had five yield trait related variables such as leaf length (X9), leaf width (X10), number of spikes per vine (X17), fresh spike yield per vine (X18) and fresh berry yield per vine (X19). Among these, leaf length (X9) and leaf width (X10), fresh spike yield per vine (X18) and fresh berry yield per vine (X19) were strongly correlated each other. The second quadrant consisted of two yield related traits such as number of nodes per lateral branch (X15) and number of spikes per 30 cm^2 (X16) which were strongly correlated each other. Yield related trait was absent in third quadrant whereas, the fourth quadrant contained one yield related trait, juvenile leaf length (X7). As per the biplot, the traits observed near the origin such as the vine column height (X1), vine column diameter (X2), support height (X3), support diameter (X4), spike peduncle length (X11) and underdeveloped berries per spike (X14) had smaller loading effects and less influence on yield variability.

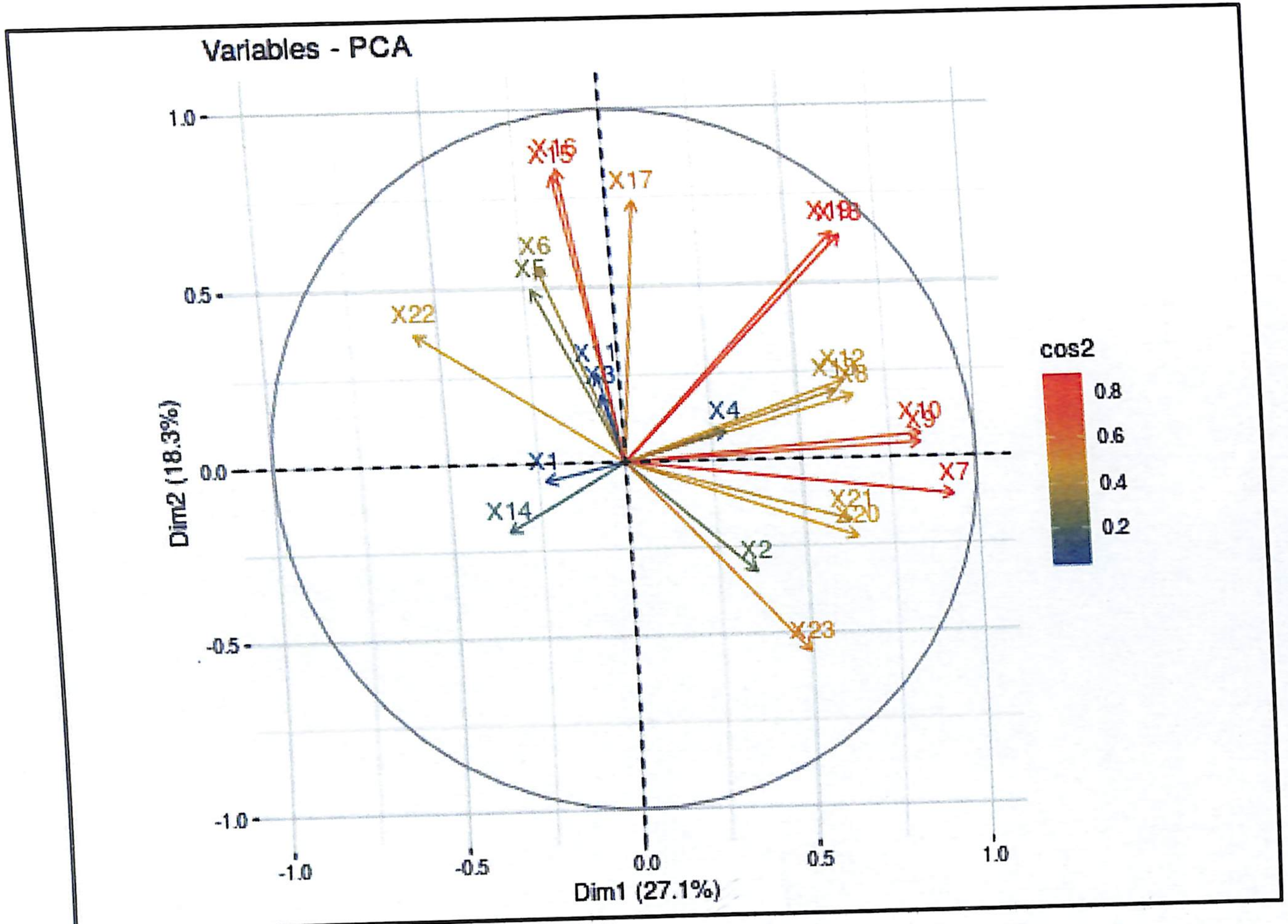
A score plot showing distribution of selected twenty one black pepper genotypes based on PC1 and PC2 is given in Figure 3. The selected genotypes were assembled into fifteen clusters based on the score plot. The listing of the constituent members of the fifteen quantitative clusters is given in Table 22. The distribution of 21 genotypes into 15 clusters was at random with maximum number of genotypes in cluster III and cluster VIII (3 each). Cluster II and Cluster VII were found to be the second largest with 2 genotypes each. All other clusters had one genotype each. Summary of mean performance of yield and yield attributing traits contributed in PC1 and PC2 of fifteen clusters is presented in Table 23. The mean maximum fresh spike yield and fresh berry yield were recorded from Cluster XII (G_{15} Kuthiravally), followed by Cluster XV (G_{21} Panniyur 1). Mean number of spikes per vine, number of spikes per 30 cm^2 and number of nodes per lateral were high in G_{14} (Jeerakamunda).

The mean juvenile leaf length was highest in Cluster V (G_5 Nadan). Mean leaf length was found to be highest in cluster XV (G_{21} Panniyur 1) whereas, mean leaf width was highest in Cluster I (G_1 Wayandan).

A biplot was plotted for the visualization of the results of PCA (Fig. 4) which optimally represented the distance between the observed quantitative characters and also the relationship between the selected genotypes and observed quantitative characters. In the present study, the biplot between PC1 and PC2 was plotted by using the variability of all 23 yield and yield related variables. The biplot showed the distribution of genotypes based on both PCs. The variables with higher values were located away from the origin. As per the biplot, the variability for yield among the selected genotypes was mainly influenced by the variables such as juvenile leaf length (X7), leaf petiole length (X8), leaf length (X9), leaf width (X10), spike length (X12), number of well developed berries/spike (X13), number of spikes per lateral branch (X15), number of spikes per 30 cm^2 (X16), fresh spike yield per vine (X18), fresh berry per vine (X19), bulk density (X22) and berry diameter (X23). The bulk density (X22) was strongly negatively correlated to berry diameter (X23), indicated by the vectors of these two variables pointed in opposite directions. The biplot showed maximum variability for G_1 (Wayanadan), G_4 (Nadeshan), G_5 (Nadan), G_{15} (Kuthiravally) and G_{21} (Panniyur 1) in positive quadrants and were identified as genotypes with high yield. The most important characters which contributed yield variability in G_1 (Wayanadan) were hundred fresh berry weight (X20) and hundred fresh berry volume (X21). Yield variability in G_4 (Nadeshan) was contributed by berry diameter (X23). High yield in G_5 (Nadan) was due to yield related traits like spike length (X12), number of well developed berries/spike (X13) and leaf petiole length (X8). G_{15} (Kuthiravally) was influenced by number of spikes per vine (X17). The most important characters contributed yield variability in G_{21} (Panniyur 1) were leaf length (X9) and leaf width (X10). The negative quadrants exhibited maximum variability for yield contributing characters and G10 (Thulamundi), G14 (Jeerakamunda) and G17 (Arimulak) exhibited maximum variability and were the low yielding ones among the selected genotypes.

Table 22. Clustering based on yield and yield attributing traits in selected black pepper genotypes

Cluster number	Number of genotypes	Cluster members
I	1	G_1 (Wayanadan)
II	2	G_2 (Chumala) G_{18} (Padappan)
III	3	G_3 (Vellayaranmunda) G_6 (Karimunda) G_{20} (Narayakodi)
IV	1	G_4 (Nadeshan)
V	1	G_5 (Nadan)
VI	1	G_7 (Neelamundi)
VII	2	G_8 (Cheppukulamundi) G_{16} (Kottanadan)
VIII	3	G_9 (Vattamundi) G_{11} (Manjamunda) G_{12} (Chengannurkodi)
IX	1	G_{10} (Thulamundi)
X	1	G_{13} (Vellanamban)
XI	1	G_{14} (Jeerakamunda)
XII	1	G_{15} (Kuthiravally)
XIII	1	G_{17} (Arimulak)
XIV	1	G_{19} (Karivilanchy)
XV	1	G_{21} (Panniyur 1)



X1- Vine column height
X2- Vine column diameter
X3- Support height
X4- Support diameter
X5- Lateral branch length
X6- Number of nodes per lateral branch
X7- Juvenile leaf length
X8- Leaf petiole Leaf
X9- Leaf length
X10- Leaf width
X11- Spike peduncle length
X12- Spike length
X13- Number of well developed berries per spike
X14- Number of underdeveloped berries per spike
X15- Number of spikes per lateral branch
X16- Number of spikes per 30 cm^2
X17- Number of spikes per vine
X18- Fresh spike yield per vine
X19- Fresh berry yield per vine
X20- Hundred fresh berry weight
X21- Hundred fresh berry volume
X22- Bulk density
X23- Berry diameter

Fig. 2. Loading plot showing distribution of 23 variables in PC1 and PC2

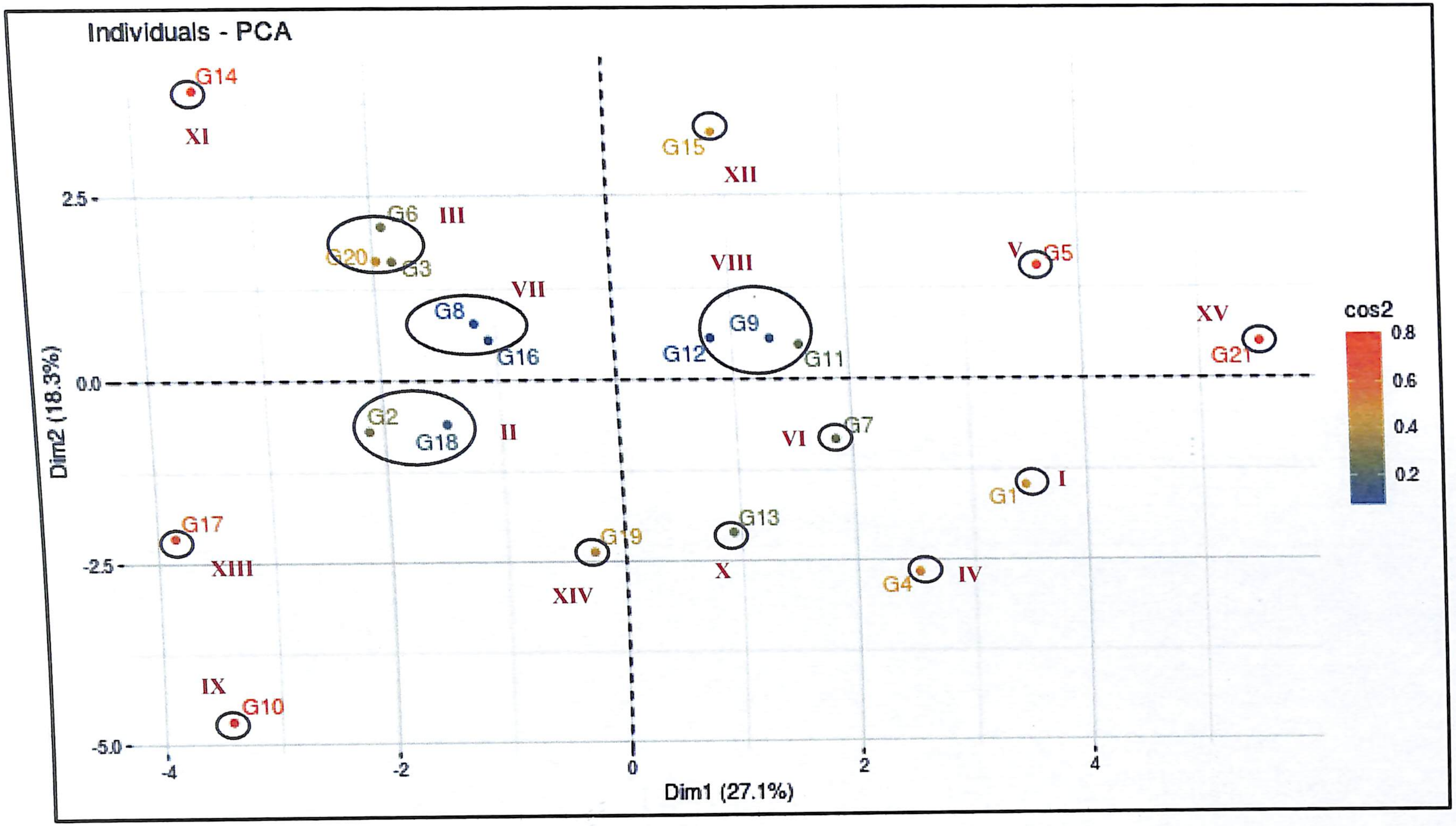


Fig. 3. Score plot showing clusters

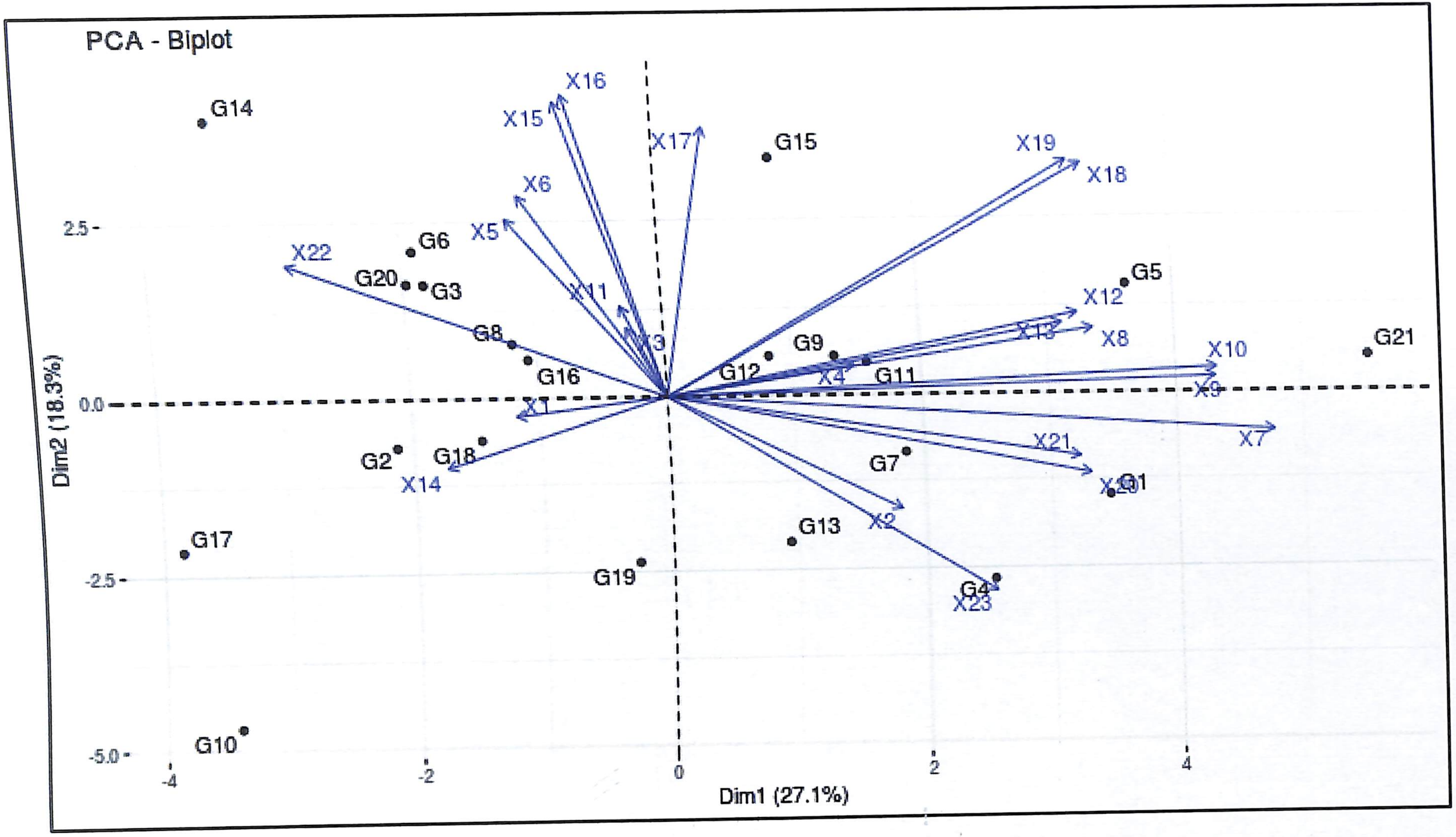


Fig. 4. Biplot of 21 genotypes across PC 1 and PC2 of yield and yield related trait

Table 23. Mean performance of yield and yield attributing traits of clusters

Variables	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	XIII	XIV	XV
Number of nodes per lateral branch	5.2	9.63	17.83	8.96	12.74	12.5	17.81	13.09	6.4	22.23	24.2	20.14	11.4	8.25	12.01
Juvenile leaf length (cm)	6.5	4.78	4.72	7.4	6.8	5.6	4.76	5.90	4.25	5.7	3.5	5.75	4.2	5.01	7.5
Leaf length (cm)	16.01	10.77	12.51	17.01	16.2	15.25	11.31	14.29	8.5	15.2	9.52	15.4	9.1	14.14	17.25
Leaf width (cm)	14.63	6.35	7.25	12.42	14.3	8.5	7.8	7.33	7.0	7.31	6.54	11.5	6.5	6.8	15.5
No. of spikes per 30 cm^2	40.75	44.02	46.78	24.74	40.34	31.02	40.64	35.15	19.15	34.78	57.12	44.44	29.41	18.69	38.17
No. of spikes per vine	449	396.5	485.33	345	452	414	463.5	390.67	320	375	542	423	303	398	478
Fresh spike yield per vine (kg)	3.2	3.52	3.43	3.35	3.7	3.4	3.3	3.6	2.3	3.15	3.2	4.6	2.45	3	4.1
Fresh berry yield per vine (kg)	2.95	3.0	2.65	2.55	3.1	2.83	2.8	2.97	1.45	2.5	2.6	3.9	1.9	2.25	3.5

4.2.9.2 Minimum Data Set Characters for Black Pepper

From the 23 yield and yield related characters of selected black pepper genotypes, characters with higher percentage contribution in first seven principal components were selected for generating minimum data set (MDS) for black pepper. The characters such as juvenile leaf length (13.22% in PC1), leaf length (13.39% in PC1), leaf width (13.44% in PC1), number of spikes/30 cm^2 (16.54% in PC1), number of spikes/lateral branch (14.76%), number of spikes/vine (13.09%), number of nodes/lateral branch (14.99% in PC3), number of well developed berries/spike (15.49% in PC4), support height (13.13% in PC5), vine column diameter (13.58 % in PC6) and berry diameter (14.83% in PC7) had high contribution on yield variability. The correlation between the variables was worked out and when the correlation of selected variables was <0.6, both the variables were selected whereas when correlation was >0.6, highly weighed variables were selected. Only four characters were found finally, after rejecting the remaining variables based on the correlation values. Number of nodes per lateral, number of well developed berries/spike, number of spikes/30 cm^2 and berry diameter were selected for developing minimum data set for black pepper.

4.2.9.3 Principal Component Analysis of Physiological Parameters

Physiological parameters such as leaf thickness, relative water content, epicuticular wax, specific leaf area and stomatal density were statistically analyzed using PCA. Only the first principal component was significant (eigenvalue >1) and contributed to 73.34% of the variance (Appendix IV). The remaining 4 axes contributed 26.66 per cent of the variability. Loadings and percentage contribution of each physiological parameters on PC1 are depicted in Table 24. The direction of contribution of different traits in the different principal components is shown in Figure 5. Parameters such as leaf thickness (0.43), relative water content (0.45) and epicuticular wax (0.44) were positively loaded whereas specific leaf area (-0.45) and stomatal density (-0.48) were negatively loaded in the biplot. The coefficient of the parameters regardless its sign, will be effective in discriminating the genotypes. Higher the coefficient more will be the effectiveness. Results from the PCA indicated that stomatal density had high percentage

(22.88%) contribution on variability for drought tolerance among the selected genotypes, followed by specific leaf area (20.12%). But these two parameters contributed drought tolerance in a negative direction. The variables such as leaf thickness, relative water content and epicuticular wax contributed drought tolerance in a positive direction and among these relative water content had the highest percentage (19.76%) of contribution on variability for drought tolerance, followed by epicuticular wax (18.99%) and leaf thickness (18.25%). The variables such as leaf thickness and relative water content were strongly correlated each other while specific leaf area and epicuticular wax were negatively correlated each other. All the studied variables had significant influence on drought tolerant trait variability.

The selected genotypes were assembled into sixteen clusters based on the biplot. The listing of the constituent members of the sixteen clusters is given in Table 25. The maximum number of genotypes were in Cluster I and Cluster IV (3 each), followed by Cluster IX (2). All other clusters had one genotype each. Summary of mean performance of drought tolerance attributing traits of sixteen clusters is presented in Table 26. The positively loaded variables such as leaf thickness, relative water content and epicuticular wax were highest in Cluster XII (G_{16} Kottanadan) whereas, the negatively loaded variables specific leaf area and stomatal density were lowest.

The biplot between PC1 and PC2 was plotted by using the variability of five physiological parameters. The biplot shows the distribution of genotypes based on both PCs. The biplot showed maximum variability for G_{16} (Kottanadan) and G_{13} (Vellanamban) in the positive quadrants indicating that these are drought tolerant genotypes. The other drought tolerant genotypes clearly revealed from PCA are G_6 (Karimunda), G_7 (Neelamundi), G_{18} (Padappan) and G_{20} (Narayakodi) which are all exhibited in quadrant I and IV contributed by three variables such as leaf thickness, relative water content and epicuticular wax. All the remaining genotypes were drought susceptible ones.

Table 24. Loadings of each variable and percentage contribution of variables on PC1

Sl. No.	Variables	Loadings of each variable on PC1	Percentage contribution of variables on PC1
1	Leaf thickness	0.43	18.25
2	Relative water content	0.45	19.76
3	Epicuticular wax	0.44	18.99
4	Specific leaf area	-0.46	20.12
5	Stomatal density	-0.48	22.88

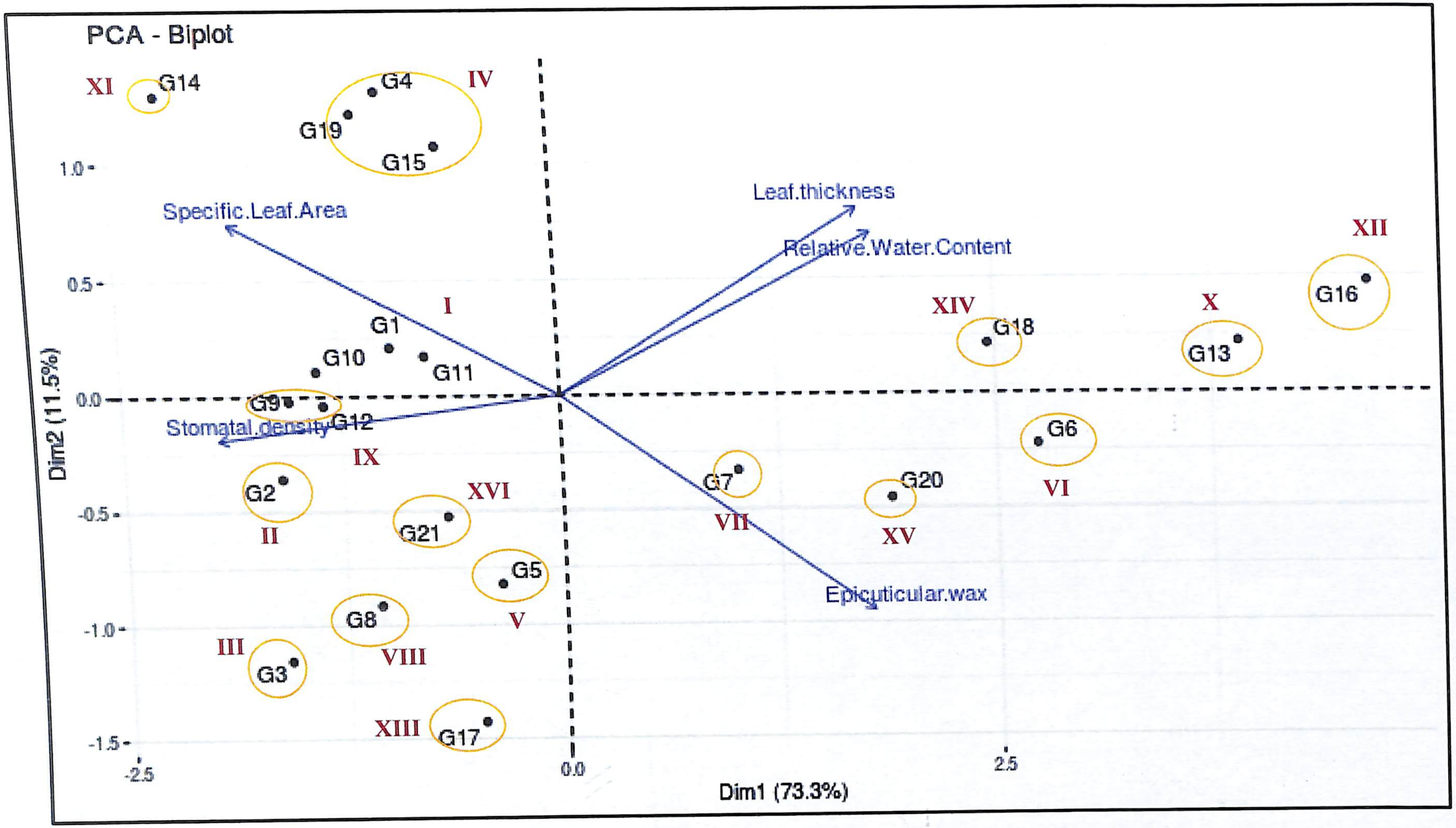


Fig. 5. Biplot of 21 genotypes across PC1 and PC2 of physiological parameters

Table 25. Clustering based on physiological parameters in black pepper genotypes

Cluster number	Number of genotypes	Cluster members
I	3	G_1 (Wayanadan) G_{10} (Thulamundi) G_{11} (Manjamunda)
II	1	G_2 (Chumala)
III	1	G_3 (Vellayaranmunda)
IV	3	G_4 (Nadeshan) G_{15} (Kuthiravally) G_{19} (Karivilanchy)
V	1	G_5 (Nadan)
VI	1	G_6 (Karimunda)
VII	1	G_7 (Neelamundi)
VIII	1	G_8 (Cheppukulamundi)
IX	2	G_9 (Vattamundi) G_{12} (Chengannurkodi)
X	1	G_{13} (Vellanamban)
XI	1	G_{14} (Jeerakamunda)
XII	1	G_{16} (Kottanadan)
XIII	1	G_{17} (Arimulak)
XIV	1	G_{18} (Padappan)
XV	1	G_{20} (Narayakodi)
XVI	1	G_{21} (Panniyur 1)

Table 26. Mean performance of clusters based on physiological parameters

Clusters	Leaf thickness	Relative water content	Epicuticular wax	Specific leaf area	Stomatal density
I	0.25	93.58	1.54	218.78	11.4
II	0.26	91.54	1.51	198.52	12.4
III	0.24	92.10	1.61	200.3	13.5
IV	0.3	93.51	1.53	234.49	11.79
V	0.28	92.2	1.7	213.25	11.6
VI	0.31	97.11	1.75	167.56	9.5
VII	0.30	94.0	1.68	190.14	10.2
VIII	0.21	93.52	1.64	216.89	11.6
IX	0.27	92.69	1.61	235.46	12.45
X	0.32	93.69	1.57	231.12	12.4
XI	0.25	92.8	1.72	200.12	12.4
XII	0.35	98.41	1.82	160.25	8.01
XIII	0.33	96.4	1.70	168.4	10.05
XIV	0.29	94.6	1.52	230.2	12.4
XV	0.31	95.4	1.78	190.56	10.1
XVI	0.24	93.2	1.67	230.41	10.80

4.2.9.4 Principal Component Analysis of Quality Attributes

Quality attributes such as piperine, oleoresin, essential oil, starch, crude fibre and total ash were statistically analyzed using principal component analysis. Two principal components (eigenvalue >1) contributed to 66.62% of the variance as revealed from PCA (Appendix V). The remaining 4 axes contributed 33.38 per cent of the variability. The component loading of each variable on principal components is given in Table 27. Variables such as oleoresin (0.58), crude fibre (0.57), piperine (0.46) and essential oil (0.29) contributed high variability in PC1. Starch and total ash were highly loaded in PC2 with loading value of -0.63 each. The contribution of piperine (-0.36) and essential oil (0.28) were also high in PC2. The percentage contribution of biochemical variables on principal components is depicted in Table 28. The relative contribution of piperine, oleoresin, essential oil and crude fibre were 20.87%, 33.38%, 8.6% and 32.95%, respectively.

The genotypes were grouped into seventeen clusters based on score plot (Figure 6). The listing of the constituent members of the seventeen clusters is given in Table 29. Cluster V had maximum number of genotypes (3). Cluster I and Cluster IX were found to be the second largest with 2 genotypes each. All other clusters had one genotype each. Summary of mean performance of quality attributing traits contributed in PC1 and PC2 of seventeen clusters is presented in Table 30. The Cluster XIII (G_{16}, Kottanadan) had highest piperine content (5.6%) among all, followed by Cluster XVII (G_{21}, Panniyur 1) (5.2%). Oleoresin content was highest (13.2%) in Cluster XIII (G_{16}, Kottanadan), followed by Cluster XII (G_{15}, Kuthiravally) (10.9%). The Cluster XII (G_{15}, Kuthiravally) had high essential oil content (4.5%), followed by Cluster IV (G_6, Karimunda). Cluster XVII (G_{21}, Panniyur 1) had high starch content (38.40%), followed by Cluster XV (G_{19}, Karivilanchy). Crude fibre content was high in Cluster XIII (G_{16}, Kottanadan) (14.26%), followed by Cluster X (G_{12}, Chengannurkodi) (12.8%). The total ash content was highest in XVII (G_{21}, Panniyur 1) (5.5%), followed by Cluster III (G_3, Vellayaranmunda) and Cluster XI (G10, Thulamundi and G11, Manjamunda) (5.4%).

Table 27. Loadings of each variable on PC1 and PC2

Sl. No.	Variables	PC1	PC2
1	Piperine	0.46	-0.36
2	Oleoresin	0.58	-0.03
3	Essential oil	0.29	0.28
4	Starch	0.08	-0.63
5	Crude fibre	0.57	0.063
6	Total ash	-0.19	-0.63

Table 28. Percentage contribution of variables on PCs

Sl. No.	Variables	PC1	PC2
1	Piperine	20.87	13.09
2	Oleoresin	33.38	0.11
3	Essential oil	8.66	7.95
4	Starch	0.68	39.09
5	Crude fibre	32.95	0.39
6	Total ash	3.45	39.36

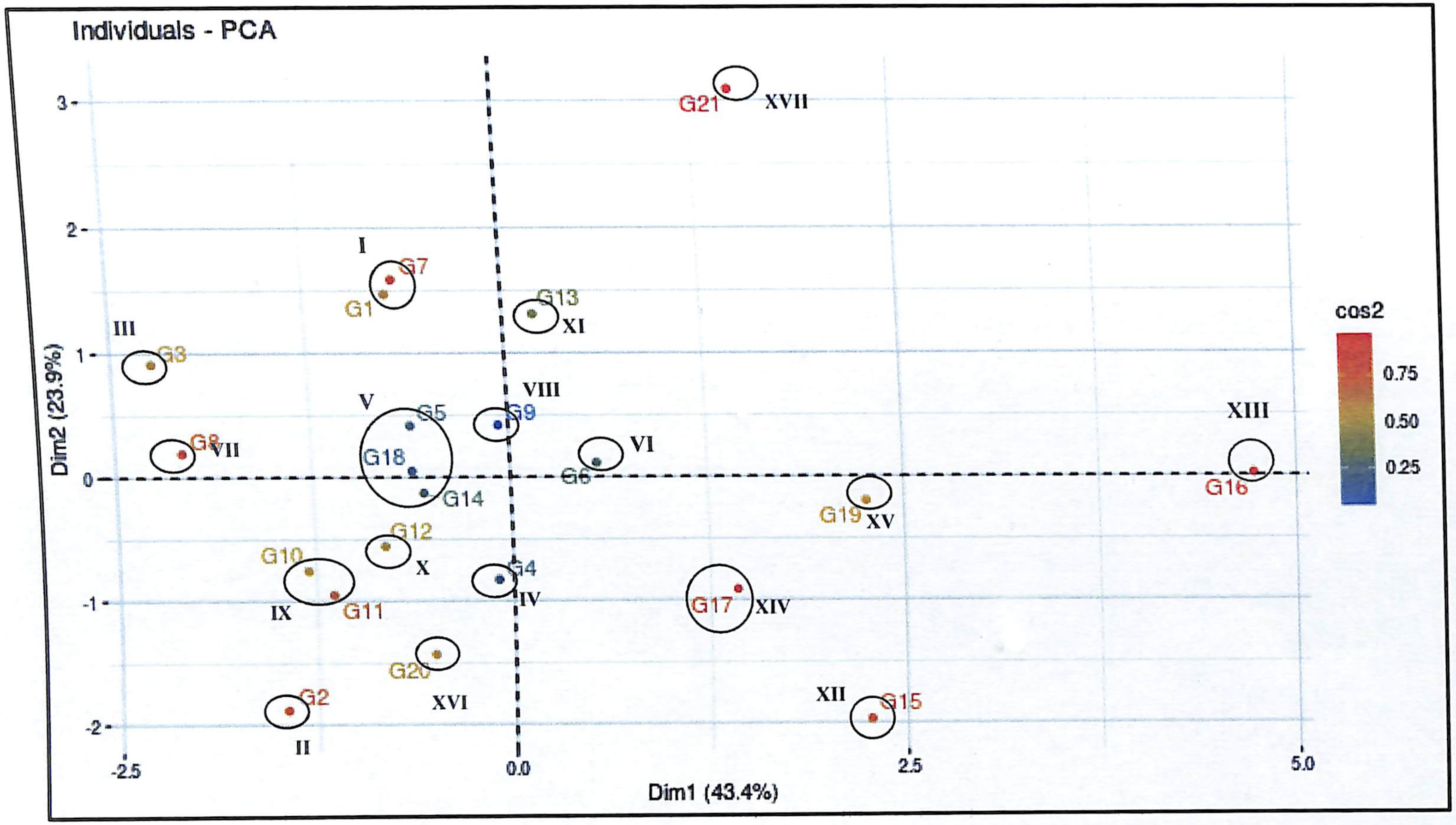


Fig. 6. Score plot showing the clustering of selected genotypes based on quality attributes

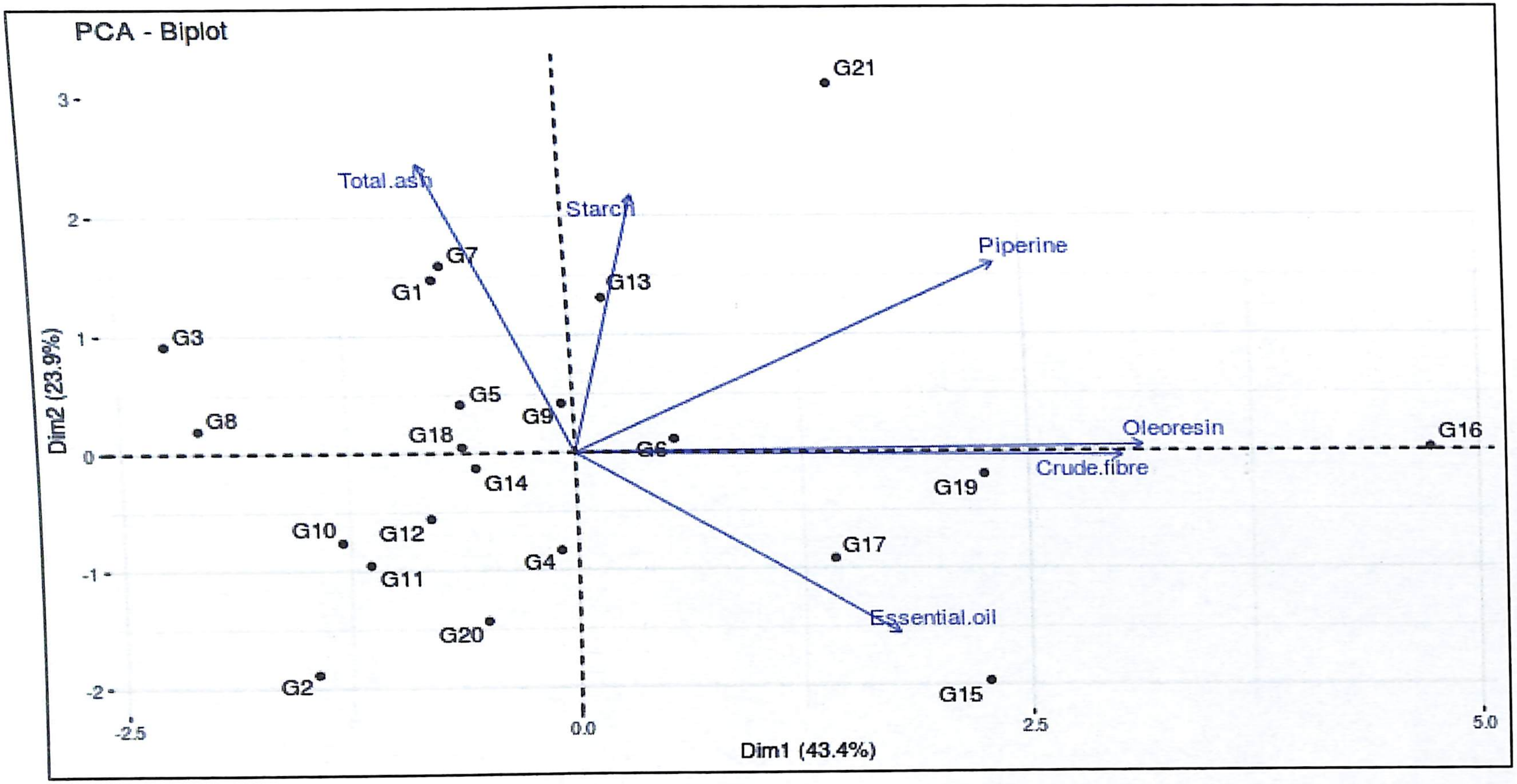


Figure 7. Biplot of 21 genotypes across PC1 and PC2 of quality attribute

Table 29. Clustering selected black pepper genotypes based on quality attributes

Cluster	Number of genotypes	Cluster members
I	2	G_1 (Wayanadan) G_7 (Neelamundi)
II	1	G_2 (Chumala)
III	1	G_3 (Vellayaranmunda)
IV	1	G_4 (Nadeshan)
V	3	G_5 (Nadan) G_{14} (Jeerakamunda) G_{18} (Padappan)
VI	1	G_6 (Karimunda)
VII	1	G_8 (Cheppukulamundi)
VIII	1	G_9 (Vattamundi)
IX	2	G_{10} (Thulamundi) G_{11} (Manjamunda)
X	1	G_{12} (Chengannurkodi)
XI	1	G_{13} (Vellanamban)
XII	1	G_{15} (Kuthiravally)
XIII	1	G_{16} (Kottanadan)
XIV	1	G_{17} (Arimulak)
XV	1	G_{19} (Karivilanchy)
XVI	1	G_{20} (Narayakodi)
XVII	1	G_{21} (Panniyur 1)

Table 30. Mean performance of clusters based on quality attributes

Clusters	Piperine	Oleoresin	Essential oil	Starch	Crude fibre	Total ash
I	4.10	7.70	3.25	37.05	10.70	5.15
II	3.00	6.80	3.80	35.10	10.50	4.20
III	3.90	6.30	3.00	33.00	10.20	5.40
IV	3.06	9.10	3.90	35.50	9.50	5.10
V	3.64	7.37	3.53	35.27	10.24	4.93
VI	4.20	9.30	3.10	33.10	11.70	4.40
VII	3.75	6.40	3.00	33.20	9.20	4.90
VIII	3.40	8.40	3.90	37.00	11.40	5.20
IX	3.53	7.25	3.35	34.15	10.55	4.50
X	3.90	7.40	3.80	34.00	12.80	4.20
XI	3.40	7.80	3.80	37.40	10.60	5.40
XII	3.90	10.90	4.50	33.20	12.40	4.70
XIII	5.60	13.20	3.80	34.40	14.26	4.50
XIV	4.21	10.30	3.70	33.60	12.10	4.60
XV	4.50	10.50	3.70	38.00	12.50	4.10
XVI	3.60	8.90	3.20	34.00	10.10	4.20
XVII	5.20	10.30	3.40	38.40	11.60	5.50

4.2.9.5 Selection of Genotypes Based on Quantitative Characters

The selected twenty one black pepper genotypes did not show significant yield variability as revealed from the ANOVA. However, the principal component analysis revealed five genotypes as high yielding ones viz., G_1 (Wayanadan), G_4 (Nadeshan), G_5 (Nadan), G_{15} (Kuthiravally) and G_{21} (Panniyur 1). All these genotypes had medium to long, broad, cordate leaves and close setting of berries on spike. G_{21} (Panniyur 1) had highest number of well developed berries, high berry diameter and high fresh berry yield. G_{15} (Kuthiravally) had high spike length and high fresh spike yield among all the studied genotypes.

Principal component analysis for physiological parameters clearly revealed six genotypes such as G_{16} (Kottanadan), G_{13} (Vellanamban), G_6 (Karimunda), G_7 (Neelamundi), G_{18} (Padappan) and G_{20} (Narayakodi) as the drought tolerant ones. Leaf thickness, relative water content and epicuticular wax were highest G_{16} (Kottanadan), followed by G_{13} (Vellanamban). Specific leaf are and stomatal density were lowest in G_{16} (Kottanadan).

The high quality genotypes observed were G_{16} (Kottandan), G_{15} (Kuthiravally), G_{21} (Panniyur 1), G_{19} (Karivilancy), G_{17} (Arimulak), G_{13} (Vellanamban) and G_6 (Karimunda). G_{16} (Kottanadan) had highest piperine, oleoresin and crude fibre content among all the selected genotypes. The essential oil content was highest in G_{15} (Kuthiravally). G_{21} (Panniyur 1) had highest starch content, followed by G_{19} (Karivilanchy). The total ash content of G_{21} (Panniyur 1) was the highest, followed by G_{13} (Vellanamban).

DISCUSSION

5. DISCUSSION

The genus *Piper* includes the world's most valuable and economically important spice crop, black pepper (*Piper nigrum* L.), also known as the 'King of Spices'. The primary centre of origin of black pepper is the Western Ghats of the Indian peninsula (Ravindran, 2000). Black pepper grows well in the hot and humid climate of the sub mountainous tracts of Western Ghats (Joy *et al.,* 2007). Kerala, India's southernmost state, covers a large part of the Western Ghats.

Due to its popularity and innate quality, Indian black pepper earns a premium price in the international market (Thomas, 2010). The local cultivars of Kerala have good quality attributes, though they yield less. To satisfy the industrial and global demand for high quality pepper an attempt was made to identify the black pepper genotypes from the main black pepper growing areas of Kerala by their quality. The results of the experiment entitled "Characterization and quality analysis of black pepper (*Piper nigrum* L.) genotypes of Kerala" conducted during 2020-2021 are discussed in this chapter.

5.1. SURVEY

All traditional black pepper growing areas of Kerala have their own popular cultivar (Prasannakumari *et al.*, 2001). Survey conducted in locations where black pepper is widely cultivated can provide unique gene sources that can be employed in crop improvement of black pepper or can be directly used (Saji *et al.,* 2013). In this study, purposive survey carried out in fourteen locations, including black pepper plantations and homestead gardens of Kerala, especially AEU 3 (Onattukara Sandy Plains) of Alappuzha, AEU 4 (Kuttanad) of Kottayam, AEU 8 (Southern Laterites) of Thiruvananthapuram, AEU 12 (Southern and Central Foothills) and AEU 14 (Southern High Hills) of Idukki and AEU 21 (Wayanad Eastern Plateau) of Wayanad, identified twenty one genotypes. Fifty plants were surveyed and from those, twenty one genotypes were selected based on special characters such as vigorous vine nature, good fruit set, high spiking intensity, close berry setting, long spikes, regular yield, early maturity, high yield, staggered flowering, bold berries, suitability in higher elevation, open and shade conditions and good sensory characteristics.

The brief passport data of the selected twenty one black pepper genotypes identified as G_1 (Wayanadan), G_2 (Chumala), G_3 (Vellayaranmunda), G_4 (Nadeshan), G_5 (Nadan), G_6 (Karimunda), G_7 (Neelamundi), G_8 (Cheppukulamundi), G_9 (Vattamundi), G_{10} (Thulamundi), G_{11} (Manjamunda), G_{12} (Chengannurkodi), G_{13} (Vellanamban), G_{14} (Jeerakamunda), G_{15} (Kuthiravally), G_{16} (Kottanadan), G_{17} (Arimulak), G_{18} (Padappan), G_{19} (Karivilanchy), G_{20} (Narayakodi) and G_{21} (Panniyur 1) (Table 2a, 2b, 2c, 2d, 2e and 2f) revealed that the genotypes were selected both from plains and high range areas at an altitude of 13 m above MSL to 880 m above MSL. The selected genotypes were from a latitude of 8°42'96" to 11°65'47" and of longitude 76°17'39" to 77°06'24". A survey conducted by Prasannakumari *et al.* (2001) in the homesteads of Thodupuzha and Meenachil taluks of Kerala reported Karimunda, Narayakody, Neelamundi, Kaniyakkadan, Mundi, Panniyur 1, Nedumchola, Perumkody and Jeerakamunda as the major pepper cultivars growing there. In a study conducted by Saji *et al.* (2013), a unique black pepper accession with a very long spike from a coffee plantation in the Coorg district of Karnataka was reported. Sasikumar *et al.* (2013) reported a rare accession with high dry recovery and bulk density with round, bold and attractive black corns. Observations on the major biochemical parameters such as piperine, oleoresin and essential oil suggested that this was an accession of high quality. A trait specific survey conducted by Sasikumar *et al.* (2014) reported two unique black pepper accessions having very long spikes with poor setting from Coottanadu Estate, Wayanad. Shivakumar *et al.* (2019) conducted surveys in Madikeri black pepper plantations to collect black pepper germplasm and collected 31 accessions among which four unique genotypes having long spike up to 30 cm, trimonoecious flowers, sweet type/low pungency and Vadakkan (triploid) with elongated leaves. The black pepper accession with sweet berries (less pungent) would be a good source for evolving sweet black pepper genotypes or for product diversification.

The survey conducted revealed fast genetic erosion in genotypes G_{16} (Kottandan), G_{18} (Padappan) and G_{19} (Karivilachy). The other genotypes represented intermediate and slow genetic erosion. A field survey undertaken by Mathew *et al.*

(2005) revealed that the genetic base of black pepper has been shrinking over the years mainly due to gene erosion by fast disappearance of many landraces from cultivation. A significant proportion of landraces and wild forms of black pepper are under threat of extinction especially the low yielding ones which are being replaced by farmers on their farms with improved cultivars. The introduction of enhanced varieties of black pepper causes a danger to many of the older cultivars. These landraces may be lost forever unless collected and conserved (Saji *et al.,* 2019). Though on the one hand genetic erosion due to the spread of high yielding varieties and rampant destruction of the natural habitat is a fact in this spice, self-grown seedlings in black pepper plantations remain an untapped source of variation (Shivakumar *et al.*, 2019).

5.2. CHARACTERIZATION AND QUALITY ANALYSIS OF SELECTED BLACK PEPPER GENOTYPES

5.2.1. Morphological characterization

According to Bekele *et al.* (2006), morphological characterization is used to generate economic and breeding benefits from germplasm collection. It has been a standard method for identifying and describing distinct black pepper germplasm (Hussain *et al.*, 2017b; Bermawie *et al.*, 2019; Prayoga *et al.*, 2020).

Traditional classification of black pepper genotypes has been based on plant characteristics such as leaf length, leaf breadth, shoot tip colour, leaf shape, features of the leaf tip and base, berry size, spike length, spike composition (bisexual, female, and male), fruit set, number of fruits/spike, 1000 fruit volume, 1000 fruit weight, yield/ vine, and dry recovery. Quality parameters such as piperine, oleoresin and essential oil were also used (Sreedevi *et al.*, 2005).

In order to characterize the genotypes morphologically, both quantitative and qualitative characters were recorded in the present investigation.

5.2.1.1. Qualitative characters

The qualitative characters observed in the selected genotypes included plant, leaf, inflorescence, fruit and seed characters. Only twenty two of the thirty four qualitative features exhibited variability among selected black pepper genotypes. Characters such as runner shoot production, pubescence on the stem, type of veining, leaf texture, spike colour, spike orientation, spike shape, spike fragrance, spike proliferation, colour change during fruit ripening, fruit taste and seed texture were all uniform among all genotypes.

5.2.1.1.1. Plant characters

Plant characters like shoot tip colour, lateral branch pattern, lateral branch length and number of nodes per lateral branch were shown to have variability in this study (Table 3a, 3b).

The runner shoot tip colour of black pepper is an essential flag characteristic of black pepper cultivars and it was discovered to be regulated by two sets of genes having complementary action (Ravindran *et al.*, 1992a). The shoot tip colour of runner shoots observed in the selected twenty one black pepper genotypes were light green, light purple and dark purple. The majority of the genotypes had (76.19%) light purple colour shoot tips. Prakash *et al.* (2020) found similar results with 50 black pepper accessions, reporting that the majority of them (66%) exhibited light purple shoot tips.

The shoot tip colour of G_{21} (Panniyur 1) was observed to be light green and that of G_7 (Karimunda) was light purple in the present study. Similar shoot tip colour on these genotypes were reported in the DUS guidelines by PPVFRA (2009).

The lateral branch pattern observed in the selected black pepper genotypes included semi-erect, horizontal and hanging. The majority of the genotypes (66.67%) had horizontal branch habit followed by hanging type (23.81%). Semi-erect type of lateral branch pattern which ensured better light penetration was observed for only 9.52 per cent of genotypes. Genotype G_7 (Neelamundi) showed a horizontal lateral branch pattern in this investigation, which was also supported by DUS guidelines (PPVFRA, 2009). Panniyur-1 was described as having hanging lateral branch habit (Hussain *et al.* 2016, 2017a). Prakash *et al.* (2020) reported that the majority of the black pepper accessions included in their study exhibited horizontal lateral branch pattern and erect type of lateral branch habit was observed in only 20% of the accessions.

The lateral branch length and number of nodes per lateral branch was found to be variable among the selected genotypes. Expressions of lateral branch length were short, medium and long. The number of nodes per lateral branch ranged from few to medium. As per DUS guidelines, cultivar Pannalkodi had short laterals, Perumkodi had medium laterals, variety IISR Thevam had long laterals and cultivar Vadakkan had few nodes per lateral branch, Kanjirakkodan had medium nodes and IISR Thevam had many number of nodes per lateral branch (PPVFRA, 2009).

5.2.1.1.2. Leaf characters

Variability was found among the genotypes on leaf characters such as leaf lamina shape, leaf base shape, leaf margin, juvenile leaf length, leaf length, leaf width and leaf petiole length (Table 5a, 5b).

The shape and size of the leaf lamina vary greatly in black pepper. The shape of the leaf lamina may be ovate, ovate elliptic, ovate lanceolate, elliptic lanceolate or cordate. The leaf base may be round, cordate, acute or oblique. The leaf margins are either even or wavy (Ravindran *et al.*, 2000b).

The genetics of black pepper leaf shape has been found to be of three fundamental shapes such as cordate, ovate and oblong elliptical, which are all governed by multiple alleles (Sasikumar *et al.*, 1992). There noted some variation in these basic classes in this study. In majority of genotypes leaf lamina shape was ovate-lanceolate (28.57%) and cordate (28.57%), followed by ovate (23.81%) and ovate-elliptic (19.05%). The leaf base shapes recorded include acute, round and cordate. Krishnamurthy *et al.* (2000) reported that leaf characters form a major feature for cultivar identification in black pepper. Prakash *et al.* (2020) reported oval, ovate-elliptical, ovate-lanceolate, cordate and elliptic-lanceolate leaf shapes and acute, round and cordate leaf bases in black pepper.

The types of leaf margin observed among the selected genotypes were even and wavy. Nineteen genotypes (90.48%) possessed even leaf margin and two genotypes showed wavy leaf margins. In the present study, G_{12} (Chengannurkodi) and G_{20} (Narayakodi) had wavy leaf margin. The wavy leaf margin of Narayakodi genotype was also mentioned by PPVFRA (2009) in DUS guidelines. Prakash *et al.* (2020) found even type of leaf margin in all the fifty accessions they studied.

The studied black pepper genotypes were grouped into short, medium and long based on the length of the leaf petiole. Majority of the selected genotypes were under the category medium. Genotypes such as G_7 (Neelamundi), G_{15} (Kuthiravally) and G_{21} (Panniyur 1) possessed long leaf petioles. Similar result in cultivar Neelamundi was given in DUS guidelines (PPVFRA, 2009).

The selected genotypes were classified into short, intermediate and long based on length of juvenile leaf as per IPGRI descriptor. Majority of the selected genotypes (52.38%) showed medium juvenile leaf length. Genotypes with short, medium and long leaves were observed among the twenty one genotypes. Majority of the genotypes (52.38%) produced medium leaves. As per DUS guidelines, Nedumchola had short leaves, Subhakara had medium leaves and Balankotta had long leaves (PPVFRA, 2009).

The genotypes were classified into narrow, medium and broad based on the width of the leaf. Majority of the genotypes (42.86%) were medium. G_{21} (Panniyur 1) had broadest leaf among all genotypes. PPVFRA (2009) also reported broad leaves in Panniyur 1.

5.2.1.1.3. Inflorescence, fruit and seed character

Variability was found among the genotypes on characters like spike twisting, spike setting, berry shape, berry size, seed shape, spike peduncle length, spike length, number of berries/spike, number of spikes/spike, number of spikes/laterals, bulk density and time of harvest maturity (Table 7a, 7b and 7c). Among the selected black pepper genotypes, spike twisting was present in G_{16} (Kottanadan) and G_{20} (Narayakodi). As per DUS guidelines, Aimpiriyan had twisted spikes (PPVFRA, 2009).

The genotypes were grouped into loose and compact based on the extent of compactness of the berries. Majority of the selected genotypes (85.71%) had compact spike setting. Three genotypes G_8 (Cheppukulamundi), G_{10} (Thulamundi) and G_{14}

(Jeerakamunda) possessed loose spike setting. As per DUS guidelines, Vadakkan had loose and Aimpiriyan had compact spike setting (PPVFRA, 2009).

The berry shape was round for all genotypes with the exception of oval shape for the genotypes G_{20} (Narayakodi) and G_{19} (Karivilanchy). Berry shape of Karivilanchy was also reported as oval in DUS guidelines (PPVFRA, 2009).

Velayudan *et al.* (2006) observed oval shaped berries among seven accessions they have studied. Prakash *et al.* (2020) observed oval shaped fruit only in one accession out of 50 accessions they studied which was similar to *Piper attenuatum*, a wild relative of *Piper nigrum*.

The seed shapes recorded include round and ovate. In majority of genotypes seed shape was round (90.48%) followed by ovate (9.52%). The genotypes which had oval shaped fruits had ovate shaped seeds as observed in G_{20} (Narayakodi) and G_{19} (Karivilanchy).

Fruit shape and size, although strongly associated, are less useful in cultivar delimitation, except in the case of cultivars with clearly defined characteristics, such as the oblong fruit shape of Karivilanchy (Ravindran *et al.*, 1997a).

Three types of berries viz., small, medium and bold were observed among the selected genotypes. Bold berries were seen in G_1 (Wayanadan), G_7 (Neelamundi), G_9 (Vattamundi), G_{13} (Vellanamban), G_{18} (Padappan), G_{19} (Karivilanchy) and G_{21} (Panniyur 1). As per DUS guidelines, Jeerakaumunda produced small berries, Karimunda had medium and Panniyur 1 had bold berries (PPVFRA, 2009). Shango *et al.* (2021) reported a significant variation in spike length, berry size and berries of all genotypes were large.

Genotypes were grouped into short, medium and long based on spike peduncle length. Long spike peduncle was observed in G_9 (Vattamundi). The genotype G_{21} (Panniyur 1) had short peduncle and was similar to the report of PPVFRA (2009) in DUS guidelines.

The spikes can be straight or twisted. Cultivars differ in their spike length. The leaf-spike relationship revealed that the spike length is nearly the same as the leaf length in the majority of cultivars (Ravindaran *et al.*, 2000a). The length of the spikes, the number of berries per spike and the fullness of the spikes vary with the cultivar (Parthasarathy *et al.,* 2007).

Variation in spike length was observed as short, medium and long. Among the twenty one genotypes evaluated, medium spike length was found to be common followed by short and long. Two genotypes such as G_{15} (Kuthiravally) and G_{21} (Panniyur 1) exhibited long spike length. As per DUS guidelines, Panniyur 1 had long spikes (PPVFRA, 2009).

The number of berries per spikes varied from medium to many. Genotypes such as G_4 (Nadeshan), G_5 (Nadan), G_9 (Vattamundi), G_{11} (Manjamunda), G_{15} (Kuthiravally) and G_{21} (Panniyur 1) showed many number of berries per spike. Similar result on the genotype Panniyur 1 was given in DUS guidelines (PPVFRA, 2009).

The selected genotypes were grouped into few, medium and many based on the number of spikes/lateral branch. Few spikes per lateral branches were recorded in G_4 (Nadeshan) and G_{10} (Thulamundi). Perumkodi had few, Panniyur 1 had medium and Subhakara had many (PPVFRA, 2009).

The genotypes were grouped into low, medium and high based on bulk density. Genotypes such as G_{15} (Kuthiravally) and G_{17} (Arimulak) had high bulk density. The genotypes were classified into early, medium and late. Genotypes such as G_{11} (Manjamunda) and G_{17} (Arimulak) exhibited early harvest maturity and G_9 (Vattamundi) showed late harvest maturity. Majority of the genotypes showed medium maturity. As per DUS guidelines, Arakkulammunda showed early, Karimunda had medium and Aimpiriyan had late maturity (PPVFRA, 2009).

5.2.1.2. Non variable characters observed among selected black pepper genotypes

Characters such as runner shoot production, pubescence on the stem, type of veining, leaf texture, spike colour, spike orientation, spike shape, spike fragrance, spike proliferation, colour change during fruit ripening, fruit taste and seed texture were uniform among all the twenty one genotypes.

The selected genotypes showed few runner shoot production. Prakash *et al.* (2020) observed a few runner shoot production in more than half of the genotypes among fifty accessions they have studied. In the present study, pubescence on stem was absent in all the selected genotypes.

The leaf texture of selected genotypes was glabrous coriaceous and leaf venation was campylodromous. According to Ravindran *et al.* (2000b), leaf texture can be glabrous coriaceous, glabrous membraneous, glabrous sarcous, downy membraneous, downy coriaceous or downy along the veins.

The spike colour observed was greenish yellow in all the genotypes. According to Parthasarathy *et al.* (2007), spikes may be light yellow, white or purple. Prakash *et al.* (2020) observed three types of spike colours viz., light yellow, green and greenish yellow, among fifty accessions studied. The selected genotypes showed prostrate type of spike orientation, filiform spike shape and all the genotypes had a spike fragrance. Spike proliferation was absent in all the twenty one genotypes. Shango *et al.* (2021) observed prostate or pendant spike orientation and filiform spikes in black pepper varieties of Morogoro.

The colour change while fruit ripening was observed to be green to yellow, orange and then to red. All the genotypes had spicy fruit taste. The seed texture of all the genotypes were smooth. The similarity of various characters among genotypes could be attributed to accidental crossing over in generations as a result of their coexistence in the wild, sharing common support trees in the natural ecosystem and the conservation of variability due to successful vegetative propagation (Ravindran, 1991).

5.2.1.3. Cluster analysis based on qualitative characters

Cluster analysis is widely applied for the assessment of genetic distance of definite set of genotypes. The application of cluster analysis in taxonomic studies has previously been reported in *Piper* species (Ravindran *et al.*, 1992). According to Chaturvedi *et al.* (2005) high level of polymorphism (96.6%) was reported among the cultivars of *Piper nigrum* L. indicating extensive genetic variation of the Indian germplasm. Mathew *et al.* (2005) reported a significant variability among the black pepper landraces in terms of plant morphological characters, granting them the status of different plant types, each with its own distinctive traits. The morphological variations exhibited by the landraces were stable and determined genetically.

Cluster analysis based on twenty two qualitative characters revealed that all the twenty one genotypes could be grouped into 15 clusters at 73 per cent similarity. The Cluster I comprised of genotype G_1 (Wayanadan) and Cluster II included G_7 (Neelamundi). The Cluster III had two subclusters. Subcluster IIIA included genotypes G_2 (Chumala) and G_6 (Karimunda) and subcluster III B included G_{16} (Kottanadan) alone. The fourth group of cluster comprised of G_3 (Vellayaranmunda). The Cluster V contained G_{13} (Vellanamban) and G_{18} (Padappan). The Cluster VI consisted of two sub Clusters VIA and VIB. G_8 (Cheppukulamundi) and G_{12} (Chengannurkodi) belonged to subcluster VIA and G_{14} (Jeerakamunda) belonged to subcluster VIB. Cluster VII included G_{19} (Karivilanchy), Cluster VIII contained G_{20} (Narayakodi), Cluster IX contained G_{10} (Thulamundi), Cluster X with G_{17} (Arimulak), Cluster XI included G_4 (Nadeshan) and G_5 (Nadan), Cluster XII contained G_{11} (Manjamunda), Cluster XIII with G_{15} (Kuthiravally), Cluster XIV included G_{21} (Panniyur 1) and Cluster XV with G_9 (Vattamundi). The genotype G_9 (Vattamundi) in Cluster XV showed maximum diversity due to dark purple colour for runner shoot tip, semi erect branching pattern, broad and cordate leaf, bold berries and low bulk density. Cluster III and VI had only three genotypes each while Cluster V and XI had two genotypes. The other clusters had only single genotypes showing their divergence in morphological characters considered.

Cluster analysis of fourty four cultivars and seven wild black pepper accessions using twenty two morphological characters identified eleven clusters. Karimunda, Panniyur-1, Vadakkan and Kuthiravally were the cultivars that were unique and did not cluster with any other cultivars. The presence of 28 cultivars in one category further demonstrates that the majority of common cultivars closely mimic one another and most likely have a common origin (Ravindran *et al.*, 1997a). Genetic diversity analysis based on clustering of fifty one cultivars of black pepper was performed by Mathew *et al.* (2001). In a study, fifty accessions were grouped based on morphological similarity. The hierarchical cluster analysis showed that 35 out of 50 black pepper accessions clustered in a single group, which indicated the absence of significant morphological divergence among them (Prakash *et al.,* 2020).

5.2.1.4. Sensory parameters

Quality attributes of black pepper such as flavour, taste and pungency vary among cultivars (Mamatha *et al.*, 2008). People appreciate black pepper for its enticing aroma as well as the typical pungent and tingling orosensory impression (Hailemichael *et al.,* 2009). A sensory evaluation of the selected black pepper genotypes was carried out for the parameters such as appearance, colour, odour, taste and flavour.

Dried berries of genotype G_{13} (Vellanamban) recorded the highest mean score for appearance (8.30) followed by G_{15} (Kuthiravally) (8.0) and G_6 (Karimunda) (7.90). The highest mean score of G_{13} (Vellanamban) might be due to its bold and black colour berries. The lowest mean score (7.10) for appearance was recorded for G_{17} (Arimulak). There was no significant difference among the selected black pepper genotypes for the appearance of the dried berries.

There was a significant variation for colour, odour, taste and flavour among the selected twenty one genotypes. The genotype G_6 (Karimunda) recorded the highest mean (7.8) for colour followed by G_{13} (Vellanamban), G_{14} (Jeerakamunda), G_{16} (Kottanadan) and G_{19} (Karivilanchy) (7.67). The lowest mean score (5.67) for colour was recorded for G_9 (Vattamundi). The highest mean score for colour of G_6 (Karimunda) might be due to its dark brown to black colour. According to Zachariah and Parthasarathy (2008), the appearance in terms of colour was important when black pepper is intended to use as a spice in whole or ground form. The best price is paid for dried peppercorn that is uniformly dark brown to black in colour (Hailemichael *et al.,* 2009).

Powder sample of G_{15} (Kuthiravally) recorded the highest mean score (8.46) for odour followed by G_1 (Wayanadan) and G_7 (Neelamundi) (7.8). The lowest mean score (7.0) for odour was recorded for G_3 (Vellayaranmunda), G_{10} (Thulamundi) and G_{13} (Vellanamban). The biochemical analysis of all the selected genotypes revealed that G_{15} (Kuthiravally) had the maximum percentage of essential oil content. According to

Mathai (1981) aroma of black pepper was due to the essential oil it produced. So, the highest mean score of G_{15} (Kuthiravally) for odour could be attributed to its highest essential oil content (4.5%).

Among the selected genotypes, G_{16} (Kottanadan) recorded the highest mean score (8.47) for taste (pungency) followed by G_{21} (Panniyur 1) (8.01). The lowest mean score (6.2) for taste was recorded for G_2 (Chumala). Genotypes such as G_{16} (Kottanadan) (5.6%) and G_{21} (Panniyur 1) (5.2%) had high piperine content as revealed from the Table 12. Highest mean score for the pungent taste of G_{16} (Kottanadan) and G_{21} (Panniyur 1) would be the result of their highest piperine content since piperine contributes pungency in black pepper.

The highest mean score (8.93) value for flavour was noted in G_{15} (Kuthiravally) followed by G_{16} (Kottanadan) (7.87). The lowest mean score (7.07) for flavour was recorded in G_9 (Vattamundi). According to Dhas *et al.* (2003), oleoresin contributed pungent taste and strong flavour in black pepper. The genotype G_{15} (Kuthiravally) had oleoresin content of 10.90% along with high essential oil content (4.5%). This might be attributed to the highest mean score of G_{15} (Kuthiravally) for flavour. G_{16} (Kottanadan) had the highest oleoresin (13.20%) content among all the genotypes studied. The mean score for flavour of G_{16} (Kottanadan) was 7.87 and this might due to its high oleoresin conent. According to Suhaj (2006), Flavour was an extremely essential determinant in the economy, demand and acceptance or rejection of black pepper.

5.2.1.5. Quantitative characters

5.2.1.5.1. Plant characters

The plant characters recorded include vine column height, vine column diameter, support height, support diameter, lateral branch length and number nodes per lateral branch (Table 13a and 13b).

Black pepper can reach a height of 10 m or more. The mature vine is of columnar appearance and has a height of around 4 m when its height is limited (Purseglove *et al.*, 1981). In the present study the vine length ranged from 4.10 m to 6.10 m. The highest vine height among the selected genotypes was in G_{18} (Padappan). Genotype G_9 (Vattamundi) had the lowest height. The diameter of the vine column varied from 0.53 cm in G_{12} (Chengannurkodi) to 0.94 cm in G_1 (Wayanadan). Prakash *et al.* (2020) reported a variation in vine length of three years old black pepper accessions, where it ranged from 1.6 m to 3.95 m.

Height of the support tree ranged from 12 m to 19.7 m. Height was highest for the support tree of G_{18} (Padappan) and lowest for the support tree of G_6 (Karimunda). The diameter of the support ranged from 16.70 cm to 30.12 cm. Diameter was highest in the support tree of G_{17} (Arimulak) and lowest for the support tree of G_{13} (Vellanamban).

The lateral branch length varied from 27.25 cm in G_{10} (Thulamundi) to 65.20 cm in G_{14} (Jeerakamunda). The number of nodes per lateral branch was observed to be ranged from 5.2 in G_1 (Wayanadan) to 24.2 in G_{14} (Jeerakamunda). The highest number of nodes per lateral branch (24.2) in G_{14} (Jeerakamunda) might be due to the longest lateral branch length reported (65.20 cm). Preethy *et al.* (2018) reported variation in vegetative characters such as vine column height, leaf weight, leaf width and internodal length among the ten black pepper accessions they have studied and Karimunda had the shortest leaf length and width among them. Prakash *et al.* (2020) reported a moderate variability in lateral branch length and wide variation in number of nodes per lateral branch.

5.2.1.5.2. Leaf characters

The leaf characters recorded include juvenile leaf length, leaf petiole length, leaf length and leaf width (Table 14).

According to Ravindran *et al.* (2000), the leaf size varied from 8 to 20 cm in length and 4 to 12 cm in width or longer. In the present study length of the juvenile leaf ranged from 4.1 cm to 7.5 cm. Leaf length ranged from 8.5 cm to 17.25 cm and leaf width ranged from 5.2 cm to 15.5 cm. The size of the leaf lamina varies greatly in black pepper. Juvenile leaf length and leaf length were found to be highest in G_{21} (Panniyur 1) and lowest in G_6 (Karimunda). Leaf width was highest in G_{21} (Panniyur 1) whereas it was lowest in G_2 (Chumala).

The leaf petiole length of the selected genotypes varied from 1.52 cm in G_6 (Karimunda) to 3.51 cm in G_{21} (Panniyur 1). According to Krishnamurthy *et al.* (2000) The mean petiole length of leaves on lateral branches in cultivars ranged between 1.2 cm in Sreekara and Subhakara to 1.9 cm in Girimunda. Mathew *et al.* (2005) reported low intraspecific variability for leaf petiole length and a significant intraspecific variability for leaf length and leaf breadth. Prakash *et al.* (2020) reported wide variability for leaf petiole length and less variability for leaf length and width.

5.2.1.5.3. Inflorescence, fruit and seed characters

Spike characters taken for observation were spike peduncle length, spike length, number of well developed and underdeveloped berries per spike, number of spikes per lateral branch, number of spikes per 30 cm^2, number of spikes per vine, spike yield per vine, berry yield per vine, hundred fresh berry weight, hundred fresh berry volume, bulk density and berry diameter (Table 15a, 15b, 15c and 15d).

The spike peduncle length of selected genotypes ranged from 0.58 cm in G_{13} (Vellanamban) to 2.08 cm G_9 (Vattamundi) with mean value of 1.17 cm and a standard deviation of 0.43, indicating less variability for the trait. Mathew *et al.* (2005) reported low intraspecific variability for spike peduncle length. Prakash *et al.* (2020) reported a peduncle length variation from 0.76 cm to 1.58 cm with a CV value 14.87 indicated less variability.

Black pepper cultivars differed in their spike length (Figure 6). It ranged from 6.5 cm in G_3 (Vellayaranmunda) to 17.5 cm in G_{15} (Kuthiravally) with a mean value of 10.89 cm and a standard deviation of 2.89. A positive and significant influence of spike length on yield was reported by Sujatha and Namboothiri (1995). Spike length is a significant yield contributing character in black pepper and thus amenable to selection (Krishnamurthy *et al.*, 2010).

In the present study, the number of well developed berries per spike varied from 30.12 in G_8 (Cheppukulamundi) to 88.25 in G_{21} (Panniyur 1). In general, cultivars with increased spike length will have more berries/spike. The number of under developed berries ranged from 3.26 in G_{21} (Panniyur 1) to 21.4 in G_8 (Cheppukulamundi) (Figure 7).

According to Ravindran *et al.* (2000b), the number of berries per spike in black pepper normally ranges from thirty to less than a hundred, depending on the variety or hybrid. Krishnamurthy *et al.* (2000) reported that pollination, water, and nutrient availability, pest and disease attack during initial berry development period influence berry number/spike. According to Parthasarathy *et al.* (2007) failure of berry set or undeveloped ovules on pepper varieties has been associated with insuffcient pollination, unfertilized flowers or imperfect fertilization, loss of stigma receptivity before pollination either singly or a combination of these factors.

The number of spikes per lateral branch ranged from 3.24 in G_4 (Nadeshan) to 15.7 in G_{14} (Jeerakamunda). The mean number of spikes/lateral branch was found to be 8.19 with a standard deviation of 3.09. Prakash *et al.* (2020) reported a wide variation in number of spikes per lateral.

The number of spikes per 30 cm^2 ranged from 18.69 in G_{19} (Karivilanchy) to 57.12 in G_{14} (Jeerakamunda), with mean of 37.13 and a standard deviation of 10.34, indicating possibility of selection of genotypes with a greater number of spikes.

Number of spikes per vine ranged from 303 in G_{17} (Arimulak) to 542 in G_{14} (Jeerakamunda). The mean number of spikes per vine was 419.14, with a standard deviation of 64.82. The higher the standard deviation, the higher the variability and it was revealed from the wide range of spikes/vines (303 to 542) (Figure 8).

The pooled mean of fresh spike yield per vine varied from 2.3 kg in G_{10} (Thulamundi) to 3.85 kg in G_{15} (Kuthiravally) with a mean of 3.35 kg and standard deviation of 0.41. G_1 (Wayanadan), G_5 (Nadan), G_6 (Karimunda), G_{11} (Manjamunda), G_{12} (Chengannurkodi), G_{15} (Kuthiravally) and G_{21} (Panniyur 1) were high yielders yielding more than 3.5kg/vine as revealed from the pooled mean. The pooled mean of fresh berry yield per vine varied from 1.45 kg in G_{10} (Thulamundi) to 3.15 kg in G_{21} (Panniyur 1) with a mean of 2.69 kg and standard deviation of 0.43 (Figure 9). According to Deka *et al.* (2016), Karimunda had higher number of laterals with more spread and higher number of spikes. Preethy *et al.* (2018) recorded high fresh berry weight in Karimunda and Panniyur 1.

Hundred berry weight ranged from 10.03 g in G_{16} (Kottanadan) to 20.10 g in G_{13} (Vellanamban) with a mean of 13.77 g and standard deviation of 3.84. Hundred fruit volume ranged from 9.2 ml in G_2 (Chumala) to 18.74 ml in G_7 (Neelamundi) with a mean of 12.81 ml and standard deviation of 3.67. Prakash *et al.* (2020) reported a significant variation in hundred fruit weight and a wide variation in hundred fruit volume.

Bulk density ranged from 481.6 g in G_1 (Wayanadan) to 640 g in G_{17} (Kuthiravally) with a mean of 520.2. Bulk density was a highly variable character with a standard deviation of 49.4. The berry diameter ranged from 2.8 mm in G_3 (Vellayaranmunda) to 5.11 mm in G_{21} (Panniyur 1) with a standard deviation of 0.83, indicating less variability for this trait. According to Jayasree (2009), bulk density increased with increase in berry size and it found to decrease when the berry size was above 4.8 mm. Sruthi *et al.* (2013) reported the bulk density of dried berries of Panniyur 1 collected from different locations ranged from 460.6 g to 608.7 g. Shango *et al.* (2021) reported significant variation in berry size.

According to Sivaraman *et al.* (1999), productivity of black pepper depended on elevation, soil fertility, cultural practices, temperature, rainfall, age of the crop and climatic conditions during flowering, fruit set and development. Bermawie *et al.* (2019) reported that, black pepper yield was affected by spike length, number of fruits per spike and number of fruits/vine. Prakash *et al.* (2020) reported less variability for spike peduncle length, number of developed fruits per spike, hundred fruit weight and hundred fruit volume. They discovered a wide range of variation in the number of spikes per lateral, green spike yield, green berry yield and dry berry yield, indicating that these are the important traits that contribute to black pepper yield.

5.2.1.5.4. Physiological parameters

Physiological parameters like leaf thickness, relative water content, epicuticular wax, specific leaf area and stomatal density were recorded from the leaves of selected black pepper genotypes.

Leaf thickness of the selected black pepper genotypes ranged from 0.21 mm in G_8 (Cheppukulamundi) and G_{10} (Thulamundi) to 0.35 in G_{16} (Kottanadan). The mean leaf thickness was 0.28 mm with a standard deviation of 0.044. Genotypes G_{16} (Kottanadan), G_{13} (Vellanamban) and G_{18} (Padappan) had high leaf thickness of 0.35 mm, 0.34 mm and 0.33 mm respectively. According to Cunningham *et al.* (1999), drought tolerance is associated with an increased leaf thickness.

Relative water content ranged from 91.54% to 98.41% with a mean of 94.18% and standard deviation of 1.92. Relative water content was highest in G_{16} (Kottanadan) and lowest in G_2 (Chumala). The relative water content of G_{13} (Vellanamban) was 97.7 per cent followed by G_6 (Karimunda) with 97.11 per cent. According to Vasantha *et al.* (1990) moisture loss from excised leaves was positively linked to relative water content and thus accessions that lost less moisture had higher relative water content. Krishnamurthy *et al.* (1998) observed high relative water content in drought tolerant accessions of black pepper.

Epicuticular wax of the selected genotypes ranged from 1.50 mg cm^{-2} in G_4 (Nadeshan) to 1.82 mg cm^{-2} in G_{16} (Kottanadan). The mean epicuticular wax content was 1.63 mg cm^{-2} and the standard deviation noted was 0.10. The epicuticular wax recorded in G_{13} (Vellanamban) was 1.79 mg cm^{-2}, G_{20} (Narayakodi) was 1.78 mg cm^{-2} and G_6 (Karimunda) was 1.75 mg cm^{-2}. According to Thankamani and Ashokan (2002), epicuticular wax content on black pepper leaves was increased during water stress. Sharma *et al.* (2019) reported epicuticular wax of leaves as a protective barrier against a number of biotic and abiotic stresses.

Specific leaf area of the selected twenty one genotypes was ranged from 160.25 cm^2 g^{-1} in G_{16} (Kottanadan) to 243.12 cm^2 g^{-1} in G_{14} (Jeerakamunda). The standard deviation with respect to the specific leaf area was 28.24, indicating a wide variability among the selected genotypes for specific leaf area. According to Trujillo *et al.* (2013), reduced specific leaf area indicated a more positive response to drought. In this present study, genotypes G_{16} (Kottanadan) (160.25 $cm^2 g^{-1}$), G_6 (Karimunda) (167.56 $cm^2 g^{-1}$) and G_{18} (Padappan) (168.4 $cm^2 g^{-}1$) showed low values for specific leaf area.

Stomatal density of the selected genotypes ranged from 8.01 to 13.5 per cm^2 area with a mean of 11.24 and a standard deviation of 1.49. The mean stomatal density of the leaf was the lowest in G_{16} (Kottanadan) (8.01 per cm^2) followed by G_{13} (Vellanamban) (8.2 per cm^2) and G_6 (Karimunda) (9.5 per cm^2). The mean stomatal density of the leaf was highest in G_3 (Vellayaranmunda) (13.5 per cm^2). According to Hussain *et al.* (2017), genotypes with less number of stomata per unit area could be considered as drought resistant ones due to less rate of transpiration.

5.2.1.5.5. Quality attributes

The selected twenty one genotypes were subjected to analysis of quality parameters such as piperine, oleoresin, essential oil, starch, crude fibre and total ash (Table 18).

According to Narayanan (2000), the presence of piperine is mostly attributable to the pungency of black pepper. In the present study, piperine content was highest in G_{16} (Kottanadan) (5.6%) followed by G_{21} (Panniyur 1) (5.2%). The lowest piperine content was observed in G_2 (Chumala) (3%). (Figure 10). The mean piperine content among the selected genotypes was 3.89 % with a standard deviation of 0.66. The genotypes G_{16} (Kottanadan), G_{21} (Panniyur 1), G_7 (Neelamundi) and G_{19} (Karivilachy) had piperine content ranged from 5.6% to 4.5%, indicating high piperine content. According to (Zachariah *et al.*, 2005), piperine concentration varied from 2.8 per cent to 3.8 per cent in popular black pepper cultivars. However, the piperine concentration of Panniyur 2 was found to be 6.6 per cent (Zachariah, 2008). Biochemical characterization of black pepper accessions by Prakash (2020) identified two accessions with high piperine content *viz.* 7293 with 6.96 per cent followed by 7252 with 6.71 per cent.

According to Mathai (1981), oleoresin is the commercial spice flavour of black pepper. In the present study, oleoresin content ranged from 6.3 per cent in G_3 (Vellayaranmunda) to 13.2 per cent in G_{16} (Kottanadan) (Figure 11). The oleoresin content of G_{15} (Kuthiravally) was 10.9 per cent and that for G_{19} (Karivilanchy) and G_{17} (Arimulak) were 10.5 per cent and 10.3 per cent respectively. The oleoresin content recorded from G_{21} (Panniyur 1) was also 10.3 per cent. The mean oleoresin content was found to be 8.448% with a standard deviation of 1.805. Mathai *et al.* (1981) evaluated the chemical quality of eight different wild varieties of black pepper and revealed the variation of oleoresin from 6.4 % to 25.7 %. There were very promising oleoresin yielders in comparison with the cultivated varieties in their study. Prakash (2020) reported a variation in oleoresin content from 7.10 % to 11.18 % among twenty black pepper accessions studied.

Black pepper is known for its aroma, which is generated by volatile oil (Mathai, 1981). The essential oil content of selected genotypes ranged from 3.0 per cent in G_3 (Vellayaranmunda) and G_8 (Cheppukulamundi) to 4.5 per cent in G_{15} (Kuthiravally) (Figure 12). The mean value observed was 3.54 per cent with a standard deviation of 0.39. According to Krisnamoorthy and Parthasarathy (2009), the oil content of Sreekara and Subhakara was high (> 6%). Prakash (2020) reported a volatile oil range from 3.00 % to 5.87 % among twenty black pepper accessions studied.

The content of starch ranged from 33 per cent in G_3 (Vellayaranmunda) to 38.4 per cent in G_{21} (Panniyur 1) (Figure 13). The mean starch content was found to be 35.095% with a standard deviation of 1.662. The starch content of G_{19} (Karivilanchy) was 38% and that of G_1 (Wayanadan) was 37.7%. The genotypes G_3 (Vellayaranmunda), G_6 (Karimunda), G_8 (Cheppukulamundi), G_{15} (Kuthiravally) and G_{17} (Arimulak) had low starch content (< 34%). According to Farooqi *et al.* (2005), black pepper contained 34.85 per cent starch. Zachariah *et al.* (2010) reported that the starch content of berries of 26 black pepper cultivars from Panniyur and Peruvannamuzhi was in the range of 32.1% to 43.2%.

Crude fibre content of the selected black pepper genotypes ranged from 9.01 per cent in G_{14} (Jeerakamunda) to 14.2 per cent in Kottanadan (Figure 14). Genotypes such as G_{12} (Chengannurkodi) and G_{19} (Karivilanchy) also showed high crude fibre values, 12.8 per cent and 12.5 per cent respectively. The genotypes G_{14} (Jeerakamunda) (9.01 %) and G_8 (Cheppukulamundi) (9.2 %) had low crude fibre values among all the genotypes.

Total ash content of the dried berries ranged from 4.1 per cent to 5.5 per cent. It was highest in G_{21} (Panniyur 1) (5.5%) and lowest in G_{19} (Karivilanchy) (4.1%) (Figure 15). G_{13} (Vellanamban) also had high total ash content (5.4 per cent). According to Kolhe *et al.* (2011) total ash content of black pepper berries collected from the local market was 1 per cent. Abukawsar (2018) reported high total ash percentage in Kerala cultivar (5.55%) compared to Bangladesh cultivar (4.08%).

Variability of quality attributes was common among cultivars of black pepper (Ravindran and Kallupurackal, 2001). Bekele and Gedebo (2020) reported biochemical variability among thirteen black pepper genotypes from Ethiopia.

According to Krishnamoorthy and Parthasarathy (2010), the Indian cultivars Kottanadan, Kumbakodi, Kuthiravally and Nilgiri had high piperine and oleoresin content, whereas Balankotta, Kaniyakadan and Kumbakody had high essential oil content. Sruthi *et al.* (2013) reported that there was profound variability in essential oil, oleoresin, piperine, total phenol, crude fibre, starch and total fat in dried berries of the black pepper variety, Panniyur-1 collected from eleven locations.

5.2.1.6. Quantitative characterization

A multivariate analysis of the quantitative characters was carried to summarize the variation among the selected genotypes. Three separate PCA were carried out for yield related traits, physiological parameters and quality attributes.

5.2.1.6.1. PCA of yield and yield related traits

Quantitative characters such as vine column height, vine column diameter, support height, support diameter, lateral branch pattern, number of nodes per lateral branch, juvenile leaf length, leaf petiole length, leaf length, leaf width, spike peduncle length, spike length, number of well developed fruits per spike, number of under developed fruits per spike, number of fruits per 30 cm^2, number of spikes per vine, fresh spike yield per vine, fresh berry yield per vine, hundred fresh berry weight, hundred fresh berry volume, bulk density and berry diameter were analyzed using PCA. The percentage of variance explained by the first seven principal components was 85.53 and those characters which

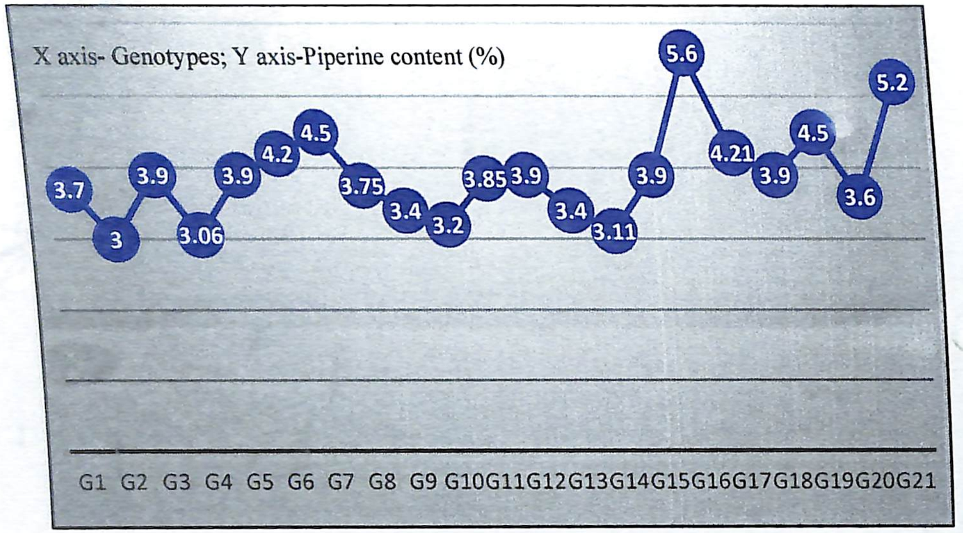


Fig. 8. Variation in piperine content in selected black pepper genotypes

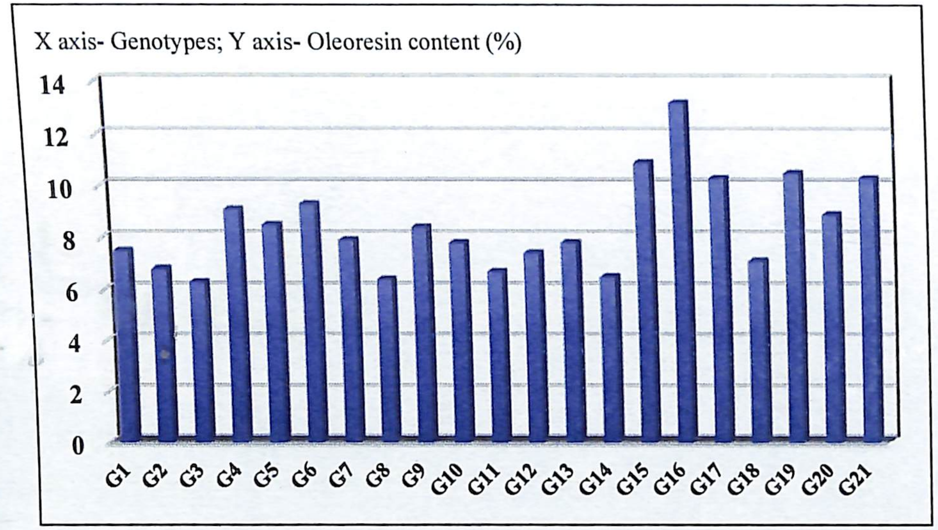


Fig. 9. Variation in oleoresin content in selected black pepper genotypes

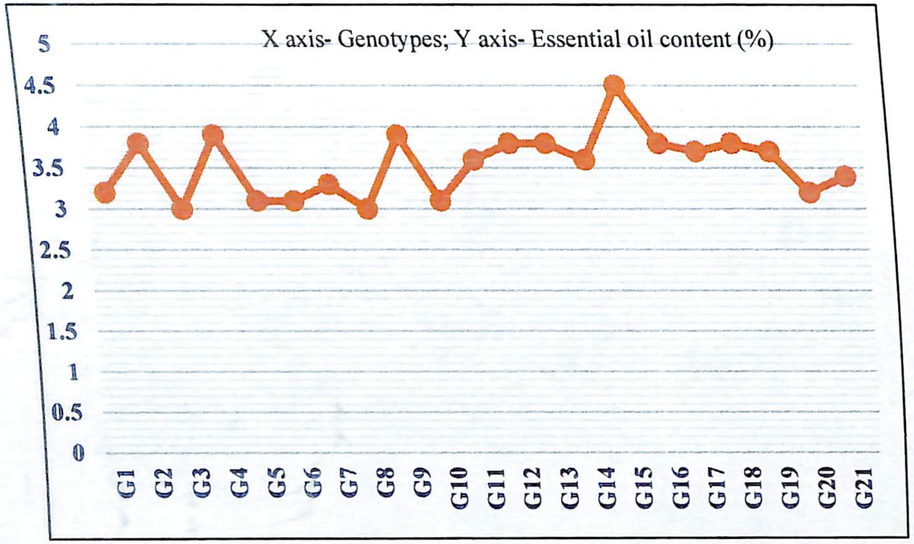


Fig. 10. Variation in essential oil content in selected black pepper genotypes

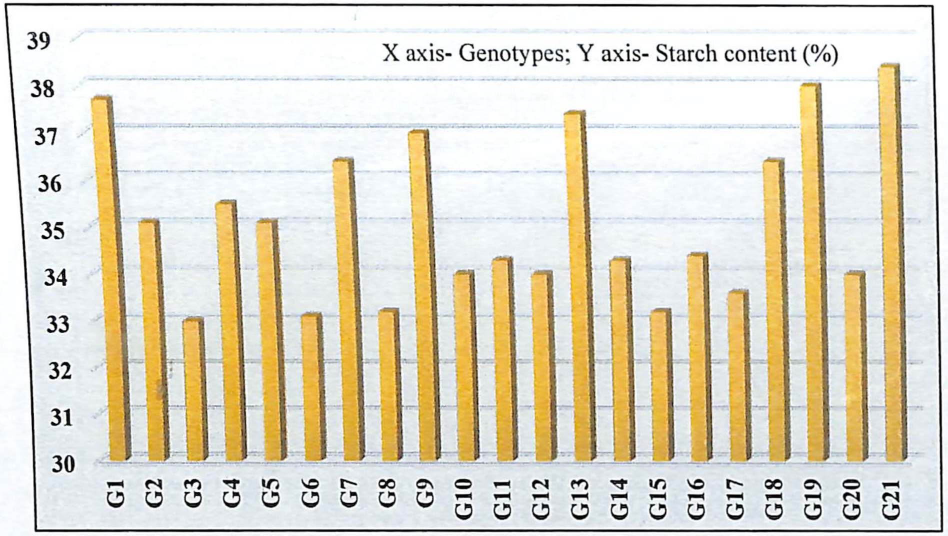


Fig. 11. Variation in starch content in selected black pepper genotypes

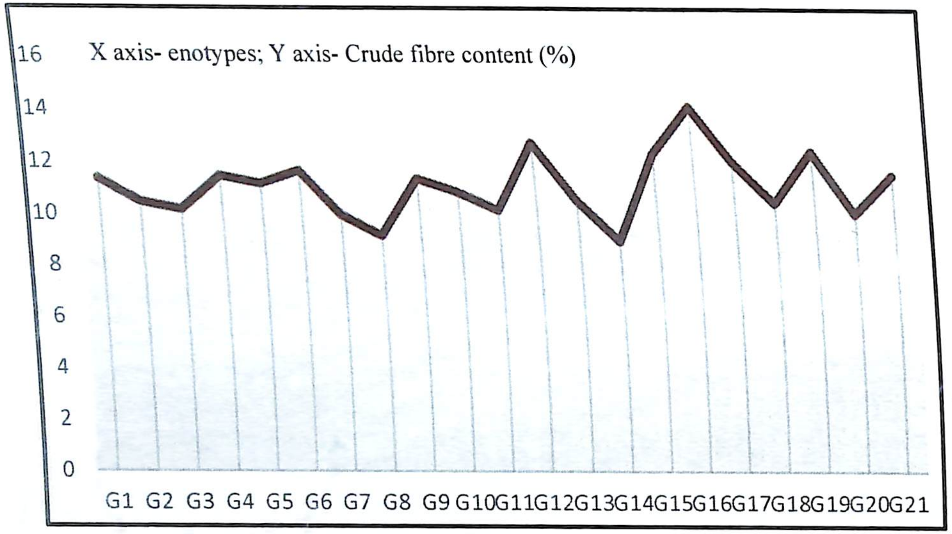


Fig. 12. Variation in crude fibre content in selected black pepper genotypes

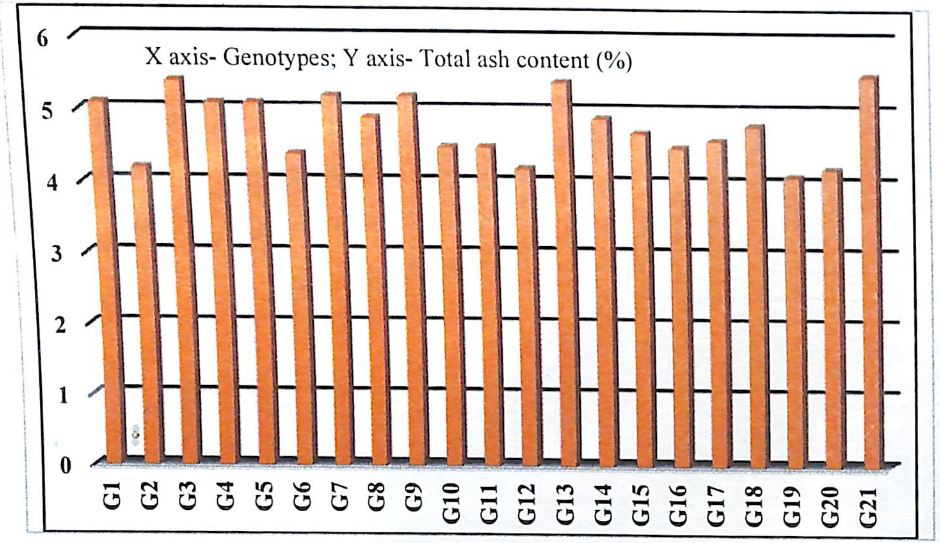


Fig. 13. Variation in total ash content in selected black pepper genotypes

contribute more to the PC1 to PC7 were considered as important characters that contribute variation in the selected twenty one black pepper genotypes. The contribution of quantitative characters such as juvenile leaf length, leaf length, leaf width, number of fruits/30 cm^2, number of spikes/lateral branch, number of spikes/vine, number of nodes/lateral branch, number of well developed berries/spike, support height, vine column diameter and berry diameter was high on yield variability. According to Sujatha and Namboothiri (1995), spike length had a positive and significant influence on yield of black pepper. Hussain *et al.* (2017b) reported two important characters such as higher number of spikes and relative high leaf area as the major yield contributing characters in Panniyur 1. A study conducted by Preethy *et al.* (2018) revealed spike length, hundred berry weight and number of berries per spike as the yield attributing characters among different black pepper accessions. Bermawie *et al.* (2019) reported number of berries/spike as the most important morphological character that had direct and positive effect on pepper yield.

In the present study biplot explained the highest variability contributing traits as leaf length, leaf width, number of spikes per vine, fresh spike yield per vine and fresh berry yield per vine. Among these, leaf length and leaf width, and fresh spike yield per vine and fresh berry yield per vine were strongly correlated each other. Also, characters such as number of nodes per lateral branch and number of spikes per 30 cm^2 were strongly correlated each other. As per the biplot characters such as the vine column height, vine column diameter, support height, support diameter, spike peduncle length and underdeveloped berries per spike had less influence on yield variability. The selected genotypes were assembled into fifteen clusters based on the score plot (Figure 3.). Maximum number of genotypes were in Cluster III and Cluster VIII (3 each). Cluster II and Cluster VII were found to be the second largest with 2 genotypes each. All other clusters had one genotype each (Table 22). The maximum fresh spike yield and fresh berry yield were recorded from Cluster XII (G_{15} Kuthiravally), followed by Cluster XV (G_{21} Panniyur 1). Number of spikes per vine, number of spikes per 30 cm^2 and number of nodes per lateral were high in G_{14} (Jeerakamunda). The juvenile leaf length was highest in Cluster V (G_5 Nadan). Leaf length was found to be highest in Cluster XV (G_{21} Panniyur 1) whereas, leaf width was highest in Cluster I (G_1 Wayandan) (Table 23.) The biplot showed maximum variability for G_1 (Wayanadan), G_4 (Nadeshan), G_5 (Nadan), G_{15}

(Kuthiravally) and G_{21} (Panniyur 1) positioned in positive quadrants and were identified as genotypes with high yield. The genotype G_{21} (Panniyur 1) showed high variability in yield and it was contributed mainly by leaf length and leaf width. According to Vanaja *et al.* (2006) high yield in Panniyur 1 was due to its high photosynthetic rate. Hussain *et al.* (2017b) reported the yield contributing character of Panniyur 1 as its relative high leaf area. A multivariate hierarchical cluster analysis by Prakash *et al.* (2020) grouped fifty black pepper accessions into two major clusters. The first cluster had 46 accessions and the remaining four genotypes were grouped under the second cluster.

5.2.1.6.2. Minimum data set characters for black pepper

From the 23 yield and yield related characters of selected black pepper genotypes, characters with higher percentage contribution in first seven principal components were selected for generating minimum data set (MDS) for black pepper. The characters such as juvenile leaf length (13.22% in PC1), leaf length (13.39% in PC1), leaf width (13.44% in PC1), number of spikes/30 cm^2 (16.54% in PC1), number of spikes/lateral branch (14.76%), number of spikes/vine (13.09%), number of nodes/lateral branch (14.99% in PC3), number of well developed berries/spike (15.49% in PC4), support height (13.13% in PC5), vine column diameter (13.58 % in PC6) and berry diameter (14.83% in PC7) had high contribution on yield variability. The correlation between the variables was worked out and when the correlation of selected variables was <0.6, both the variables were selected whereas when correlation was >0.6, highly weighed variables were selected. From the eleven characters found initially the minimum data set was restricted for four characters finally after rejecting the remaining variables based on the correlation values. Number of nodes per lateral, number of well developed berries/spike, number of spikes/30 cm^2 and berry diameter were selected for developing minimum data set for black pepper.

5.2.1.6.3. Principal component analysis of physiological parameters

Physiological parameters such as leaf thickness, relative water content, epicuticular wax, specific leaf area and stomatal density were statistically analyzed using PCA. Only the first principal component was significant (eigenvalue >1) and contributed to 73.34% of the variance Parameters such as leaf thickness (0.43), relative water content (0.45) and epicuticular wax (0.44) were positively loaded whereas specific leaf area (-

0.45) and stomatal density (-0.48) were negatively loaded in the biplot. The coefficient of the parameters regardless its sign, will be effective in discriminating the genotypes. Higher the coefficient more will be the effectiveness. Results from the PCA indicated that stomatal density had high percentage (22.88%) contribution on variability for drought tolerance among the selected genotypes, followed by specific leaf area (20.12%). But these two parameters contributed drought tolerance in a negative direction. The variables such as leaf thickness, relative water content and epicuticular wax contributed to drought tolerance in a positive direction and among these relative water content had the highest percentage (19.76%) of contribution on variability for drought tolerance, followed by epicuticular wax (18.99%) and leaf thickness (18.25%). The variables such as leaf thickness and relative water content were strongly correlated to each other while specific leaf area and epicuticular wax were negatively correlated to each other. The high values for the characters such as leaf thickness (Cunningham *et al.*,1999), relative water content (Krishnamurthy *et al.*, 1998) and epicuticular wax (Thankamani and Ashokan, 2002) indicated drought tolerance in black pepper. Drought tolerance has an inverse relationship with specific leaf area (Trujillo *et al.*, 2013) and number of stomata per unit leaf area (Hussain *et al.*, 2017). Morphological adaptations such as reduced leaf area, epicuticular wax deposition, leaf rolling, presence of hairiness etc induced drought tolerance (Janani, 2019).

In the present study, selected genotypes were assembled into sixteen clusters based on the biplot. The maximum number of genotypes were in Cluster I and Cluster IV (3 each), followed by Cluster IX (2). All other clusters had one genotype each. The positively loaded variables such as leaf thickness, relative water content and epicuticular wax were highest in Cluster XII (G_{16} Kottanadan) whereas, the negatively loaded variables specific leaf area and stomatal density were low. The biplot between PC1 and PC2 was plotted by using the variability of five physiological parameters. The biplot showed the distribution of genotypes based on both PCs. The biplot showed maximum variability for G_{16} (Kottanadan) and G_{13} (Vellanamban) in the positive quadrants indicating that these were drought tolerant genotypes. The other drought tolerant genotypes clearly revealed from PCA are G_6 (Karimunda), G_7 (Neelamundi), G_{18} (Padappan) and G_{20} (Narayakodi) which were exhibited in quadrant I and IV contributed by three variables such as leaf thickness, relative water content and epicuticular wax. All the remaining genotypes were drought susceptible ones.

SUMMARY

6. SUMMARY

The study entitled "Characterization and quality analysis of black pepper (*Piper nigrum* L.) genotypes of Kerala" was carried out to characterize and analyse the quality of black pepper genotypes of Kerala. The work was initiated with a survey in black pepper growing areas of Kerala comprising of the agro-ecological units, AEU 3, AEU 4, AEU 8, AEU 12, AEU 14 and AEU 21, during the year 2019-2020. A brief passport data of fifty black pepper genotypes were also recorded based on the survey.

Twenty one black pepper genotypes were selected based on the survey viz., G_1 (Wayanadan), G_2 (Chumala) and G_3 (Vellayaranmunda) from the plantation of Noolpuzha, Wayanad, G_4 (Nadeshan) and G_5 (Nadan) from homestead in Nenmani, Wayanad, G_6 (Karimunda) and G_7 (Neelamundi) from the plantation of Cheppukulam, Idukki, G_8 (Cheppukulamundi) from homestead in Cheppukulam, Idukki, G_9 (Vattamundi) and G_{10} (Thulamundi) from the plantation of Peringassery, Idukki, G_{11} (Manjamunda) from the plantation of Uppukunnu, Idukki, G_{12} (Chengannurkodi), G_{13} (Vellanamban) and G_{14} (Jeerakamunda) from the plantation of Senapathy, Idukki, G_{15} (Kuthiravally), G_{16} (Kottanadan) and G_{17} (Arimulak) from the homestead in Vallikunnam, Alappuzha, G_{18} (Padappan) from homestead in Kalliyoor, Trivandrum, G_{19} (Karivilanchy) from homestead in Vellayani, Trivandrum, G_{20} (Narayakodi) and G_{21} (Panniyur 1) from Vakathanam, Kottayam. Morphological characterization based on the qualitative and quantitative characters was done as per the descriptor for black pepper published by International Plant Genetic Resource Institute (IPGRI, 1995) and the guidelines for the conduct of test for distinctiveness, uniformity and stability on black pepper (*Piper nigrum* L.) by PPV & FRA (2009). The same genotypes were physiologically characterized and the fruits were analysed for quality parameters. The evaluation based on yield characters was taken for two years, during 2019-2021.

The qualitative characterization was done based on 34 characters in which characters such as runner shoot production, pubescence on stem, type of veining, leaf texture, spike colour, spike orientation, spike shape, spike fragrance, spike proliferation, colour change while fruit ripening, fruit taste and seed texture did not show any variability among the genotypes studied.

In the vine characters evaluated, light purple shoot tip colour was observed in 76.19% of the genotypes, followed by light green (14.29%) and dark purple (9.52%). The horizontal lateral branch pattern was common (66.67%) followed by hanging (23.81%) and semi-erect (9.52%). The majority of the selected genotypes (52.38%) showed long lateral branches followed by short or medium (23.81% each). In 66.67 per cent of genotypes, there were a few nodes per lateral branch, followed by medium in 33.33 per cent.

The leaf characters of the selected black pepper genotypes were variable. The most common leaf lamina shapes were ovate lanceolate and cordate (28.57% each), followed by ovate (23.81%) and ovate elliptic (19.05%). Round leaf bases were found in 42.86%, followed by cordate or acute leaves (28.57% each). Even leaf margin was seen in 90.48% genotypes and wavy was in 9.52%. Medium juvenile leaves were common in 52.38% of all genotypes, followed by medium or short (23.81% each). Medium leaf petiole length was common in 66.67%, followed by short (19.04%) and long (14.29%). Medium sized leaves were common in 52.38% followed by short or medium (23.81% each). Leaves of medium width were common in 42.86% of the total, followed by narrow or broad (28.57% each).

Spike twisting was absent in 90.48% and it was present in only G_{16} (Kottanadan) and G_{20} (Narayakodi). Compact spike setting was common in 85.71%, followed by loose spike setting in 14.29%. Nineteen genotypes (90.48%) possessed round shaped fruits and seeds, while oval shaped fruits and seeds were observed only in two genotypes (9.52%). Medium sized berries were common in 47.62%, followed by bold (33.33%) and small (19.05%). The majority of the genotypes (61.91%) had medium peduncle length, followed by short (33.33%) and long (4.76%). Medium spike length was common (47.62%) compared to short (42.86%) and long (9.52%). Two genotypes such as G_{15} (Kuthiravally) and G_{21} (Panniyur 1) exhibited long spike length. The medium number of berries per spike was exhibited by 71.43%, followed by the many number of berries per spikes in 28.57%. Many spikes per lateral were observed in 61.91%, followed by medium (28.57%) and few (9.52%). Bulk density was medium in 52.38%, followed by low (38.10%) and high

(9.52%). Harvest maturity of the selected genotypes was classified as early, medium and late, of which medium maturity was common, followed by early (9.52%) and late (4.76%).

Clustering based on qualitative characters of black pepper with the Unweighted Pair Group Method with Arithmetic Mean (UPGMA) was done. The genotypes were grouped into 15 clusters at 73% similarity, based on morphological similarity of twenty two qualitative characters. Cluster III and VI had three genotypes each while Cluster V and XI had two genotypes. The other clusters had only single genotypes showing their divergence in morphological characters considered. The genotype G_9 (Vattamundi) in Cluster XV showed maximum diversity due to its dark purple colour of runner shoot tip, semi-erect branching pattern, broad and cordate leaves, bold berries, low bulk density and late maturity.

Sensory evaluation of the selected black pepper genotypes was carried out for parameters such as appearance, colour, odour, taste and flavour. There was no significant difference among the selected black pepper genotypes for the appearance of the dried berries. However there observed a significant variation for colour, odour, taste and flavour of powder samples of the selected genotypes. G_{13} (Vellanamban) recorded the highest mean score for appearance (8.30) and lowest mean score (7.10) for appearance was recorded for G_{17} (Arimulak). The genotype G_6 (Karimunda) recorded the highest mean (7.8) for colour and the lowest mean score (5.67) was recorded for G_9 (Vattamundi). Powder sample of G_{15} (Kuthiravally) recorded the highest mean score (8.46) for odour and the lowest mean score (7.0) was recorded for G_3 (Vellayaranmunda), G_{10} (Thulamundi) and G_{13} (Vellanamban). G_{16} (Kottanadan) recorded the highest mean score (8.47) for taste (pungency) and the lowest (6.2) was for G_2 (Chumala). The highest mean score (8.93) value for flavour was noted in G_{15} (Kuthiravally) and the lowest (7.07) was in G_9 (Vattamundi).

The quantitative characters recorded in the selected black pepper genotypes included plant, leaf, inflorescence, fruit and seed characters. The vine height of the selected genotypes ranged from 4.10 m in G_9 (Vattamundi) to 6.10 m in G_{18} (Padappan) and vine column diameter ranged from 0.53 cm to 0.94 cm. The height of the support trees ranged from 12 m to 19.7 m and their diameter was from 16.70 cm to 30.12 cm.

The lateral branch length of the selected genotypes varied from 27.25 cm to 65.20 cm. The number of nodes per lateral branch was observed to range from 5.2 to 24.2. The length of the juvenile leaf ranged from 4.1 cm to 7.5 cm. The length of the petiole varied from 1.52 cm to 3.51 cm. The length of the leaves ranged from 8.5 cm to 17.25 cm and the leaf width ranged from 5.2 cm to 15.5 cm.

The spike peduncle length ranged from 0.58 cm to 2.08 cm. Spike length varied from 6.5 cm to 17.5 cm. The number of well developed berries per spike varied from 30.12 to 88.25. The number of underdeveloped berries ranged from 3.26 to 21.4. The number of spikes per lateral branch ranged from 3.24 to 15.7. The number of spikes per 30 cm^2 ranged from 18.69 to 57.12. The number of spikes per vine ranged from 303 to 542 among all the genotypes.

Analysis of variance for pooled mean of fresh spike yield and fresh berry yield showed non significant variation among the genotypes studied. The pooled mean of fresh spike yield per vine varied from 2.3 kg to 3.85 kg. The pooled mean of fresh berry yield per vine varied from 1.45 kg to 3.15 kg. Hundred fresh berry weight ranged from 10.03 g to 20.10 g. Hundred fresh berry volume ranged from 9.2 ml to 18.74 ml. Bulk density of the selected genotypes ranged from 481.6 g to 640 g. Analysis of variance for pooled mean of fresh spike yield and fresh berry yield showed non significant variation among the genotypes studied.

Physiological parameters observed include leaf thickness, relative water content, epicuticular wax, specific leaf area and stomatal density. Leaf thickness of the selected black pepper genotypes ranged from 0.21 mm to 0.35 mm. Relative water content ranged from 91.54% to 98.41%. Epicuticular wax of the selected genotypes ranged from 1.50 mg cm^{-2} to 1.82 mg cm^{-2}. Specific leaf area of the selected twenty one genotypes ranged from 160.25 cm^2 g^{-1} to 243.12 cm^2 g^{-1}. The mean stomatal density of the leaf ranged from 8.01 per cm^2 to 13.5 per cm^2.

The selected twenty one genotypes were subjected to quality analysis for parameters such as piperine, oleoresin, essential oil, starch, crude fibre and total ash. Piperine content ranged from 3 to 5.6 per cent. Oleoresin content ranged from 6.3 to 13.2 per cent. The essential oil content of selected genotypes ranged from 3.0 per cent to 4.5

per cent. The content of starch ranged from 33 per cent to 38.4 per cent. The crude fibre content ranged from 9.01 percent to 14.2 percent. The total ash content of the dried berries ranged from 4.1 per cent to 5.5 per cent.

A multivariate analysis using Principal Component Analysis was carried out with 23 yield related quantitative characters. The percentage of variance explained by the first seven principal components was 85.53 per cent. Based on the principal component 1 and principal component 2, score plot and biplot was generated. From the twenty three quantitative characters evaluated, eleven characters such as juvenile leaf length, leaf length, leaf width, number of spikes/30 cm^2, number of spikes per lateral branch, number of spikes per vine, number of nodes per lateral branch, number of well developed berries per spike, berry diameter, support height and vine column diameter were identified as yield attributing characters. A minimum data set can be used to eliminate a large number of characters and generate a minimum data from which genotypes can be assessed. Based on PCA and correlation matrix of 23 quantitative characters studied, it was concluded that number of nodes per lateral, number of well developed berries/spike, number of spikes/30 cm^2 and berry diameter can be used as a minimal data set for evaluating black pepper genotypes. The selected twenty one genotypes were grouped into 15 clusters based on yield and yield attributing variables. The maximum number of genotypes were in Cluster III and Cluster VIII (3 each). Cluster II and Cluster VII were found to be the second largest with 2 genotypes each.

Physiological parameters such as leaf thickness, relative water content, epicuticular wax, specific leaf area and stomatal density were statistically analyzed using PCA. The variables such as leaf thickness, relative water content and epicuticular wax contributed drought tolerance in a positive direction and among these relative water content had the highest percentage (19.76%) of contribution on variability for drought tolerance, followed by epicuticular wax (18.99%) and leaf thickness (18.25%) whereas specific leaf area (-0.45) and stomatal density (-0.48) were negatively loaded in the biplot. The selected genotypes were assembled into sixteen clusters based on the biplot. The positively loaded variables such as leaf thickness, relative water content and epicuticular wax were highest in Cluster XII (G_{16} Kottanadan) whereas, the negatively loaded variables specific leaf area and stomatal density were lowest. The biplot showed maximum variability for G_{16} (Kottanadan) and G_{13} (Vellanamban) in the positive quadrants indicating that these are drought tolerant genotypes. The other drought tolerant genotypes clearly revealed from PCA are G_6 (Karimunda), G_7 (Neelamundi), G_{18} (Padappan) and G_{20} (Narayakodi).

Principal Component Analysis of quality attributes such as piperine, oleoresin, essential oil, starch, crude fibre and total ash revealed two principal components (eigenvalue >1) at 66.62% variability. Variables such as oleoresin (0.58), crude fibre (0.57), piperine (0.46) and essential oil (0.29) contributed high variability in PC1. Starch and total ash were highly loaded in PC2 with loading value of -0.63 each. The relative contribution of piperine, oleoresin, essential oil and crude fibre were 20.87%, 33.38%, 8.6% and 32.95%, respectively. The genotypes were grouped into seventeen clusters based on score plot. Cluster I and Cluster IX were found to be the second largest with 2 genotypes each. All other clusters had one genotype each. The genotypes such as G_{16} (Kottandan), G_{15} (Kuthiravally) and G_{21} (Panniyur 1) had high variability among the selected genotypes. The high quality genotypes observed were G16 (Kottandan), G15 (Kuthiravally), G21 (Panniyur 1), G19 (Karivilancy), G17 (Arimulak), G13 (Vellanamban) and G6 (Karimunda).

The principal component analysis revealed five genotypes as high yielding ones viz., G_1 (Wayanadan), G_4 (Nadeshan), G_5 (Nadan), G_{15} (Kuthiravally) and G_{21} (Panniyur 1), six genotypes such as G_{16} (Kottanadan), G_{13} (Vellanamban), G_6 (Karimunda), G_7 (Neelamundi), G_{18} (Padappan) and G_{20} (Narayakodi) as the drought tolerant ones and seven genotypes such as G_{16} (Kottandan), G_{15} (Kuthiravally), G_{21} (Panniyur 1), G_{19} (Karivilancy), G_{17} (Arimulak), G_{13} (Vellanamban) and G_6 (Karimunda) as high quality genotypes. Thus these genotypes can be evaluated further and utilized for further improvement studies.

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CHARACTERIZATION AND QUALITY ANALYSIS OF BLACK PEPPER (*Piper nigrum* L.) GENOTYPES OF KERALA

by

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Abstract of the thesis

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DEPARTMENT OF PLANTATION CROPS AND SPICES
COLLEGE OF AGRICULTURE
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ABSTRACT

The present study entitled "Characterization and quality analysis of black pepper (*Piper nigrum* L.) genotypes of Kerala" was taken up with the objectives of survey, characterization and quality analysis of black pepper genotypes of Kerala based on morphological and biochemical parameters.

The survey conducted in black pepper plantations and homesteads in fourteen locations of six Agro-Ecological Units (AEUs) identified twenty one genotypes. Five genotypes designated as G_1 (Wayanadan), G_2 (Chumala), G_3 (Vellayaranmunda), G_4 (Nadan), G_5 (Nadeshan) from AEU 21 (Wayanad Eastern Plateau), six genotypes designated as G_6 (Karimunda), G_7 (Neelamundi), G_8 (Cheppukulamundi), G_9 (Vattamundi), G_{10} (Thulamundi), G_{11} (Manjamunda) from AEU 12 (Southern and Central Foothills), three genotypes designated as G_{12} (Chengannurkodi), G_{13} (Vellanamban), G_{14} (Jeerakamunda) from AEU 14 (Southern High Hills), three genotypes designated as G_{15} (Kuthiravally), G_{16} (Kottanadan), G_{17} (Arimulak) from AEU 3 (Onattukara Sandy Plains), two genotypes designated as G_{18} (Padappan), G_{19} (Karivilanchy) from AEU 8 (Southern Laterites) and two genotypes designated as G_{20} (Narayakodi) and G_{21} (Panniyur 1) from AEU 4 (Kuttanad) were selected for the study.

Twenty one genotypes were morphologically characterized for both qualitative and quantitative characters. Thirty four qualitative characters were observed and among those only twenty two characters showed variability. Characters such as runner shoot production, pubescence on stem, type of veining, leaf texture, spike colour, spike orientation, spike shape, spike fragrance, spike proliferation, colour change while fruit ripening, fruit taste and seed texture were uniform in all the selected genotypes. The UPGMA dendrogram divided all the genotypes into 15 clusters at 73 per cent similarity. Sensory evaluation of the selected black pepper genotypes showed a significant variation for colour, odour, taste and flavour. G_{16} (Kottanadan) was significantly superior in taste while G_{15} (Kuthiravally) was superior in odour and flavour.

Thirty four quantitative characters were recorded for plant, leaf, inflorescence, fruit and seed characters. Summarizing these quantitative characters

using descriptive statistics revealed wide range of variability in number of well developed fruits per spike, number of spikes per 30 cm^2, number of spikes per vine, bulk density and specific leaf area.

Principal component analysis was undertaken to examine the variation and to estimate the relative contribution of various trait for total variability. The principal component analysis for twenty three yield related characters revealed seven principal components at 85.53 per cent variability. The eleven quantitative characters such as juvenile leaf length, leaf length, leaf width, number of spikes/30 cm^2, number of spikes per lateral branch, number of spikes per vine, number of nodes per lateral branch, number of well developed berries per spike, berry diameter, support height and vine column diameter contributed more to the yield. The score plot identified fifteen clusters in which genotypes with superior yield namely, G_1 (Wayanadan), G_4 (Nadeshan), G_5 (Nadan), G_{15} (Kuthiravally) and G_{21} (Panniyur 1) formed unique clusters. Minimal data set generated for black pepper included four characters namely, number of nodes per lateral, number of well developed berries/spike, number of spikes/30 cm^2 and berry diameter. The principal component analysis for five physiological parameters revealed one principal component at 73.34 per cent variability. Genotypes with high leaf thickness, high relative water content, high epicuticular wax, low specific leaf area and low stomatal density were associated with drought tolerance in black pepper. Sixteen clusters were identified based on score plot. Biplot analysis identified genotypes G_{16} (Kottanadan), G_{13} (Vellanamban), G_6 (Karimunda), G_7 (Neelamundi), G_{18} (Padappan) and G_{20} (Narayakodi) as most desirable genotypes for drought tolerance. The principal component analysis for six quality attributes revealed two principal components at 66.62 per cent variability. The genotypes were grouped into seventeen clusters based on score plot while the biplot identified genotypes G_{16} (Kottandan), G_{15} (Kuthiravally), G_{21} (Panniyur 1), G_{19} (Karivilancy), G_{17} (Arimulak), G_{13} (Vellanamban) and G_6 (Karimunda) as the high quality ones.

The genotypes studied for qualitative, quantitative, physiological and quality traits showed a moderate variability and can be used in the selection of suitable parents for breeding purpose and gene mapping studies.

APPENDICES

APPENDIX I

KERALA AGRICULTURAL UNIVERSITY
COLLEGE OF AGRICULTURE, VELLAYANI
Department of Plantation Crops and Spices

Title of thesis: Characterization and quality analysis of black pepper genotypes of Kerala

Name of student: Reshma, P. (2019-12-023)

SCORE CARD FOR ASSESSING QUALITY PARAMETERS OF BLACK PEPPER

Criteria	Samples											
	1	2	3	4	5	6	7	8	9	10	11	12
Appearance												
Colour												
Odour												
Taste												
Flavour												

Score

Like extremely -9
Like very much -8
Like moderately -7
Like slightly -6
Neither like nor dislike -5
Dislike slightly -4
Dislike moderately -3
Dislike very much -2
Dislike extremely -1

Name:

Signature:

Date:

APPENDIX II

Survey details

Sl. No.	Location	Number of genotypes	Genotype number	Special characters
1	Mr. Mathew, Kainikkal house, Noolpuzha, SulthanBathery, Wayanad	5	G_1	Vigorous vine, close setting of berries, bold berries
			G_2	Good fruit set, bold berries
2	Plantation of Mr. Jose, Noolpuzha, SulthanBathery, Wayanad	4	G_3	High spiking intensity
3	Mr. Joseph, Nenmeni, SulthanBathery, Wayanad	7	G_4	Close setting of berries
			G_5	Vigorous vine, close setting of berries, long spikes
4	Plantation of Mr. Sasidharan, Vazhithala, Thodupuzha, Idukki	6	G_6	High spiking intensity, performs well under both open and shade conditions
			G_7	Suitable for higher elevation
5	Kuttichettan, Kallarackal, Cheppukulam, Thodupuzha, Idukki	4	G_8	Regular yield
6	Plantation of Mr. Sujith, Peringassery, Thodupuzha, Idukki	2	G_9	Vigorous vine, good setting
7	Mr. Sujith, Kainootiil House, Peringassery, Thodupuzha, Idukki	1	G_{10}	Regular yield
8	Plantation of Mr. Joseph, Uppukunnu, Thodupuzha, Idukki	5	G_{11}	Early maturity
9	Mr. Sajivan, Puthenpurakkal House, Senapathy Udumbanchola Idukki	3	G_{12}	Regular yield
			G_{13}	Regular yield. Bold berries
10	Mr. Krishnan Nair, Mangattu House, Senapathy Udumbanchola Idukki	2	G_{14}	High spiking intensity

11	Mrs. Radha, Udamvillayil, Vallikunnam, Mavelikkara, Alappuzha	4	G_{15}	Long spikes
			G_{16}	Stable yield
			G_{17}	Regular yield
12	Mr. Kamarajan, Aswathy House, Kalliyoor, Thiruvananthapuram	1	G_{18}	Stable yield
13	Ms. Latha, Vellayani, Thiruvananthapuram	1	G_{19}	Staggered flowering, bold berries
14	Mr. Biju Kumar, Vakathanam, Changanaseri, Kottayam	2	G20	Stable yield
			G21	Vigorous vine, bold berries, performs well under open condition, high fruit set

APPENDIX III

Eigen value for yield related traits

Principal components	Eigen value	Percentage of variance	Cumulative percentage of variance
PC1	6.22	27.05	27.05
PC2	4.19	18.26	45.31
PC3	2.70	11.75	57.06
PC4	2.29	9.97	67.03
PC5	1.65	7.16	74.19
PC6	1.54	6.69	80.88
PC7	1.07	4.65	85.53
PC8	0.76	3.28	88.81
PC9	0.60	2.61	91.42
PC10	0.49	2.11	93.53
PC11	0.41	1.77	95.29
PC12	0.34	1.49	96.79
PC13	0.24	1.03	97.82
PC14	0.19	0.83	98.65
PC15	0.14	0.59	99.24
PC16	0.10	0.45	99.69
PC17	0.04	0.19	99.88
PC18	0.01	0.06	99.94
PC19	0.01	0.05	99.98
PC20	0.00	0.02	100

APPENDIX IV

Eigen value for physiological parameters

Principal_components	Eigenvalue	Percentage of variance	Cumulative percentage of variance
PC1	3.67	73.34	73.34
PC2	0.58	11.49	84.83
PC3	0.36	7.17	92.00
PC4	0.22	4.38	96.38
PC5	0.18	3.62	100

APPENDIX V

Eigen value for quality attributes

Principal components	Eigenvalue	Percentage of variance	Cumulative percentage of variance
PC1	2.61	43.49	43.49
PC2	1.39	23.13	66.62
PC3	0.97	16.18	82.79
PC4	0.63	10.56	93.36
PC5	0.23	3.80	97.16
PC6	0.17	2.84	100