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Genetic diversity of black pepper (*Piper nigrum* L.) in India: A review

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Abstract
Known as the "King of spices", black pepper is one of the most important cash crops in the world. It is a widely marketed spice as well as a plant with many medicinal properties. Black pepper is a perennial crop native to the Western Ghats of India. In its native form, it is found extensively in the evergreen forests which is a rich repository of wild relatives of black pepper. The most important and interesting aspect of black pepper diversity is its cultivar diversity. More than a hundred black pepper cultivars are known to exist in India and the main centres of variability are the southern states of India such as Kerala and Karnataka. Many molecular studies have been conducted focusing on the genetic diversity of black pepper. Diversification in plant genetic resources is very important to develop new and improved varieties with desirable traits. Most of the improved varieties released for cultivation are clonal selections from the existing landraces. Numerous surveys have found black pepper cultivars with bold berries, high pungency, oleoresin content and other desirable traits. Germplasm collection of a wide variety of landraces, natural mutants and improved varieties of black pepper will be useful for future studies and will allow genetic variation to survive without extinction.

Keywords: Black pepper, piper nigrum, genetic diversity, local cultivars, conservation

Introduction
Black pepper (*Piper nigrum* L.), glorified as the "King of spices" or "Black gold" belonging to the family Piperaceae and is believed to have originated in the sub-mountainous tracts of the Western Ghats of India (Rahiman *et al*., 1979) [24]. Black pepper was one of the early and most used spices in human history and is prized for its characteristic pungency. It is commonly used as a table condiment, a culinary spice, and is used in the ancient ayurvedic medicine of India due to its medicinal values (Mathew *et al.*, 2005) [16]. Black pepper is renowned for its intrinsic quality and its two principal components are volatile oil and pungent compounds (Sruthi *et al.*, 2013) [36]. The quality parameters for black pepper that are valuable commercially are piperine, essential oil and oleoresin content. *Piper nigrum* has many pharmacological activities such as anti-microbial, anti-obesity, carminative, anti-mutagenic, anti-cancer, antioxidant, digestive, anti-pyretic, anti-diarrhoeal and immunomodulatory activities (Saleem *et al*., 2022) [31].
Piper nigrum is a perennial woody climber that can reach a height of 10 metres or more, having ivy-like roots that adhere to a support tree. The vines possess a dimorphic branching pattern with monopodial orthotropic branches and sympodial laterally spreading plagiotropic fruiting branches (Parthasarathy *et al.*, 2007) [18]. *Piper* has an x = 13 basic chromosome number, whereas Piper nigrum is tetraploid with 2n = 52. Cross pollination between various Pipers species may have happened naturally when multiple species climbed the same support trees. In these progenies, subsequent gene flow was restricted due to the lack of a pollen transfer mechanism. The survival and spread of progenies were ensured through successful vegetative propagation. The present-day *Piper nigrum* cultivars are the descendants of such segregated populations, which are vegetatively propagated by farmers through cuttings (Ravindran, 2000) [25]. *Piper* breeding and conservation programmes by humans based on good fruit set, pungency and several other factors contribute to cultivar diversity. In its native form, it is found extensively in the evergreen forests of the Western Ghats and in adjoining areas, almost from sea level up to an elevation of 1300 m. Kerala, India's southernmost state, covers a considerable portion of the Western Ghats and is a rich repository of wild relatives of black pepper (Joy *et al*., 2007) [11]. This region is endowed with many landraces of black pepper besides the progenitors of cultivated ones (Mathew *et al.*, 2005) [16]. Samuel *et al.* (1986) [32] have emphasised the importance of genetic variety in black pepper for crop improvement. Inter and intra-clonal relationships are important in black pepper improvement.

Also, black pepper has a high degree of variability in terms of productivity and quality characteristics within a single cultivar. Therefore, the authors are interested in reviewing the genetic diversity of black pepper in India.

Biodiversity and distribution of black pepper

Piper is the largest genus of the Piperaceae family, including over 1000 species found in the tropics and subtropics. *Piper* grows from sea level to the Andes and Sub-Himalayan highlands (Royle, 1839) [28]. The Trans Gangetic and South Deccan regions of India have been identified as the two distinct origins of the genus *Piper* (Hooker, 1886) [6]. As the most diverse genus among angiosperm basal lineages, *Piper* is a significant structural component of the forest understorey (Gentry, 1990) [3]. *Piper* species diversity is richest in the American tropics (700 species), followed by Southern Asia (300 species), the South Pacific and the African tropics (Jaramillo and Manos, 2001) [10]. *P. nigrum* (black pepper), *P. longum* (long pepper), *P. betle* (betel vine), *P. chaba* (Indonesian or Java long pepper), *P. peepuloides, P. hapnium, P. cubeba* (Cubeb or tailed pepper), *P. methysticum*, etc. are the most important species of the Piperaceae family (Prasath *et al.*, 2017) [22], wherein *P. nigrum* L. is the most important one among these. The Western Ghats are largely comprised of the related species of *P. nigrum*, with the Southern Western Ghats having the highest cultivar diversity. Geographically, the Western Ghats of the South Indian Peninsula is the principal hub of black pepper cultivation and domestication. It is said to have occurred many years ago in this area. Since then, black pepper cultivation has been introduced to other countries in South and Southeast Asia (Ravindran, 2000) [25]. Despite its long history of cultivation, black pepper is yet to be introduced and grown in many regions. Currently, this crop is chiefly cultivated in the tropical regions of the world, such as Ethiopia, Vietnam, Indonesia, India and Brazil. According to statistics from the Food and Agriculture Organization, global production of black pepper was 1,103,024 MT in 2021. India is the fourth largest producer of black pepper in the world, with an estimated annual production of 61,004 MT (FAO, 2022). The climatic requirements of black pepper such as minimum temperature of the coldest month, the mean monthly temperature range and the precipitation of the wettest month inhibited this species from dispersing and gaining a larger geographical range (Chaoyun *et al.*, 2012) [1].

Cultivar diversity

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 (Table 1). More than a hundred black pepper cultivars are known to exist in India and the main centres of variability are Kerala and Karnataka (Ravindran *et al.*, 1997a) [27]. More than seventy distinct cultivars are being cultivated in the state of Kerala (Mathai *et al*., 1981) [15], both as a mixed crop in domestic gardens and on a semi-plantation scale. Every traditional pepper growing tract in Kerala has its own popular cultivars (Prasannakumari *et al.*, 2001) [21]. The diversity among *Piper nigrum* is mostly due to the occurrence of the species in a wide range of altitudinal zones and its high adaptability to a broad range of environmental conditions. Morphologically diverse intraspecific variants of this species have been found in both wild and cultivated populations The present cultivars have evolved by accidental selection from natural hybridization and vegetative propagation, encompassing a wide range of variation in size and shape of fruits and fruiting behaviour. Introductions from one region to another have also occurred, resulting in the same cultivar being known by different names in other locations (Govindarajan, 1977) [5]. 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) [16]. They have been named for specific features of the vine, such as the vine 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) [13]. Most black pepper fields are grown mainly with landraces or the most popular hybrid, Panniyur1 (George *et al*., 2005) [4].

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 their own distinctive traits. The morphological variations exhibited by the landraces are stable and determined genetically (Mathew *et al.*, 2005) [16]. Germplasm collection and further evaluation at IISR revealed considerable variability among the accessions with regard to various morphological as well as floral characters like leaf shape, leaf size, spike length, spiking intensity, composition of male, female and bisexual flowers in the spike, fruit set, shape, weight and volume of the fruit etc. (Table 2). An analysis of 44 major cultivars and 7 wild black pepper collections has shown a variation based on morphological characters (Ravindran *et al*., 1997a, b) [27]. The cultivars show variability not only in morphological characters but also in quality aspects. Variability of quality attributes is common among cultivars and even within the same cultivar (Ravindran and Kallupurackal, 2001) [26]. Zachariah (1995) [38] evaluated selected black pepper accessions and observed good variability for both flavour and quality. Kurian *et al*. (2002) [14] reported varietal variations of oleoresin and piperine in black pepper. 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) [18]. Many popular cultivars of black pepper grown in Kerala have considerable variations in the composition of major volatiles (Zachariah and Parthasarathy, 2008) [38]. 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 in the wild types. There were very promising oleoresin yielders in comparison with the cultivated varieties in this group. Among these, two of the wild types were pungency free but had a black pepper aroma (Mathai *et al.*, 1981) [15].

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), Amplified Fragment Length Polymorphism (AFLP), Inter Simple Sequence Repeat (ISSR) Polymorphism and isozymes. These markers have been used to fingerprint different cultivars and species to examine genetic

variation within plant germplasm collections. Pradeepkumar *et al.* (2001) [1] were the first to use RAPD to characterise distinct cultivars of black pepper, employing 24 accessions which included 13 landraces and 9 advanced cultivars. Twenty-two out of thirty-four tested primers produced consistent and visible banding patterns. Except for one cultivar, all the released cultivars had specific bands. Further studies (Pradeep Kumar *et al*., 2003) [20] using 22 *P. nigrum* cultivars found that genetic proximity between cultivars may be associated to phenotypic similarities or geographical distribution. Landraces had a higher degree of divergence than improved cultivars. Landraces grown in southern coastal India and those grown in northern India were separated into two dendrogram groups. Sreedevi *et al.* (2005) [35] used RAPD markers to describe seven high yielding and promising black pepper lines. They found that nine out of 14 tested random decamer primers could generate unique bands in six of the lines tested. Based on the data generated by both RAPD and AFLP analyses among 49 cultivars or accessions of black pepper, Nazeem *et al.* (2005) [17] attempted to assess the variability and relatedness. And based on the RAPD analysis, these 34 cultivars were divided into five clusters. Microsatellite based analysis of genetic diversity of popular black pepper genotypes in South India emphasised the possibility of introduction of black pepper from South India to Malaysia (Joy *et al*., 2011) [12].

Worldwide surveys in locations of black pepper cultivation 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) [29] 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) [29] reported a rare accession with high dry recovery and bulk density, as well as round, solid, bold and attractive black berries. The modest quantities of piperine, oleoresin, and essential oil suggest that the berries were of high quality. This accession was quite tolerant to pests. A trait-specific survey conducted by Sasikumar *et al.* (2014) [33] reported two unique black pepper accessions with very long spikes and poor setting from Coottanadu Estate, Wayanad, Kerala, bordering the evergreen forest of the Western Ghats.

Table 1: Popular traditional cultivars of black pepper in India

Sl. No.	Cultivar	Special characters
1	Aimpiriyan	High yielding cultivar with twisted spikes, performs well in high elevations, vigorous vine, large heart shaped leaves, close berry setting, late maturing, popular in Wayanad and Coorg
2	Arakkulammunda	It derives its name from a village Arakkulam in Kerala. Common in central and northern Kerala. Moderate, regular and earlier bearer. Large ovate leaves with wavy margin. Spikes are medium-long, and the berries are bold. Average yield is 1.5-2 kg fresh pepper/vine. Dry recovery is 33%. Moderate in quality
3	Aranavalan	It is found in the Malayatoor- Kalady areas of Kerala. It is a variant of cultivar Kuthiravally
4	Attamuriyan	Short spikes, poor yielder, regular yielder
5	Arayanmunda	It is a high yielder from Idukki district, tolerates drought
6	Arimulak	Early bearer, stable yielder, medium sized leaves, short to medium spike length, small berries, high bulk density
7	Balankotta	It is a vigorous cultivar with large droopy leaves which are light green in colour with even margin. Spikes are straight medium- long with loosely arranged pale green bold berries, moderate setting, Moderate and irregular bearing. Average yield is 1-3 kg/vine fresh. Dry recovery is 33%. Medium quality. Adapted to shade, performs well as mixed crop
8	Bilimallegesara	Moderate yielder, grown in Karnataka state, produces medium sized berries on straight medium long spikes
9	Chengannurkodi	Moderate yielder from South Kerala, medium in quality
10	Cheppakulamundi	Moderate yielder from Central Kerala, medium long spikes, moderate setting, medium in quality
11	Cheriyakaniakadan	Popular in North Kerala, leaves are small and elliptic, medium spike length, medium- sized berries, moderate and early bearing variety
12	Cheriyakodi	Popular cultivar in North Kerala, dark green narrow leaves, short spikes, dwarf and bushy vine, small berries, alternate bearer
13	Cholamundi	Elliptical and medium sized drooping leaves. Spikes curved and medium long
14	Chumala	Small to medium leaves, short spikes, close berry setting
15	Daddayya	Popular cultivar in North Kanara (Karnataka), broad leaves, long spikes, large sized fruits
16	Irumaniyan	Medium leaves, bold berries, loose berry setting, poor yielder
17	Jeerakamundi	Cultivar with small leaves and short spikes, alternate bearing nature, small berries
18	Kalluvally	A promising cultivar of North Kerala with medium ovate-elliptic leaves, twisted spikes and small to medium sized berries. It is a good yielder, medium in quality with high dry recovery (about 40%), drought tolerant, moderately tolerant to Phytophthora wilt.
19	Kallubalankotta	Medium straight spikes, round medium berries
20	Kaniakkadan	Popular cultivar of Eastern part of Kottayam and Quilon districts of Kerala. It's a bisexual type with small elliptical leaves, medium-long spikes and medium-sized berried. Average and regular bearer.
21	Karimunda	Dark green leaves and berries, small berries and short to medium long spikes. Most popular cultivar suitable for most of the black pepper growing areas, high yielder, regular bearer, medium in quality and shade tolerant, suitable for intercropping.
22	Karimkotta	Dark green large leaves, short spikes, dark green large berries, regular bearer, popular in North Kerala.
	Kottan	A cultivar found in North Kerala, moderate in yield and medium in quality.
23	Kottanadan	A high-yielding cultivar from South Kerala, drought-tolerant type. It produces medium-sized berries, large, broad, ovate leaves and medium spikes. It is reported to have high oleoresin content (17.8%).
24	Kumbhakodi	It is grown in certain areas of Quilon district of Kerala, seems to be a variant of Kottanadan.
25	Kurimalai	A cultivar from Karnataka, moderate yielder with medium quality.
26	Kuriyalamundi	Elliptic to lanceolate leaves, good spiking, spikes very short and twisted, small berries, good setting

27	Kuthiravally	A cultivar with long spikes, high yield and good quality. It is popular in South Kerala. Medium- large ovate leaves, long and slender spikes, medium sized berries, but an alternate bearer. Dry recovery is 39%. Kuthiravally produces high quality pepper (15% oleoresin, 6% piperine and 4.5% essential oil).
28	Kuttianikodi	A moderate yielder from Central Kerala with relatively long spikes and good spiking intensity
29	Malamundi	A moderate yielder, medium in quality
30	Malligesara	A common cultivar from Karnataka, medium- large leaves and spikes, relatively good in yield. In the Malnad areas of Karnataka, it is intercropped with arecanut. Two types of Malligesara found; Karimalligesara and Billimalligesara, which can be differentiated based on the runner shoot tip colour. It is purple- white in Karimalligesara and pale green in Billimalligesara.
31	Manjamundi	A moderate yielder from North Kerala, medium in quality
32	Marampadarthi	Moderate yielder from Idukki district, bold berries
33	Mundi	Straight spikes, round bold berries
34	Nadan	Long spikes, bold berries, cordate leaves, vigorous vine. Popular in North Kerala
35	Nateshankodi	Popular in Wayanad, bold berries, regular yielder
36	Narayakodi	Popular in Central Kerala. Leaves are small- medium, ovate with wavy margin. Spikes are medium in length, twisted due to thick berry setting. Berries are oval with persistent stigma. It is a regular, moderate yielder with high dry recovery (37.5%) and medium quality. This cultivar is not easily affected by foot rot
37	Neelamundi	A good yielder from Central Kerala medium in quality, tolerant to Phytophthora infection
38	Nedumchola	A cultivar with small leaves and short spikes, moderate yielder
39	Neyyattinkaramundi	A cultivar from Central Kerala, medium in quality and yield
40	Padarppan	Medium sized dark green leaves, medium length spikes, loose berry setting, medium berries, tolerant to drought
41	Perambramunda	A cultivar from North Kerala, moderate yielder with medium quality
42	Perumkodi	A cultivar from Central Kerala, moderate in yield and quality
43	Poonjaranmunda	A cultivar originally from Central Kerala, sporadically found in gardens of North Kerala. Moderately good in yield and quality
44	Thevanmundi	A cultivar from Idukki district having field tolerance to foot rot disease
45	Thippalikodi	Small spikes, small leaves
46	Thommankodi	A cultivar from central Kerala, moderately good in yield and quality. It seems to be a variant of Kuthiravally, but produces short spikes
47	Thulamundi	A Central Kerala cultivar, medium in yield and quality
48	Uddagara	A popular cultivar of Karnataka, good in yield and medium in quality
49	Uthirankotta	Predominantly female. Usually poor yielder, but good during certain years, spikes long and straight with sparsely set bold berries
50	Vadakkan	A cultivar from North Kerala, medium in quality and yield with relatively large berries
51	Valliyakaniyakadan	A cultivar with larger leaves, longer spikes, bold berries, medium in yield and quality
52	Vattamundi	A moderate yielder from Central Kerala
53	Vellanamban	Relatively moderate yielder and medium in quality characterized by the white colour of the young shoot tip
54	Valiyaranmunda	Medium straight spikes, round medium berries
55	Vokkalu	Short straight spikes, round medium berries
56	Wayanadan	Cordate large leaves, medium length spikes, bold berries
57	Workalamorata	Female cultivar with short spikes. Light green coloured foliage. Long leaves

Table 2: Variability observed in important characters among the accessions

Sl. No.	Characters	Range		Mean	CV (%)
		Minimum	Maximum		
1	Vine column height (cm)	100	1180	335.9	46.8
2	Vine column circumference (m)	0.4	11.5	3.26	46.22
3	Lateral branch length (cm)	9.8	70	36.51	27.66
4	No. of nodes / lateral branch	2.0	95	15.4	57.75
5	Leaf petiole length (cm)	0.8	5.0	1.74	28.9
6	Leaf length (cm)	4.8	23.0	13.29	16.98
7	Leaf width (cm)	2.1	16.6	8.49	21.52
8	Spike length (cm)	3.2	17.6	7.5	28.4
9	Peduncle length (cm)	0.3	5.0	1.2	30.57
10	No. of spikes / lateral branch	1.0	56	5.97	50.52
11	No. of spikes / vine	10	720	158	56.6
12	No. of berries in 10 spikes	10	115	51.4	36.09
13	Fresh weight of 100 berries (gm)	5	23	12.4	22.01
14	Volume of 100 berries (ml)	4	22	11.8	21.49
15	Volatile oil (%)	1	9	3.5	36.8
16	Oleoresin (%)	5.09	19.8	9.21	20.50
17	Piperine (%)	0.96	3.95	2.15	26.53

Source: IISR (2009) [9]

Table 3: Improved varieties of black pepper in India

Variety	Pedigree	Institutes	Dry yield (kg/ha/year)	Dry Recovery (%)	Quality attributes (%)			Salient features
					Piperine	Oleoresin	Essential oil	
Panniyur-1	F_1 of Uthirankotta x Cheriyakaniyakadan	Kerala Agricultural University, Pepper Research Station, Panniyur	1,242	35.3	5.3	11.8	3.5	This is the first released variety in 1971. It produces vigorous vine, large cordate leaves, non-pigmented growing tip, long spikes and bold berries, suited to all pepper growing regions, but not suited to heavily shaded areas. It performs well only under adequate sunlight, gives an average yield of 2.2 kg green pepper per vine, potential yield is 8800 kg per hectare. The setting percentage is 96.
Panniyur-2	Clone from the open-pollinated progeny selection of Balankotta		2,570	35.7	6.6	10.9	-	It is released in 1989. This cultivar is popular in the northern districts of Kerala and the South Kanara district of Karnataka. Reported to be shade tolerant. It is vigorous in growth and has a non-pigmented growing tip. It gives a yield of 4.5 kg green pepper per vine with a dry recovery of %. The potential yield is 3,313 kg/ha.
Panniyur-3	Progeny of Uthirankotta x Cheriyakaniyakadan		1,953	27.8	5.2	12.7	-	Its characteristics are like Panniyur-1, but it has faint pigmentation on the growing tip. The average yield of green berry per vine is 4.4 kg. The potential yield is 3,269 kg/ha. Late maturing. Suited to all pepper growing regions.
Panniyur-4	Clonal selection from Kuthiravally		1,277	34.7	-	9.2	-	Stable yielder. The yield per vine is 2.3 kg green pepper, potential yield is 2,443 kg/ha.
Panniyur-5	Open-pollinated progeny selection of Perumkodi		1098	-	5.5	12.3	3.8	It is a high yielding and regular bearing variety. Tolerant to nursery diseases and shade. This variety is suited to all pepper growing tracts.
Panniyur-6	Clonal selection of Karimunda		2127	32.9	4.9	8.3	1.3	Suited to all pepper tracts. It gives stable and regular yield and performs well under open as well as partial shaded conditions. Special attribute of this variety is production of a greater number of spikes per unit area with close setting and attractive bold medium berries. Its potential yield 3359 kg dry pepper/ha.
Panniyur-7	Open-pollinated progeny of Kalluvally		1410	33.6	5.6	10.6	1.5	Suited to all pepper tracts. It is a vigorous, hardy and a regular bearing variety. It is recommended for Kerala under open conditions and partial shade. It has high piperine content and has long spike. It has potential yield of 2770 kg dry pepper/ha.
Panniyur-8	Hybrid (HB 20052), Panniyur 6 × Panniyur 5		1365	39.0	5.7	12.2	1.2	High yielding, field tolerant to Phytophthora foot rot and drought.
Panniyur-9	Open pollinated progeny selection of Panniyur 3			38	6.11	12.71	5	This variety perform well in hilly tracts. It is extremely tolerant to drought.
Panniyur-10	Progeny of Panniyur 1 x Cul 54 (OP of cv. Karivally)		-	-	-	-	-	High yielding climate resilient variety producing long spikes and bold berries. It is tolerant to Phytophthora infection. High quality variety with high bulk density.
Vijay	Panniyur 2 x Neelamundi	College of Horticulture, Vellanikkara, Kerala	-	-	-	-	-	It is released for cultivation in Kerala. The variety is high yielding with bold berries and high quality. Field tolerant to Phytophthora foot rot.
Subhakara	Clonal selection from Karimunda (KS 27)	ICAR-Indian Institute of Spices Research, Kozhikode, Kerala	2352	35.5	4.0	10.0	6.0	A selection with high quality pepper and wider adaptability. It is suited to all pepper growing regions of Kerala and Southern Karnataka. It gives an average yield of 4.2 kg green pepper per vine. Its potential yield is 4487 kg per hectare.
Sreekara	Clonal selection from Karimunda (KS 14)		2677	35.0	4.2	13.0	4.0	Suited to all pepper growing regions of Kerala and Southern Karnataka and gives high quality pepper. Its potential yield is 4200 kg per hectare.
Panchami	Germplasm selection from Aimpiriyan		2828	34.0	4.7	12.5	3.4	A high yielding variety (5.2 kg green pepper/ vine) with excellent fruit set.

	(Coll.856)							Spike twisted in appearance due to high fruit set. Oleoresin content is high (12.5%). Late maturing type suited to all pepper growing areas. Potential yield is 5356 kg/ha.
Pournami	Germplasm selection from Ottaplackal (coll.812)		2333	31.0	4.1	13.8	3.4	A moderately high yielding vine (4.7 kg green pepper/ vine) with high oleoresin content (13.8%). It is tolerant to root knot nematode (*M. incognita*). Potential yield is 6528 kg/ha.
PLD-2	Clonal selection from Kottanadan (Coll.2559)		2475	-	3.3	15.5	3.5	A variety with high quality and suitable to all Pepper growing areas. Late maturing type suited to Trivandrum and Quilon districts of Kerala. Potential yield is 4731 kg/ha.
IISR Thevam	Clonal selection of Thevanmundi		2481	32.0	1.7	8.2	3.1	Tolerant to foot rot disease (durable resistance). Suited to high altitudes and plains. It is a medium maturing type produces high yield (5.17 kg fresh pepper/vine).
IISR Malabar Excel	F_1 of Cholamundi x Panniyur-1		1440	32.0	4.9	14.6	4.1	Suited to high altitudes and rich in oleoresin.
IISR Girimunda	F_1 of Narayakodi x Neelamundi		2880	32.0	2.2	9.7	3.4	High yielding variety (6.14 kg fresh pepper/vine) suited to high altitudes.
IISR Sakthi	Open-pollinated progeny of Perambramundi		2253	43.0	3.3	10.2	3.7	Tolerant to foot rot disease in the juvenile phase. It is suitable to both plains and high ranges under rain fed conditions. Average yield 2253 kg dry pepper/ha.
Arka Coorg Excel	Seedling selection	ICAR-Indian Institute of Horticulture Research, CHES, Chettali and ICAR-Indian Institute of Spices Research, Regional Station, Appangala, Karnataka	3267	40	2.1	6.9	1.6	It is suited to Kodagu district of Karnataka and similar areas. High yielding, with long spikes and bold berries. It produces 7.15 kg fresh pepper/vine.

Loss of biodiversity and conservation

Cultivar diversity is contributed to breeding and conservation programmes. The genetic resources of black pepper in India are a great strength for its improvement. This germplasm, which includes native cultivars, wild forms from the area of origin, and related species, can be used in crop improvement. Most of the improved varieties released for cultivation are clonal selections from the existing landraces (Table 3). Germplasm collection of local, native and wild black pepper can serve as a source of genetic diversity (Prayoga *et al*., 2020) [23]. 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 primarily to gene attrition caused by the rapid displacement of many local cultivars by high yielding varieties. Field surveys undertaken by Mathew *et al.* (2005) [16] revealed that a significant proportion of *Piper nigrum* 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. As a result, a field gene bank of the species is being built at the Tropical Botanic Garden and Research Institute in Trivandrum, with the goal of maintaining the primary gene pool of the black pepper. Even if the early migration of settlers across Kerala assisted in the spread of landraces to new locations, the introduction of enhanced varieties of black pepper poses a danger to many of the older cultivars. These landraces may be lost forever unless collected and conserved (Saji *et al.*, 2019) [30].

It is necessary to establish sanctuaries for wild relatives of crop species and other commercially significant species in the Western Ghats and Northeastern regions of India, which are known to be the origins of *Piper* species (Prasath *et al*., 2017) [22]. Systematic surveys of all pepper growing areas, forests of the Western Ghats and parts of the Northeastern regions were conducted to collect the available variability of cultivated forms and wild relatives and these accessions are maintained at the black pepper germplasm conservatory at the Indian Institute of Spices Research, Kozhikode, Kerala, as field gene bank as well as in the nursery. IISR has the world's largest collection of black pepper germplasm consisting of 3467 accessions being maintained at ICAR-IISR, Chelavoor: Experimental Farm, Peruvannamuzhi as well as in alternate sites (Appangala and Chettalli of Karnataka) (IISR, 2021). Besides the germplasm collections of IISR, Kozhikode some accessions of black pepper germplasm are also maintained under the All India Coordinated Research Project on Spices at various places. Also, certain lines have been found to be able to tolerate diseases, pests, and drought stress during germplasm screening in IISR.

The germplasm conserved in-situ and ex-situ through field gene bank is vulnerable to a variety of threats, including natural calamities, disease epidemics and so on. At IISR Calicut, in-vitro conservation of significant Piper species is being undertaken to save the germplasm as an alternate source. Slow growth technologies for in-vitro conservation have been standardised and the in-vitro gene bank currently holds 35 accessions, including exotic species (IISR, 2003). *Piper* species are also conserved in the national conservatory of the NBPGR, New Delhi. Furthermore, the introduction of exotic germplasm with desirable characteristics may be

required to improve this spice and meet worldwide demand (Prasath *et al*., 2017) [22].

Conclusion

Black pepper genetic diversity is primarily found in the Western Ghats, where it originated. Over 100 black pepper cultivars are known. Local cultivars and wild relatives of this crop are important sources of genetic material contributing to desirable traits such as bold berries, high fruit set, high quality and pest, disease, and drought tolerance. The Western Ghats are home to the majority of *Piper nigrum* species, with the Southern Western Ghats having the maximum cultivar diversity. Many natural populations of *P. nigrum* have been wiped out in recent years due to extensive land use changes and habitat changes in the Western Ghats. Wild relatives of various crop plants, including black pepper, are under grave threat and conservation of these precious resources is desperately necessary.

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