



REVIEW ARTICLE

ORIGIN, TAXONOMY, BOTANICAL DESCRIPTION, GENETIC DIVERSITY, BREEDING AND CULTIVATION OF BLACK PEPPER

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ABSTRACT

Pepper or peppercorn belongs to the family Piperaceae, genus *Piper* and species *Piper nigrum* L. Black pepper (*Piper nigrum* L., Piperaceae) – ‘King of spices’ – is one of the oldest spices known. Since black pepper is essentially a spice, varieties that are developed should have good quality attributes such as significant levels of oleoresins, piperine and volatile essential oil. Black pepper also has important medicinal properties. Importance is also given to caryophyllene content, which is known for its antioxidant properties as well as its contribution to flavour. Chemoprofiling of black pepper accessions with gas chromatography mass spectrometry (GCMS) is being done to identify genotypes with hitherto undetected compounds for their pharmaceutical properties. The identification of newer properties adds value addition to black pepper, thus increasing the demand for its use for pharmaceutical products. The word “pepper” has its roots in the Dravidian word for long pepper, pippali. Ancient Greek and Latin turned pippali into the Latin piper, which was used by the Romans to refer both to black pepper and long pepper, as the Romans erroneously believed that both of these spices were derived from the same plant. Today's "pepper" derives from the Old English pipor. The Latin word is also the source of Romanian **piper**, Italian pepe, Dutch peper, German Pfeffer, French poivre, and other similar forms. In the 16th century, pepper started referring to the unrelated New World chili pepper as well. "Pepper" was used in a figurative sense to mean "spirit" or "energy" at least as far back as the 1840s; in the early 20th century, this was shortened to pep. The word *pepper* derives from Old English *pipor*, Latin *piper*, and Greek: *πέπερι*. The Greek likely derives from Dravidian *pippali*, meaning "long pepper". Sanskrit *pippali* shares the same meaning (Wikipedia, 2024). 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. Black pepper is a flowering vine in the family Piperaceae, cultivated for its fruit (the peppercorn), which is usually dried and used as a spice and seasoning. The fruit is a drupe (stone fruit) which is about 5 mm in diameter (fresh and fully mature), dark red, and contains a stone which encloses a single pepper seed. Peppercorns and the ground pepper derived from them may be described simply as pepper, or more precisely as black pepper (cooked and dried unripe fruit), green pepper (dried unripe fruit), or white pepper (ripe fruit seeds). In this review article on Origin, Taxonomy, Botanical Description, Genetic Diversity, Breeding and Cultivation of Black Pepper are discussed.

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INTRODUCTION

Pepper or peppercorn belongs to the family Piperaceae, genus *Piper* and species *Piper nigrum* L. (Hai and Long An, 2015; Mia, 2016; Wikipedia, 2024; Plantae, 2024; Invasive, 2024). Black pepper (*Piper nigrum* L.) – ‘King of spices’ – is one of the oldest spices known (Krishnamoorthy and Parthasarathy, 2009). Since black pepper is essentially a spice, varieties that are developed should have good quality attributes such as significant levels of oleoresins, piperine and volatile essential oil. Black pepper also has important medicinal properties. Importance is also given to caryophylline content, which is known for its antioxidant properties as well as its contribution to flavour. Chemoprofiling of black pepper accessions with gas chromatography mass spectrometry (GCMS) is being done to identify genotypes with hitherto undetected compounds for their pharmaceutical properties. The identification of newer properties adds value addition to black pepper, thus increasing the demand for its use for pharmaceutical products (Krishnamoorthy and Parthasarathy, 2009). The word "pepper" has its roots in the Dravidian word for long pepper, *pippali*. Ancient Greek and Latin turned *pippali* into the Latin *piper*, which was used by the Romans to refer both to black pepper and long pepper, as the Romans erroneously believed that both of these spices were derived from the same plant. Today's "pepper" derives from the Old English *pipor*. The Latin word is also the source of Romanian *piper*, Italian *pepe*, Dutch *peper*, German *Pfeffer*, French *poivre*, and other similar forms. In the 16th century, *pepper* started referring to the unrelated New World chili pepper as well. "Pepper" was used in a figurative sense to mean "spirit" or "energy" at least as far back as the 1840s; in the early 20th century, this was shortened to *pep* (Hai and Long An, 2015). The word *pepper* derives from Old English *pipor*, Latin *piper*, and Greek: *πέπερι*. The Greek likely derives from Dravidian *pippali*, meaning "long pepper". Sanskrit *pippali* shares the same meaning (Wikipedia, 2024). Those Indian tongues which changed the meaning of the old pepper word to chile may still retain the original meaning in combination with qualifying adjectives. Examples are provided by Hindi and Urdu names of black pepper, *kali mirch* and *gol mirch*, which literally mean black chile and round chile, respectively. A rather absurd example is Malayalam *vellakurumulaku* white pepper, literally white black chile. That pepper is named after chile in Indian languages is quite ironic as pepper is native to India, whereas chile has been introduced only 500 years ago. Sanskrit *marichan* is also the source of modern Indonesian *merica* and Khmer *marich*, which has conserved the original meaning pepper, supposedly, that word has been transferred to Southeast Asian languages at the same time when pepper became known in Malesia and the South East Asian peninsular due to Indian influence (about 1000 years ago). Sanskrit is rich in synonyms and has many more names for black pepper, some of which derive from the adjective *krishna* black. Yet another name is *yavanapriya* conserved in Modern Tamil as *yavanappiriyam*. The meaning of this compound is dear to the Greeks, hinting at the high commercial value of pepper (Katzner, 2024). 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.

Black pepper is considered the King of Spices and is the most widely used spice in the world. Mature berries (fruit), harvested and dried, are the black pepper of commerce. Ripe berries are harvested and decorticated for production of white pepper. It is valued for its characteristic pungency and flavor, the former due mainly to the alkaloid piperine and the later due to a volatile oil. Black pepper has multiple uses in the processed food industry, the kitchen, in perfumery, traditional medicines and in beauty care (Sarma *et al.*, 2014). Black pepper is mainly grown in tropical regions of the world, such as India, Indonesia, Malaysia, Sri Lanka, Thailand, China, Vietnam, Cambodia, Brazil, Mexico, and Guatemala. The estimated production of black pepper (including long pepper) in the world is approximately 409 899 ton on an approximate area of 583 897 ha. The International Pepper Community members namely India, Brazil, Malaysia, Indonesia, Vietnam, and Sri Lanka are the main suppliers to the world market (Sarma *et al.*, 2014). Major importers of Indian pepper include USA, Russia, Canada, Germany, Italy, Netherlands, France, Japan, Morocco, Poland, UK, Canada, and Saudi Arabia. Black pepper accounts for approximately 6.2% of the total spices traded internationally. Demand for black pepper and its products in the world market are increasing at the rate of 3.2% annually in volume and 8% in value (Sarma *et al.*, 2014). The black pepper plant (scientific name *Piper nigrum*, also called the peppercorn plant or pepper tree) is a flowering vine that produces green flower spikes and small, dark fruits (or drupes) called peppercorns that you can dry and grind into a common table seasoning (Master, 2021). Native to southern India and now common across Indonesia, Southeast Asia, Vietnam, Brazil, and other tropical regions, the black pepper is a tropical plant that enjoys warm, wet conditions with mild winters. Nowhere in the United States do winters stay warm enough for year-round black pepper growth, though the southernmost parts of the country might allow for perennial black pepper growth. In other climates, gardeners can grow black pepper vines as an ornamental annual or bring the plants inside or into a greenhouse over the colder months (Master, 2021).

The major difference between these two is the matter of process. People are usually familiar with black peppercorns, which are harvested when the berries are ready to ripen. After gathering, these berries are sun-dried, which darkens their outermost layer. The black pepper has a very powerful flavour by the time it dries. It tastes finest when freshly ground. Black pepper is richer and more robust. It also has a powerful aroma and a lot of spicy heat. Whole black peppercorn can be stored in an airtight container for up to a year.

The pre-ground product, on the other hand, loses its finest flavour after a few months. That is why you may get pepper bottles with built-in grinders. While black pepper is considerably more popular in American kitchens. Black pepper, when consumed on a regular basis, assists in weight loss, improves digestion, increases metabolism, cures skin issues, asthma, and sinus and nasal congestion. It also lowers the risk of cancer, heart disease, and liver disease (Vasantmasala, 2021). White peppercorns, on the other hand, have the outer covering of the berry removed either before or after sun drying, leaving just the lighter-coloured interior seed. White pepper is ideal if you have a softer palate. The taste is mild, earthy, and straightforward. It's great for spicing up meals that only require a dash of flavour. White pepper loses taste considerably faster than black pepper because it is more "exposed." It will go stale, and you may be unaware of it. White pepper's aesthetic charm has made it a fundamental ingredient in French, Chinese, Vietnamese, and Swedish cuisines. White pepper is ideal for individuals who are experiencing appetite loss since it stimulates appetite and supports a healthy gut. It is also used to treat constipation since it promotes peristalsis in the large intestine and speeds up metabolism. It has anti-inflammatory properties. It also freshens the breath, strengthens the immune system, and tones the entire body. It cleanses the body of toxic pollutants and improves circulation (Vasantmasala, 2021).

Black pepper is also well-known as the King of Spice. It is widely used for culinary purposes, especially for the growing pre-treatment food business. The demand for black pepper increases with industrialized food economies like fried food, pastries and bakery products. Aside from being a condiment, black pepper has anticancer, antidiabetic, and antimicrobial properties, as well as the ability to improve digestion (Meghwal, 2012). According to the global black pepper market research, worldwide black pepper production was recorded at its maximum volume at 752 K tonnes in the year 2018 with a value of 4.1b US dollars. The production is likely to continue its growth as the consumption from all over the world indicates a substantial expansion (Khew, *et al.*, 2022). In Malaysia, black pepper is an important cash crop that remains one of the biggest foreign exchange-earners. Almost 95% of Malaysian black pepper is produced in the state of Sarawak, keeping the country in the top 5 after Vietnam, Brazil, Indonesia, and India in black pepper production (International Pepper Community, 2020). Black pepper was introduced to Sarawak in the 18th century by the Chinese Hakka (Kejia), who came to Bau to mine gold and plant black pepper (Sim and Paulus, 2011). During the British Rajah era, black pepper planting was encouraged in Sarawak. Land incentives and foreign labor importation policies introduced by Charles Brooke's administration have been highly effective in promoting its expansion. However, with depressed black pepper prices and replacement by other commodities, the cultivation area for black pepper was subsequently declined. Today, national black pepper production in 2020 was about 35,000 metric ton lower than other countries, namely India at 61,000 metric ton, Indonesia at 78,000 metric ton and Vietnam at 250,000 metric ton. While Malaysia still exported some 9,820 tonnes of black pepper in 2019 and 11,714 tonnes in 2018, the volume was RM 228.7 million and RM 318.4 million, respectively (Khew, *et al.*, 2022).

This climbing vine is currently providing a living for 35,000 farmers in Sarawak. Planting areas are clustered in various districts in Kuching, Sarikei, Serian, and Betong. Smallholder farming is the main cultivation practice, with an estimated cultivated area of 7,414 hectare. Although the demand for black pepper is increasing, the cultivation of black pepper is labor intensive. It is beset with difficulties like the incidence of serious diseases and pests and high cost of inputs. The production of black pepper is greatly affected by the volatility of the process. Low prices led to poor maintenance and even abandonment of farms. Therefore, it is necessary to develop a cost-effective package of black pepper production to make the cultivation more sustainable. One of the components in this package would be the availability of new varieties which are high yielding, resistant or tolerant to the major pests and diseases, as well as abiotic stress. In developing a new variety of pepper with desired traits, new plant breeding techniques should be explored as the conventional breeding methods are slow (Khew, *et al.*, 2022). To provide more efficient black pepper production systems, it is undeniable that crop genetics must be improved concurrently with planting practices. Recent advancement in genome-editing technologies like CRISPR/Cas9, CRISPR/Cpf1, prime editing, base editing and dCas9 epigenetic modification has changed the plant breeding science and has significant potential in crop genetic improvement. In addition, the revolutionized sequencing technologies are amenable to producing high-density DNA markers and genetic information efficiently at a low cost. These have transformed the strategy in plant breeding to develop crops with desired characteristics by establishing predictive breeding methods (Khew, *et al.*, 2022). Amidst significant improvement in breeding technology, developing an improved black pepper variety still faces extended plant generation cycle constraints. In Sarawak, systematic black pepper breeding research was started in 1971 (Sim and Paulus, 2011). However, it takes more than two decades to release a new variety, "Semongok Emas", with several desirable traits like good setting and more uniform ripening of berries; less susceptible to the attack of black berry disease, *Phytophthora* foot rot and pepper weevil (Sim, 1993). As a result, a more robust and faster method than traditional breeding must be used to establish the crucial cross needed to meet the pace of global demand. The emerging technology of speed breeding appears to be a potential tool to accelerate the breeding cycle to develop a new variety in a short span of time. Furthermore, the speed breeding technology will further empower the development of designer black pepper with all economic importance traits. This review summarised all the recent advancements in crop improvement technology potential for black pepper new variety development (Khew, *et al.*, 2022).

Black Peppercorns are the dried drupe fruits of the pepper plant, botanically classified as *Piper nigrum*. The fruits of this perennial climbing vine grow in clusters with over thirty individual fruits on each tendril. The peppercorns are harvested when they begin to change color from green to red. They are then boiled for an hour and set out to dry for up to four days, resulting in a hard, shriveled, and black outer skin. The pepper plant also produces green, red, and white peppercorns, depending on the stage at which the fruit is harvested and how they are treated after harvest. White peppercorns, the second most popular pepper, is created by removing the pepper fruit's dark outer skin and flesh, leaving behind the seed of the peppercorn. With the exterior removed, it has a milder and less fruity flavor than black pepper with notes of musty wet hay. If the peppercorns are harvested early, while they are still green, they are green peppercorns. These are often treated with sulfur dioxide or freeze-dried to maintain their color during the drying process, or they can be pickled to retain a softer texture and fresher flavor. If the peppercorns are left to ripen on the

vine, they will turn a bright red color known as red peppercorns. These must also be treated to maintain their luminous hue. Another well-known pepper, pink peppercorns, are the fruit of a South American tree, *Schinus molle*, and are not related to black peppercorns (Invasive, 2024).

Black pepper, (*Piper nigrum*), perennial climbing vine of the family Piperaceae and the hotly pungent spice made from its fruits (Petruzzello, 2024). Black pepper is native to the Malabar Coast of India and is one of the earliest spices known. Widely used as a spice around the world, pepper also has a limited usage in medicine as a carminative (to relieve flatulence) and as a stimulant of gastric secretions (Petruzzello, 2024). In early historic times pepper was widely cultivated in the tropics of Southeast Asia, where it became highly regarded as a condiment. Pepper became an important article of overland trade between India and Europe and often served as a medium of exchange; tributes were levied in pepper in ancient Greece and Rome. In the Middle Ages the Venetians and the Genoese became the main distributors in Europe, and their virtual monopoly of the trade helped instigate the search for an eastern sea route. The plant is widely cultivated throughout Indonesia and has been introduced into tropical areas of Africa and of the Western Hemisphere (Petruzzello, 2024).

Growing black pepper is a feasible and rewarding endeavor, offering benefits beyond mere cost savings. Peppercorns have a rich history, having been traded between East and West for centuries, known to the ancient Greeks and Romans, and even used as currency in some European countries. This highly valued spice stimulates salivation and gastric juice production, enhancing the flavor of dishes worldwide. The peppercorn plant, scientifically known as *Piper nigrum*, is a tropical species cultivated for its black, white, and red peppercorns. The different colors represent various stages of the same fruit. Black peppercorns are dried, immature fruits known for their robust flavor and aroma. White pepper, on the other hand, is derived from the mature fruit's inner portion, offering a milder taste. Understanding these stages highlights the versatility and culinary significance of peppercorns, making them an essential ingredient in global cuisine. Cultivating black pepper can thus connect you to a tradition that spans millennia and continents, enriching your kitchen with a spice celebrated for both its historical importance and culinary excellence (Kelvine, 2024). Black pepper is a perennial vine grown for its berries extensively used as spice and in medicine. India is one of the major producer, consumer and exporter of black pepper in the world. Black pepper is cultivated to a large extent in Kerala, Karnataka and Tamil Nadu and to a limited extent in Maharashtra, North eastern states and Andaman & Nicobar Islands. Kerala and Karnataka account for a major portion of production of black pepper in the country (Vikaspedia, 2024).

Black pepper is a flowering vine in the family *Piperaceae*, cultivated for its fruit (the peppercorn), which is usually dried and used as a spice and seasoning. The fruit is a drupe (stonefruit) which is about 5 mm in diameter (fresh and fully mature), dark red, and contains a stone which encloses a single pepper seed. Peppercorns and the ground pepper derived from them may be described simply as *pepper*, or more precisely as *black pepper* (cooked and dried unripe fruit), *green pepper* (dried unripe fruit), or *white pepper* (ripe fruit seeds) (Wikipedia, 2024). Black pepper is native to the Malabar Coast of India, and the Malabar pepper is extensively cultivated there and in other tropical regions. Ground, dried, and cooked peppercorns have been used since antiquity, both for flavour and as a traditional medicine. Black pepper is the world's most traded spice, and is one of the most common spices added to cuisines around the world. Its spiciness is due to the chemical compound piperine (Wikipedia, 2024). Black pepper, the king of spices, is obtained from the perennial climbing vine, *Piper nigrum* which is indigenous to the tropical forests of Western Ghats of South India. It is one of the important and earliest known spices produced and exported from India. It is grown in about 1.36 lakhs ha land with an annual production of 32 thousand tonnes, largely distributed in Kerala (94%), Karnataka (5%), the rest being Tamil Nadu, Andhra Pradesh and north eastern states especially Assam. India accounts for 54 per cent of the total area under pepper in the world but its share of production is only 26.6 per cent where as the other countries like Brazil, Indonesia, Malaysia accounts for lesser percentage of area but with more share in the total production due to their productivity. Annually, India is exporting about 41000 tonnes of black pepper earning a foreign exchange of Rs. 240 crores (TNAU, 2024). In this review article on Origin, Taxonomy, Botanical Description, Genetic Diversity, Breeding and Cultivation of Black Pepper are discussed.

ORIGIN AND DISTRIBUTION

It originated in the humid, tropical evergreen forests of Western Ghats of India and is now grown in more than 25 countries, particularly in tropics. Important growing locations are India, Indonesia, Malaysia, Brazil, Thailand, Sri Lanka, Vietnam and China (Krishnamoorthy and Parthasarathy, 2009). 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 (Chao-yun *et al.*, 2012). Black pepper is native to Kerala, the southern state of India. Within the genus *Piper*, it is most closely related to other Asian species such as *Piper caninum*. Other source: Black pepper is either native to Southeast Asia or South Asia. Peppercorns are often categorized by their place of origin. Two types come from India's Malabar Coast: *Malabar* and *Tellicherry*. Tellicherry comes from grafted Malabar plants grown on Mount Tellicherry. Sarawak pepper is native to the Malaysian portion of Borneo. White Muntok pepper comes from Indonesia and Lampung hails its island of Sumatra. Vietnam produces both white and black pepper in the provinces of Bà Rịa - Vũng Tàu, Chu Se District, Bình Phước, and Phú Quốc Island in Kiên Giang Province. Kampot Pepper is native to Kampot, Cambodia and received Geographical indication (GI) status in 2008. This pepper is grown in a limited geographical region in four varieties: black, green, red, and white (Hai and Long An, 2015). Black pepper is native either to Southeast Asia or South Asia. Within the genus *Piper*, it is most closely related to other Asian species such as *P. Caninum* (Wikipedia, 2024). Black pepper is native to South Asia and Southeast Asia, and has been known to Indian cooking

since at least 2000 BCE. J. Innes Miller notes that while pepper was grown in southern Thailand and in Malaysia, its most important source was India, particularly the Malabar Coast, in what is now the state of Kerala. The lost ancient port city of Muziris in Kerala, famous for exporting black pepper and various other spices, gets mentioned in a number of classical historical sources for its trade with Roman Empire, Egypt, Mesopotamia, Levant, and Yemen. Peppercorns were a much-prized trade good, often referred to as "black gold" and used as a form of commodity money. The legacy of this trade remains in some Western legal systems that recognize the term "peppercorn rent" as a token payment for something that is, essentially, a gift (Wikipedia, 2024). Black peppercorns were found stuffed in the nostrils of Ramesses II, placed there as part of the mummification rituals shortly after his death in 1213 BCE. Little else is known about the use of pepper in ancient Egypt and how it reached the Nile from the Malabar Coast of South Asia. Pepper (both long and black) was known in Greece at least as early as the fourth century BCE, though it was probably an uncommon and expensive item that only the very rich could afford (Wikipedia, 2024).

By the time of the early Roman Empire, especially after Rome's conquest of Egypt in 30 BCE, open-ocean crossing of the Arabian Sea direct to Chera dynasty southern India's Malabar Coast was near routine. Details of this trading across the Indian Ocean have been passed down in the *Periplus of the Erythraean Sea*. According to the Greek geographer Strabo, the early empire sent a fleet of around 120 ships on an annual trip to India and back. The fleet timed its travel across the Arabian Sea to take advantage of the predictable monsoon winds. Returning from India, the ships travelled up the Red Sea, from where the cargo was carried overland or via the Nile-Red Sea canal to the Nile River, barged to Alexandria, and shipped from there to Italy and Rome. The rough geographical outlines of this same trade route would dominate the pepper trade into Europe for a millennium and a half to come (Wikipedia, 2024). With ships sailing directly to the Malabar coast, Malabar black pepper was now travelling a shorter trade route than long pepper, and the prices reflected it. Pliny the Elder's *Natural History* tells us the prices in Rome around 77 CE: "Pliny also complains, 'There is no year in which India does not drain the Roman Empire of 50 million sesterces', and further moralizes on pepper. It is quite surprising that the use of pepper has come so much into fashion, seeing that in other substances which we use, it is sometimes their sweetness, and sometimes their appearance that has attracted our notice; whereas, pepper has nothing in it that can plead as a recommendation to either fruit or berry, its only desirable quality being a certain pungency; and yet it is for this that we import it all the way from India! Who was the first to make trial of it as an article of food? and who, I wonder, was the man that was not content to prepare himself by hunger only for the satisfying of a greedy appetite?' (Wikipedia, 2024).

Black pepper is native to Malabar, a region in the Western Coast of South India; today, this region belongs to the union state Kerala. Pepper is cultivated since millennia. The wild form has not yet been unambiguously identified, but there are closely related pepper species in South India and Burma. While black and white pepper were already known in antiquity, but green pepper (and even more, red pepper) is a recent invention. Pepper reached South East Asia more than two thousand years ago and is grown in Malaysia and Indonesia since about that time. In the last decades of the 20th century, pepper production increased dramatically as new plantations were founded in Thailand, Vietnam, China and Sri Lanka. In the New World, Brazil is the only important producer; pepper plantations there go back to the 1930s (Katzer, 2024). Black pepper, grown in Southern India since more than two thousand years, has always been much valued all over the world. After Alexander the Great had warred upon Central Asia, and indeed even reached India (4th century BC), new trading routes were established that brought, for the very first time, pepper into the West. Within short time, pepper's growing popularity made it a most important item of commerce. Soon, Arabic traders established a pepper monopoly and transferred the spice via the spice route through the Arab peninsular and Egypt to their European customers, whom they denied any knowledge about the actual origin of pepper (Katzer, 2024). Black Peppercorns are native to the Malabar Coast of India, where evidence shows the spice has been used for over 4,000 years. Indian traders spread the spice east to China and west into Ancient Egypt, Greece, and Rome. The Roman Empire controlled the trade of the spice until the empire fell in the 5th century. Arab traders took control of the spice trade through the Middle Ages, creating fantastic stories of the spice's origin to drive up its demand and price. By the 10th century, Black Pepper had gained in popularity throughout much of Europe, leading to taxes being levied on its trade. The spice's exorbitant price led many countries to seek out its origin. These quests led the Spanish to discover the New World and the Portuguese to discover the Spice Islands of Indonesia (Invasive, 2024).

TAXONOMY

Pepper or peppercorn belongs to the family Piperaceae, genus *Piper* and species *Piper nigrum* L. (Hai and Long An, 2015; Mia, 2016; Wikipedia, 2024; Plantae, 2024; Invasive, 2024). The genus *Piper* comprises around 1200 species, approximately 60% of which occur in Central and Northern South America. The Malabar Coast of South West India is the traditional home of black pepper, grown from almost sea level to approximately 1500 m. Black pepper was the first oriental spice to be introduced into the western world (Sama *et al.*, 2014). Pepper can also be raised in bush form. The fruiting lateral branches of any cultivar can be rooted and the resultant plant grown like a small bush, which flowers in the same year and continues to yield throughout the year under irrigation. These bush peppers can be accommodated well in homes and terrace gardens. Pepper plants take 6–8 months from flower to harvest depending on the cultivar and rains. Whole spikes are hand-picked when a few berries in the spikes turn orange red. Harvesting is also done based on processing requirements. Harvested spikes are kept overnight for easy despiking. Berries are separated from spikes manually or mechanically using threshers. To give a uniformly lustrous black color and to prevent moldiness, the separated berries are dipped in boiling water for 1 min before drying. Drying is done both by sunlight for 7–10 days or using mechanical dryers to a moisture content of 10–12%. Dried pepper is cleaned to remove extraneous matter and graded according to size before packing (Sama *et al.*, 2014). Rooted lateral branches grown as bushes are known as bush pepper. Bush pepper can be raised as potted bushes or field grown bushes. Bush pepper yields green pepper throughout the year and the fresh yield per bush can be up to 1 kg after 3 years of planting (Vikaspedia, 2024). It is a method of cultivating the vine in the form of bush. One year old healthy fruiting branches are selected with 3 to 5 nodes and all the leaves except the flag leaf are removed and planted in a shaded area in the nursery, either in trenches or in polybags (45 cm x 30 cm) containing moist coir dust.

Before planting, the cuttings are dipped in 1000 ppm of IBA for 45 seconds. After planting, the trenches are covered with polythene sheets and in the case of polybags; the mouth is tightly tied with coir thread to avoid moisture loss. They normally root in 30 to 50 days. Such rooted cuttings are planted in pots or fields after sufficient hardening treatment. Cuttings grow like a bush and flower in the same year itself. These bushes produce more and more of fruiting branches only. Adequate manuring *i.e.*, 2 to 5 kg of FYM along with 10 g of NPK 1:1:2 mixtures may be given per bush at 3 months interval. Watering and plant protection may be adopted according to necessity. Under average management a good bush pepper plant may yield 1.5 kg green pepper in a span of 2 to 3 years (TNAU, 2024). There are hundreds of Pepper varieties. All Pepper varieties are derived from the same vine (*Piper nigrum*). Different varieties result from picking the berries at various stages of ripening and processing them differently. Common varieties include the following (Hai and Long An, 2015):

Black peppercorns: This is the most popular form of pepper on the World. Black peppercorns are produced by picking the mature but unripe berries as they are beginning to turn from green to yellow. They are then boiled briefly and then allowed to ferment and dry naturally in the sun (or by forced-air heating) until wrinkled and black. Black Pepper is moderately hot, pungent and aromatic. Most generic black pepper sold in stores is a mixture from a variety of sources bought at the lowest possible price. None of the varieties or grades that we offer would fall into this category. On the World's markets sell only distinct varieties of the highest grade available with the names indicating the origin (Hai and Long An, 2015).

White Peppercorns: These are fully mature berries that have been picked partially ripe and had their outer skin removed. This is generally done by soaking the berries in water for a number of days and then rubbing the outer skins off. It is also sometimes done mechanically while dry. The aroma is earthy and taste is hot and creamy but not pungent or aromatic. It is quite distinctive in aroma and flavor from that of the black pepper and almost never used as final seasoning. White pepper is commonly used for sauces, soups, potatoes and beverages. (This is most popular pepper in northern Europe, outselling black pepper by 10:1, reverse the ratio of the USA.) Due to the extra processing involved white pepper is slightly more expensive than black peppercorns from the same origin (Hai and Long An, 2015).

Green peppercorns: These are berries that are picked long before maturity in the green stage and either air-dried, freeze-dried or pickled in brine to prevent fermentation. They are aromatic with a fresh flavor, but are not pungent. In the dried form they are considered essential for French, Creole and some Thai cooking. This is the also the pepper called for in a traditional "peppercorn" sauce. Because of the extra processing required and the smaller yield, these are some of the more expensive peppercorns. In recent years Brazil has become the chief source for this variety if you are able to find them at all. It is offer freeze-dried green peppercorns from Brazil, which are more expensive, but widely recognized to have superior appearance and a flavor that some prefer. It is also offer air-dried peppercorns from India. These are much more economical and some prefer the flavor of the air-dried variety (Hai and Long An, 2015).

Red Peppercorns: In the world of pepper, there is probably no other term that causes more confusion than "Red Peppercorns". Some persons or cookbook publishers use this term interchangeably with what we call "Rose" or "Pink" peppercorns. That would be fine except for the fact that there is a true (*Piper nigrum*) Red Peppercorn. (Do not confuse with "Red Pepper" which is finely ground Cayenne and other capsicum peppers.) Red Peppercorns are extremely rare and not presently imported into the USA to someone's knowledge. It is generally safe to assume that any recipe that calls for "Red Peppercorns" is in fact referring to the "Rose or Pink Pepper" described below. So what are they? Red peppercorns are fully ripened berries that are bright red in color when they are picked. They may be used fresh, but they spoil quickly, so they can be preserved in brines, freeze-dried, or air dried. The air-dried samples someone evaluated from Cambodia looked like very large black peppercorns, with a slight reddish-burgundy hue mixed with the black color. The aroma is complex with little pungency, and the flavor is hot. (In this respect the flavor is very similar to what you get with the highest grades of Tellicherry, as those berries are almost ripe when picked.) It would be expected that the freeze-dried or bread peppercorns would retain their red color and have a completely different flavor. We can't say for sure until we get some to try (Hai and Long An, 2015).

Peppercorns come in a variety of colours, any one of which may be used in food preparation, especially common peppercorn sauce (Wikipedia, 2024).

Black pepper: Black pepper is produced from the still-green, unripe drupe of the pepper plant. The drupes are cooked briefly in hot water, both to clean them and to prepare them for drying. The heat ruptures cell walls in the pepper, speeding the work of browning enzymes during drying. The drupes dry in the sun or by machine for several days, during which the pepper skin around the seed shrinks and darkens into a thin, wrinkled black layer. Once dry, the spice is called black peppercorn. On some estates, the berries are separated from the stem by hand and then sun-dried without boiling. After the peppercorns are dried, pepper spirit and oil can be extracted from the berries by crushing them (Wikipedia, 2024).

White pepper: White pepper consists solely of the seed of the ripe fruit of the pepper plant, with the thin darker-coloured skin (flesh) of the fruit removed. This is usually accomplished by a process known as retting, where fully ripe red pepper berries are soaked in water for about a week so the flesh of the peppercorn softens and decomposes; rubbing then removes what remains of the fruit, and the naked seed is dried. Sometimes the outer layer is removed from the seed through other mechanical, chemical, or biological methods. Ground white pepper is commonly used in Chinese, Thai, and Portuguese cuisines. It finds occasional use in other cuisines in salads, light-coloured sauces, and mashed potatoes as a substitute for black pepper, because black pepper would visibly stand out. However, white pepper lacks certain compounds present in the outer layer of the drupe, resulting in a different overall flavour (Wikipedia, 2024).

Green pepper: Green pepper, like black pepper, is made from unripe drupes. Dried green peppercoms are treated in a way that retains the green colour, such as with sulfur dioxide, canning, or freeze-drying. Pickled peppercoms, also green, are unripe drupes preserved in brine or vinegar. Fresh, unpreserved green pepper drupes are used in some cuisines like Thai cuisine and Tamil cuisine. Their flavour has been described as "spicy and fresh", with a "bright aroma." They decay quickly if not dried or preserved, making them unsuitable for international shipping (Wikipedia, 2024).

Red peppercorns: Red peppercorns usually consist of ripe peppercom drupes preserved in brine and vinegar. Ripe red peppercoms can also be dried using the same colour-preserving techniques used to produce green pepper (Wikipedia, 2024).

Pepper is one of the oldest classic spices and is used as an ingredient in many spice mixtures, such as curry. Black pepper, white pepper, and green pepper all derive from the *Piper nigrum* plant. The distinct types of pepper are obtained by harvesting at different stages of ripeness and applying different processing techniques. Black pepper plants are cultivated to produce black, white, and green pepper. The processing methods vary for each type. Black pepper is the result of drying the fruit to produce the familiar black peppercorns. White pepper is produced by soaking the fruits in water for about a week to recover the seed from the decomposed fruit. Green pepper is produced by drying unripe fruit in a way that retains its green color. Green peppercoms are often preserved by pickling. Pepper seeds contain various components, including essential oil, piperine, chavicine, piperidine, fatty oils, resin, starch, and water. The alkaloid piperine is primarily responsible for the sharp taste associated with pepper (Plantvillage, 2024).

BOTANICAL DESCRIPTION

Black pepper is a perennial woody climber. Under cultivation, pepper vines are trailed on either living or other nonliving supports, as columns 5–10 m tall. The climbing woody stems have swollen nodes with roots at each node anchoring the vine to the support. Pepper plants exhibit two types of branches: the main stem and orthotropic vegetative climbing shoots that adhere to the support with short adventitious roots at nodes; and flowering or plagiotropic (sympodial habit of growth) branches that arise from the axils of leaves of the orthotropic shoots. The pepper plant has mostly surface-feeding root system. The flowers are minute, white to light green, arranged spirally on fleshy peduncles. The cultivated pepper is self-pollinated, and pollination is by pollen falling from upper flowers to the lower flowers by gravitational pull, a process called 'geitonogamy.' The fruit (berry) is a single-seeded drupe with a fleshy pericarp and hard endocarp, pungent and red when ripe, black when dried. White pepper is the dried berries after removing the pericarp (Sama *et al.*, 2014). Black pepper comes from the berries of the pepper plant. Black pepper, green pepper and white peppercorns are actually the same fruit (*Piper nigrum*); the difference in their color is a reflection of varying stages of development and processing methods. The pepper plant is a perennial woody vine growing up to 4 metres in height on supporting trees, poles, or trellises. It is a spreading vine, rooting readily where trailing stems touch the ground. A single stem will bear 20 to 30 fruiting spikes. The harvest begins as soon as one or two fruits at the base of the spikes begin to turn red, and before the fruit is fully mature, and still hard; if allowed to ripen completely, the fruit lose pungency, and ultimately fall off and are lost. The spikes are collected and spread out to dry in the sun, then the peppercorns are stripped off the spikes. The leaves are alternate, entire, 5 to 10 centimetres long and 3 to 6 centimetres across. The flowers are small, produced on pendulous spikes 4 to 8 centimetres long at the leaf nodes, the spikes lengthening up to 7 to 15 centimetres as the fruit matures. The fruit of the black pepper is called a drupe and when dried is known as a peppercorn. Black peppercorns are made by picking the pepper berries when they are half-ripe and just about to turn red. They are then left to dry which causes them to shrivel and become dark in color. Alternatively, green peppercoms are picked while still unripe and green in color, while white peppercorns are picked when very ripe and subsequently soaked in brine to remove their dark outer shell leaving just the white pepper seed. Technically, the pepper berry is a drupe, measuring about 5 mm in diameter, containing a single large seed at its center. The plants bear fruit from the fourth or fifth year, and typically continue to bear fruit for seven years. The pepper berry is a drupe, it contains a single large seed at its center (Hai and Long An, 2015).

Piper nigrum is a perennial glabrous woody climber to 10 m or more in height. The pepper plant has 10-20 main adventitious roots from the base of the mature stem which penetrate to a depth of 1-2 m and there is an extensive mass of surface feeding roots. The branches of the stem are dimorphic. The orthotropic vegetative climbing branches give the framework of the plant; they become stout, 4-6 cm in diameter at the base, and woody with a thick flake-like bark; the internodes are 5-12 cm long. The leaves are alternate and simple, with a petiole 2-5 cm long, which is grooved above. Two lateral stipules sheath the petiole, which turn back and fall early. The lamina is ovate, entire and coriaceous, with the base oblique, obtuse or rounded and the tip acuminate. The pendant spikes are borne opposite the leaves on the plagiotropic branches and are 3-15 cm long, bearing 50-150 minute flowers borne in the axils of ovate fleshy bracts. The flowers may be unisexual or bisexual with monoecious or dioecious forms or hermaphrodite as occurs in many cultivars. The flowers have no perianth and 2-4 minute stamens are borne on each side of the ovary in hermaphrodite flowers and are 1 mm long with small anthers with two sacs. The ovary is globose, one-celled, one-ovuled, surmounted by 3-5 rather fleshy stigma. The fruit is a sessile, globose drupe, 4-6 mm in diameter, with a pulpy pericarp, borne in spike 5-15 cm long. Each spike may produce 50-60 single-seeded fruits. The unripe fruit is green with the exocarp turning red when ripe, and drying black (Mia, 2016).

Black pepper is a perennial climbing vine that grows well in the shade with supporting trees or poles. The glabrous woody climbers grow up to 10 m or more height. Black pepper plant has 10–20 primary adventitious roots developed from the base of the mature stem. The vines are grown dimorphic branching (monopodial, orthotropic branches and sympodial, plagiotropic fruiting branches) pattern. The orthotropic shoot has indeterminate growth, and leaf axils produce lateral fruiting branches. Also, each node of the orthotropic shoot has clinging roots that help the plant climb over the support trees. Leaves are simple, alternate, with 2 to 5 cm long grooved petiole, variable leaf length and breadth, 8–20 cm and 4–12 cm respectively. In India, 2 to 3 years after

planting black pepper plants have flowering during south-east monsoon (May – July). The fruiting spikes are varied lengths (3–15 cm). After 10–15 days spike emergence, the first flower appears on the top of the spike and completed nearly 6–10 days. The inflorescence is glabrous; pendulous spike arises opposite to leaves on plagiotropic branches. Wild type flowers are mostly dioecious, but the cultivated type flowers are monoecious. Self-pollination is predominant, and protogyny also encountered in black pepper. The matured fruits are spherical in shape (~5 mm diameter) and belong to drupe type (Ashokkumar *et al.*, 2021).

It is a climbing evergreen plant and grows to a height of 10m or more. The vines branch horizontally from the nodes and do not attain length, but the full grown vines completely cover the standard presenting the appearance of bush. Based on growth habits, morphological characters and biological functions, five distinct types of stem portions can be identified in the shoot system of a pepper vine. Main stem which originate from a seed or from a stem cutting. It climbs on a support with the aid of aerial or adventitious roots. Runner shoots are produced from the basal portion of the main stem, growing at right angle to the main stem, usually restricted up to 50 cm from the ground. Fruiting branches (Plagiotropes) are produced from the nodes of the main stem and they grow laterally more or less at right angles to the main stem, bearing the spikes. After a period of vertical growth, the top portion of the main shoots attains a bushy appearance with shorter, thicker internodes and profuse branching with large number of adventitious roots at the nodes. This portion of the main shoot is called top shoots or orthotropes. Hanging shoots (Geotropes) or in a fully grown vine, some of the plagiotropes at the top portion are seen to give rise to a special type of shoots which hang down and grow geotropically. The leaves are broadly lanceolate, but wide variations occur in leaf shape and are arranged alternately. The inflorescence is a catkin produced at the nodes opposite to the upper leaves. Flowers are very minute. Monoecious or dioecious or hemiphrodite forms occur in different varieties. High yielding forms should have more percentage of bisexual flowers and in cultivated varieties these flowers will be more than 80 per cent. In case, if it is less, it is compensated by the higher per cent of female flowers. The male flowers are very few, 1 to 19 per cent in different varieties. The flowers are greenish-white in color and do not have any petals or fragrance. The fruit is a single seeded berry, which has a thin, soft pericarp surrounding the seeds. It takes approximately six months to mature after flowering. Fruit setting depends upon the sex of the vine; season etc. and it will be normally about 50 percent in cultivated varieties (TNAU, 2024).

The pepper plant is a perennial woody vine growing up to 4 m in height on supporting trees, poles, or trellises. It is a spreading vine, rooting readily where trailing stems touch the ground. The leaves are alternate, entire, 5 to 10 cm long and 3 to 6 cm across. The flowers are small, produced on pendulous spikes 4 to 8 cm long at the leaf nodes, the spikes lengthening up to 7 to 15 cm as the fruit matures. Pepper can be grown in soil that is neither too dry nor susceptible to flooding, moist, well-drained, and rich in organic matter (the vines do not do well over an altitude of 900 m above sea level). The plants are propagated by cuttings about 40 to 50 cm long, tied up to neighbouring trees or climbing frames at distances of about 2 m apart; trees with rough bark are favoured over those with smooth bark, as the pepper plants climb rough bark more readily. Competing plants are cleared away, leaving only sufficient trees to provide shade and permit free ventilation. The roots are covered in leaf mulch and manure, and the shoots are trimmed twice a year. On dry soils, the young plants require watering every other day during the dry season for the first three years. The plants bear fruit from the fourth or fifth year, and then typically for seven years. The cuttings are usually cultivars, selected both for yield and quality of fruit (Wikipedia, 2024). The black pepper plant is a woody climber and may reach heights of 10 metres by means of its aerial roots. Its broad shiny green leaves are alternately arranged. The small flowers are in dense slender spikes of about 50 blossoms each. The fruits, which are sometimes called peppercorns, are drupes about 5 mm in diameter. They become yellowish red at maturity and bear a single seed. Their odour is penetrating and aromatic; the taste is hot, biting and very pungent. Ground black pepper contains up to 3 percent essential oil that has the aromatic flavour of *Capsicum* peppers but not the pungency. The characteristic flavour is principally derived from the chemical piperine, though the seeds also contain chavicine, piperidine, and piperettine. The plant requires a long rainy season, fairly high temperatures, and partial shade for best growth. Propagation is usually by stem cuttings, which are set out near a tree or a pole that will serve as a support. Pepper plants are sometimes interspersed in tea or coffee plantations. They begin bearing in 2 to 5 years and may produce for as long as 40 years (Petruzzello, 2024). Black pepper, *Piper nigrum*, is a climbing perennial plant in the family Piperaceae. It is mainly grown for its fruit, which is processed to create black, white, and green peppercorns, commonly used as a spice in cooking. The plants of black pepper may have either vining or bushy, woody stems. The plant features simple, alternating leaves with an oval shape and produces clusters, or spikes, of 50 to 150 flowers. These flowers give rise to small, spherical green fruits that ripen to red. Each stem has the potential to produce 20-30 of these spikes. While black pepper can grow to a height of 10 meters (33 feet) in the wild, under cultivation, it is usually maintained at a more manageable 3-4 meters (10-13 feet). Black pepper is a perennial plant with a lifespan of over 30 years, and it typically has a commercial lifespan of 12–20 years. This versatile spice is native to south and southeast Asia (Plantvillage, 2024). Botanical description of black pepper is given in Fig. 1

Pollination

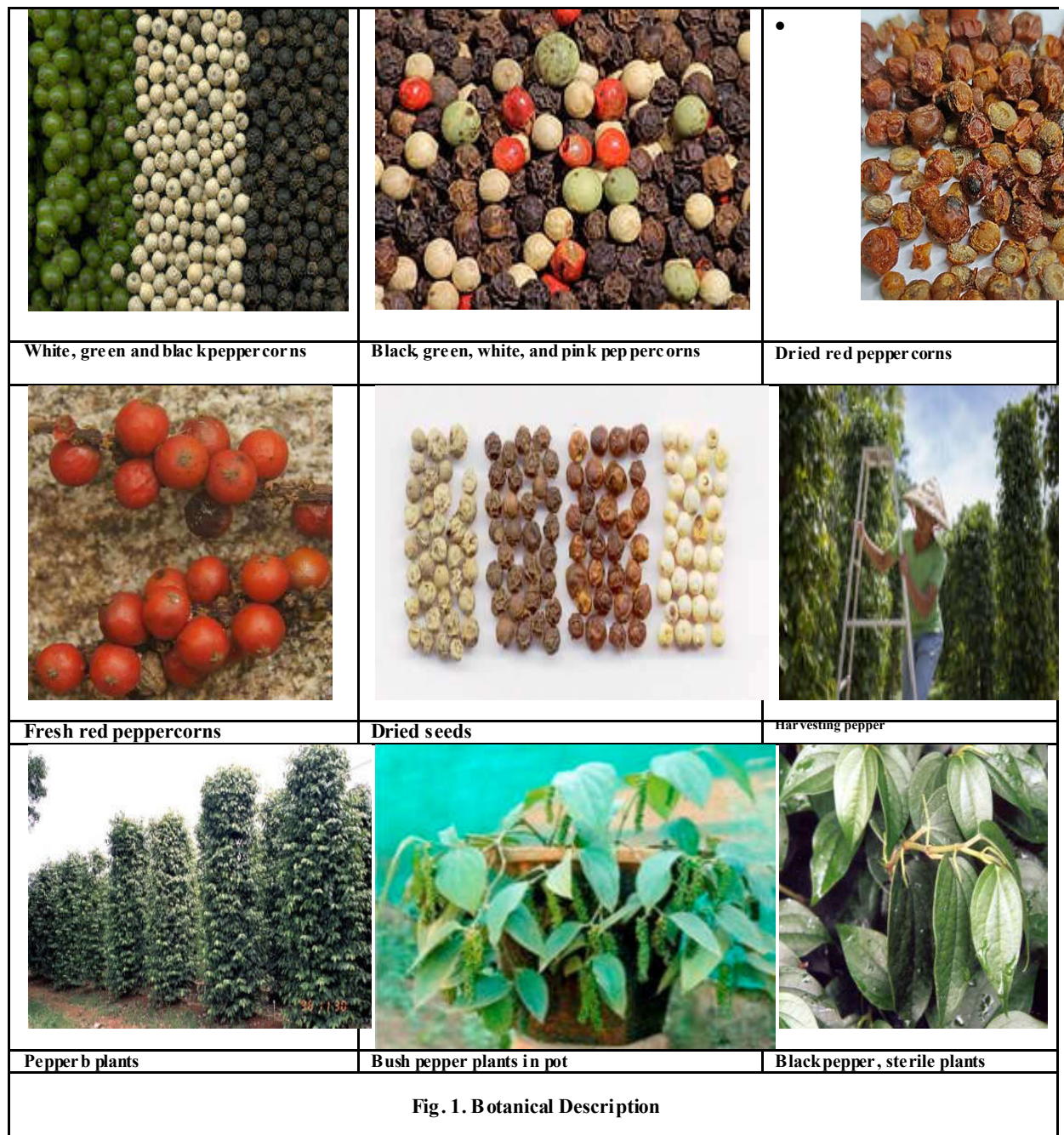
Black pepper is a vine, predominantly self-pollinated and commercially cultivated through orthotropic stem cuttings. Conventionally, clonal selection is the main breeding method and historically it was adopted by the British for introducing the crop into their colonial countries, and this practice continued for a long time (Krishnamoorthy and Parthasarathy, 2009).

GENETIC DIVERSITY

Piper has an $x = 13$ basic chromosome number, whereas *Piper nigrum* is tetraploid with $2n = 52$. Black pepper belongs to the family Piperaceae. The basic chromosome number $x = 13$ and $2n = 52$ indicates its balanced tetraploid nature.

		
Cutting planted in polybags	Seedlings	Seedlings in Nursery
		
Single stem with flowers	Single stem with flowers	Single stem with flowers
		
Flower	Spile	Spiles
		
Spiles and immature fruits	Matured fruits	Ripe fruits

Continue



Nevertheless, no species with a diploid number ($2n=26$) has been stated from India. Morphological and biosystematics studies, three species *P. wightii*, *P. trichostychon* and *P. galeatum* are the putative parents for *P. nigrum*. Genetic distance or genetic relationship among putative mutants resulting from irradiated black pepper need to be understood to assist in the selection of superior variety. This study aims to analyze and evaluate genetic variability of mutants resulting from gamma irradiation on Ciinten variety based on morphological and SSR markers. The 27 putative mutants and its original variety were used in this study. Morphological characters observed were plant height, leaf size, number of leaves, nodes and branches. Nine SSR primers were screened to analyze genetic variability. The result on morphological characters showed there are changes on mutant leaf characters from the original/unirradiated Ciinten variety on leaf shape, leaf base and leaf margin. At 18.15% similarity coefficient, 27 mutants and the original variety were clustered into one group (Group I) and separated from mutant number 15 (Group II). Further clustering of group I, at 70 % similarity coefficient, the mutant plants were clustered into two subgroups, i.e. subgroup I with three mutants (3, 9 and 17) and subgroup II consist of the Ciinten and 23 mutants. SSR markers could distinguish the original Ciinten variety from the putative mutants. At 63% similarity coefficient, the original Ciinten variety (Group I) is clearly separated from all of its 27 putative mutants (Group II). Molecular (SSR) markers have proven to be more accurate in identifying genetic variability than morphological characters (Bermawie *et al.*, 2017).

Twenty elite high yielding blackpepper accessions with field tolerance to pollubeele and phytophthora footrot were evaluated for biochemical principles of quality namely, piperine, essential oil and oleoresin. Two accessions, 7293 and 7252 recorded more than 6.5 per cent piperine which was greater than the maximum recorded value in the black pepper. Accession 7211 had high (5.87%) content of essential oil, while, accessions 7289, 7276, 7229, 7232 and 7252 211 had high amount of oleoresin. The clustering based on biochemical principles showed that the accessions can be grouped to five major clusters. Majority of the accessions belonged to

the cluster V with high piperine, medium oil content and low oleoresin content. Correlation studies indicated that there is no correlation between yield and biochemical principles (Prakash, and Jiji Joseph, 2022). 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 (Reshma *et al.*, 2022).

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 (Reshma *et al.*, 2022). 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 (Table 1) (Reshma *et al.*, 2022).

Table 1. Variability observed in important characters among the accessions

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

Variation in spike character is given in Fig.2.



Fig. 2. Variation in spike characters

BREEDING

Genetic Resources: The Indian Institute of Spices Research (IISR) at Kozhikode, Kerala, maintains the world's largest collection of black pepper germplasm containing local cultivars, wild forms collected from the area of origin and related species.

At present there are about 3516 accessions, consisting of 1266 wild relatives, 2062 cultivars, in addition to 9 exotic collections maintained in India. These collections were characterized and evaluated to estimate the genetic diversity for various yield and quality characters. The short-listed ones are being used directly for cultivation or as parents in breeding programmes (Krishnamoorthy and Parthasarathy, 2009). The genetic resources of this crop in India are a great strength. This germplasm, containing local cultivars, wild forms collected from the area of origin and related species are a wealth to be utilized for crop improvement (Krishnamoorthy and Parthasarathy, 2009). Registration of valuable and important germplasm meets the requirement of intellectual property rights and related issues, breeders' rights, farmers' rights, etc. In this regard, IISR Calicut has registered four unique black pepper germplasm with unique characters (Krishnamoorthy and Parthasarathy, 2009).

Breeding Objectives: In black pepper, a vegetatively propagated perennial, the major bottleneck is damage caused by fungus *Phytophthora capsici* (Leonian), nematode *Radopholus similis* and the pest pollen beetle (*Longitarsus nigripennis*). Resistant/tolerant sources are available in the germplasm. This, coupled with retention of good quality parameters, will help in producing high-quality black pepper with less usage of pesticides and fungicides. The most promising approach for bringing these characters into a single genotype is gene pyramiding through conventional and biotechnological methods. This, with the knowledge of the geographical region, in which high-quality market-driven organic pepper can be grown, will help India in retaining its permanent position in the pepper trade. Thus important breeding objectives in black pepper are: 1) high yield per vine (above 3 kg fresh berries per vine), and 2) high quality along with high yield (oleoresin above 10%) (Krishnamoorthy and Parthasarathy, 2009). Crop improvement aims to reassemble desirable inherited genes to grow crops with better traits. Plant breeders have concentrated mainly on increasing the economically significant portion of the plant as well as the sustainability of production through the incorporation of pest and disease resistance, nutritional value and sensory attributes, and other preferred quality characteristics. The main bottleneck in black pepper production is fungus diseases caused by *Phytophthora capsici* and *Fusarium* (Khew, et al., 2022).

Breeding Behaviour and Breeding Strategies: Black pepper is a predominantly self-pollinated (geitonogamy) perennial vine propagated by cuttings. Various degrees of protogyny are encountered in *P. nigrum*. However, the protogyny is ineffective to prevent selfing as the pendant spike is abundantly assured of pollen from the upper flowers and there will be many spikes dehiscing pollen grains simultaneously in a vine. The stigma are reported to be receptive up to 10 days after exertion and small quantities of pollen are found in pollen sac even or more days after dehiscence. The positive geotropism, spatial arrangement of flowers, sequential ripening of the stigma and non-chronological dehiscence of anthers stimulate geitonogamic fertilization. Wind may aid pollen dispersal by agitating the spikes/branches. High fruit set in a dioecious clone of black pepper with no visible staminate flowers, possibly as a result of apomixis. Indirect evidence of apomixis is observed in our studies too (Krishnamoorthy and Parthasarathy, 2009). Future black pepper production would necessitate reducing crop losses due to pests and diseases and significant developments that provide substantial yield increases. The most recent genomic advancements have accelerated breeding and trait development in order to improve the productivity and environmental resilience of crops. Using genome-wide association studies and other gene-mapping techniques based on current phenotyping tools, genetic variation can be studied with nucleotide-level (Khew, et al., 2022).

Breeding: Clonal selection, open-pollinated progeny selection and hybridization are the major approaches followed in genetic improvement of black pepper. Polyploidy breeding is also being attempted to increase the spectrum of variation. Viable sexual reproduction coupled with the excellent vegetative propagation techniques are the cornerstones in most of the breeding strategies followed in this perennial vine. Black pepper being heterozygous in its genetic architecture, as it has been propagated vegetatively over centuries; any breeding method should also ensure this heterozygosity. The breeding strategies followed in black pepper are Clonal Selection, Open-pollinated Progeny Selection, Hybridization, Polyploidy Breeding, Breeding for Nematode, Disease and Insect Resistance, Breeding for Drought Tolerance, Breeding for High Altitude and Breeding for High Quality (Krishnamoorthy and Parthasarathy, 2009).

Marker-assisted selection for disease resistance: Crop loss due to dreaded diseases is one of the major concerns in crop breeding. Most diseases attack the aerial part of the black pepper vines, while some go beyond, invading and damaging their root systems. Among the major diseases of black pepper, the foot rot caused by oomycete *Phytophthora capsici* is notoriously known for being the deadliest disease of black pepper, often leading to complete crop losses. This infection usually stems from the collar region of the vine (Khew, et al., 2022).

Genome editing: Genomic editing (GE) technology relies on modifying a genome by inserting, substituting removing, or disrupting the DNA sequences with tools like molecular scissors or artificially engineered nuclease enzymes to make it more advantageous for basic and applied science fields. With this technology, many benefits could be brought to the food and agricultural sector by improving the essential characteristics of plant agronomic traits and increasing their commercialization (Khew, et al., 2022).

Gene editing in black pepper: Given present production trends, anticipated population increase, and environmental pressures, black pepper breeding efforts should prioritize characteristics related to yield stability and sustainability. These traits include resilience to abiotic and biotic stress tolerance, as well as a good fruit set. The application of gene editing in black pepper is still in its early stages, with most research focusing on the identification of key genes in regulating various good agronomic traits (Khew, et al., 2022).

Speed breeding: Black pepper is a woody perennial vine that necessitates lengthy breeding cycles to produce a new variety. The duration of the juvenile cycle in woody perennial plants is determined by the environment and is inversely related to vigor. As a result, environmental factors that inhibit vigorous development, such as nutrient deficiencies under shaded and abiotic stresses, appear to postpone the transition from juvenile to adult (Khew, *et al.*, 2022).

Varieties of Black Pepper: Varieties of black pepper are given in Table 2 (Krishnamoorthy and Parthasarathy, 2009).

Table 2. Varieties of black pepper

Name	Pedigree	Released from	Average yield dry (kg/ha)	Oleoresin (%)	Piperine (%)	E. oil (%)	Remark
Panniyur-1	F ₁ of Uthirankotta × Cheriakaniyakadan	Pepper Research Station, Panniyur, Kerala Agricultural University (KAU), Kannur, Kerala, India.	1242.0	11.8	5.3	3.5	Suited to all pepper growing regions. Not suited to heavily shaded areas.
Panniyur-2	Open-pollinated progeny selection of Balankotta	Pepper Research Station, Panniyur, Kerala Agricultural University (KAU), Kannur, Kerala, India.	2570.0	10.9	6.6	3.4	Reported to be shade tolerant.
Panniyur-3	F ₁ of Uthirankotta × Cheriakaniyakadan	Pepper Research Station, Panniyur, Kerala Agricultural University (KAU), Kannur, Kerala, India.	1953.0	12.7	5.2	3.1	Late maturing. Suited to all pepper growing regions.
Panniyur-4	Clonal selection from Kuthiravally	Pepper Research Station, Panniyur, Kerala Agricultural University (KAU), Kannur, Kerala, India.	1277.0	9.2	4.4	2.1	Stable yielder.
Panniyur-5	Open-pollinated progeny selection of Perumkodi	Pepper Research Station, Panniyur, Kerala Agricultural University (KAU), Kannur, Kerala, India.	1098.0	12.3	5.5	3.8	Tolerant to nursery diseases and shade.
Panniyur-6	Clonal selection of Karimunda	Pepper Research Station, Panniyur, Kerala Agricultural University (KAU), Kannur, Kerala, India.	2127.0	8.3	4.9	1.3	Suited to all pepper tracts.
Panniyur-7	Open-pollinated progeny of Kalluvally	Pepper Research Station, Panniyur, Kerala Agricultural University (KAU), Kannur, Kerala, India.	1410.0	10.6	5.6	1.5	Suited to all pepper tracts.
Subhakara	Clonal selection from Karimunda	Indian Institute of Spices Research, P.O. Marikunnu Kozhikode, Kerala, India.	2352.0	12.4	3.4	6.0	Suited to all pepper growing regions.
Sreekara	Clonal selection from Karimunda	Indian Institute of Spices Research, P.O. Marikunnu Kozhikode, Kerala, India.	2677.0	13.0	5.1	7.0	Suited to all pepper growing regions.
Panchami	Germplasm selection	Indian Institute of Spices Research, P.O. Marikunnu Kozhikode, Kerala, India.	2828.0	12.5	4.7	3.4	Late maturing type suited to all pepper growing areas.
Pournami	Germplasm selection	Indian Institute of Spices Research, P.O. Marikunnu Kozhikode, Kerala, India.	2333.0	13.8	4.1	3.4	Tolerant to root knot nematode (<i>M. incognita</i>).
PLD-2	Clonal selection from Kottanadan	IISR, Kozhikode and Central Plantation Crops Research Institute, (CPCRI), Regional Station, Palode, Kerala.	2475.0	15.5	3.3	3.5	Suited to Trivandrum and Quilon districts of Kerala, India.
IISR Thevam	Clonal selection of Thevanmundi	IISR Kozhikode	1787.0	8.15	1.6	3.1	Tolerant to foot rot disease (durable resistance). Suited to high altitudes and plains.
IISR Malabar Excel	F ₁ of Cholamundi × Panniyur-1	IISR Kozhikode	1065.0	13.5	2.96	3.2	Suited to high altitudes and rich in oleoresin.
IISR Girimunda	F ₁ of Narayakodi × Neelamundi	IISR Kozhikode	2112.0	9.65	2.2	3.4	Suited to high altitudes
IISR Sakthi	Open-pollinated progeny of Perambaramundi	IISR Kozhikode	5.17**	10.2	3.3	3.7	Tolerant to foot rot disease in the juvenile phase

Important varieties and hybrids of black pepper are given in Table 3 (Hai and Long An, 2015):

Table 3. Varieties and hybrids of black pepper

Common varieties	Hybrid varieties
Cheriakodi	Panniyur-1
Chola	Panniyur-2
Chumala	Panniyur-3
Karimkotta	Panniyur-4
Karivilanchi	Panniyur-5
Kumbhakodi	Panniyur-6
Perumkodi	Panniyur-7
Thommankodi	Sreekara
Uthirankotta	Subhakara
Valliyakaniyakadan	Panchami
Vellanamban	Pournami
Nedumchola	PLD-2
Kottan	IISR Thevam
Chengannurkodi	IISR Girimunda
Cheppakulamundi	IISR Malabar Excel
Jeerakamundi	IISR Sakthi

The variety of black pepper was believed to have been derived from a wild one through domestication or selection (Ravindran, 2000) in India. Ravindran (2000) in a book entitled 'Black pepper (*Piper nigrum* L.)' that was published by Harwood Academic Publishers has described 38 cultivars of black pepper in India, with descriptions focused on leaf shape, spike length, percent fruit set, topography suitability and yield performance. The team also listed important varieties for other countries (Khew, *et al.*, 2022). 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 4) (Reshma *et al.*, 2022).

Table 4. Improved varieties of black pepper in India

Variety	Pedigree	Salient features
Panniyur-1	F1 of Uthirankotta x Cheriakanian akadan	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	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 Cheriakanian akadan	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	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	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	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	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 x Panniyur 5	High yielding, field tolerant to Phytophthora footrot and drought.
Panniyur-9	Open pollinated progeny selection of Panniyur 3	This variety perform well in hilly tracts. It is extremely tolerant to drought.
Panniyur-10	Progeny of Panniyur 1 x Cultivar 54 (OP of cv. Karivaly)	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	It is released for cultivation in Kerala. The variety is high yielding with bold berries and high quality. Field tolerant to Phytophthora footrot.
Subhakara	Clonal selection from Karimunda (KS 27)	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.
Sree kara	Clonal selection from Karimunda (KS 14)	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	Gemiplasm selection from Aimpriyan (Coll.856)	A high yielding variety (5.2 kg green pepper/ vine) with excellent fruit set. 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	Gemiplasm selection from Ottapalackal (coll.812)	A moderately high yielding vine (4.7 kg green pepper/ vine) with high oleoresin content (13.8%). It is tolerant to root knot nematode (<i>M. incognita</i>). Potential yield is 6528 kg/ha.
PLD-2	Clonal selection from Kottanadan (Coll.2559)	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 Thevamundi	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).
IISRMalabar Excel	F1 of Cholamundi x Panniyur-1	Suited to high altitudes and rich in oleoresin.
IISR Girimunda	F1 of Narayakodi x Neelamundi	High yielding variety (6.14 kg fresh pepper/vine) suited to high altitudes.
IISR Sakthi	Open-pollinated progeny of Perambundi	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	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.

Among the numerous pepper varieties, only a select few are important as spices. These include: Black pepper hails from India, Malaysia, and Indonesia. Bengal pepper originates in the mountainous regions of the lower Himalayas. Java pepper is native to Malaysia and Indonesia. Ashanti pepper is indigenous to tropical Africa. Kubeben pepper is found in Indonesia and Malaysia (Plantvillage, 2024). A majority of the cultivated types are monoecious (male and female flowers found in the same spike) though variation in sex expression ranging from complete male and complete female is found. Over 75 cultivars of black pepper are being cultivated in India. Karimunda is the most popular cultivar in Kerala. The other important cultivars are Kottanadan (South Kerala), Narayakodi (Central Kerala), Aimpriyan (Wynad), Neelamundi (Idukki), Kuthiravally (Kozhikode and Idukki), Balancotta,

Kalluvally (North Kerala), Malligesara and Uddagare (Karnataka). Kuthiravally and Balancotta exhibit alternate bearing habit. In terms of quality, Kottanadan has the highest oleoresin (17.8%) content followed by Aimpiriyan (15.7%) (Vikaspedia, 2024). Seventeen improved varieties of black pepper have been released for cultivation. Panniyur-1, Panniyur-3 and Panniyur-8 are hybrids evolved at the Pepper Research Station, Panniyur (Kerala Agricultural University). IISR Girimunda and IISR Malabar Excel are the two hybrids released from Indian Institute of Spices Research, Kozhikode, Kerala (Vikaspedia, 2024).

Nutritional Value: Black Peppercorns are rich in vitamins A and C and have a significant amount of caffeine, a stimulant that can help keep the brain alert. Black pepper is known to boost the absorption of certain essential nutrients like calcium and selenium, as well as beneficial plant compounds found in green tea and turmeric. Research has shown the spice to be rich in antioxidants, anti-microbial, and anti-inflammatory properties, all attributed to the essential oil responsible for the fruit's taste, piperine. The spice has been used in Ayurvedic medicine to treat digestive issues, earaches, gangrene, and heart disease. In Traditional Chinese Medicine, peppercorns were also historically used to reduce symptoms associated with epilepsy, although there is no current scientific research showing them as an effective treatment for neurological disorders (Invasive, 2024).

Uses: Black pepper is one of the most versatile spices used in virtually in all kinds of savoury cooking. In order to keep their fragrance and flavor intact, they are generally ground just before preparing dishes and added at the last minutes in the recipes (since prolonged cooking results in evaporation of essential oils). Ground pepper can be added to almost any cooked dish, as well as certain fresh recipes. It has a pungent, sharp taste that freshens most recipes. Additionally, though, black pepper can improve digestion and reduce gas. Ground pepper only stays fresh for about three months, but peppercorns will last indefinitely. To make the most of your harvest, store peppercorns in an airtight container in a cool, dark location. Grind them immediately before use for best flavor. Add pepper to soups, meat dishes, or salad dressings. In India and Pakistan, black peppercorn powder is mixed with salt, and the mixture is a common item found on the serving table in restaurants. The mixture is used as sprinkle over vegetable/fruit salads, chats, lemonades, in soups, etc. Lassi (chumed yogurt) is often flavored with this spice-salt mixture in the Punjab province (Hai and Long An, 2015).

Dried fruits, usually known as peppercorns. Depending on harvest time and processing, peppercorns can be black, white, green and red (actually, reddish brown). The traditional types are black and white; dried green peppercorns are a more recent innovation, but are now rather common in Western countries. Red peppercorns, however, are still a very rare commodity. Peppercorns are also available pickled in brine or vinegar. This is the traditional form of preserving green peppercorns, but in recent years, preserved red peppercorns have become increasingly popular. There is no pickled black or white pepper (Katzner, 2024). Black pepper is by far the most used type of peppercorns. It is widely employed in almost all cuisines of the world. Since pepper cultivation has much increased lately and new plantations spread to remote locations, black pepper is continually introduced into cooking styles that did not use much pepper before, mainly for reasons of expense. For example, Thai cooking has not only developed a liking for fresh unripe pepper berries, but also uses black pepper to a larger extent than before when it was an expensive import commodity. Black pepper is particularly popular for comparatively mild stews as preferred in the cuisine of the Royal Thai Court (Katzner, 2024).

Black Peppercorns are one of the most widely used spices globally and are often combined with salt tableside as a condiment. Black Peppercorns cannot be used whole but must instead be cracked or ground, using a spice mill or mortar and pestle to release their pungent aroma and fruity, picante flavor. Cracked Black Peppercorns can be used to crust cuts of steak like ribeye and T-bone, or they can be added to spice rubs for long-cooked meats. It is also an essential ingredient in almost every recipe, added to the taste of the cook along with salt. Use black pepper in spice blends for fish, poultry, meat, and vegetables. The spice is used in garam masala, ras al hanout, masala chai, berbere, and many other spice mixes worldwide. The flavor of black peppercorn is enhanced when combined with an acidic ingredient like lemon or tomatoes and can even be added to cocktails and desserts for a unique flavor experience. Uncracked, Black Peppercorns can be stored in an airtight container for up to two years. Once cracked, the spice quickly loses its fruity and picante aroma and flavor, so cracked or ground black pepper should be made in small amounts and used quickly (Invasive, 2024). 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. Black pepper is renowned for its intrinsic quality and its two principal components are volatile oil and pungent compounds. 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 immune-modulatory activities. *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

Medicinal Uses: The Ayurvedic doctors in India used black pepper for constipation, diarrhea, tooth decay, arthritis, heart disease, and lung disease, as well as many other minor ailments. Traditional Chinese medicine used black peppercorns to relieve diarrhea and relieve the symptoms of colds. Ancient Romans buried their meat and other perishable food items under pepper in order to keep it from spoiling. Modern research has discovered that the chemical compound in black peppercorns called 'piperine' gives this spice very powerful antibacterial properties and that 'piperine' can even inhibit the deadly botulism bacteria. Piperine is not only antibacterial, it also stimulates the taste buds and encourages the pancreas to begin producing digestive enzymes, which in turn helps keep your digestive system healthy. Piperine also increases the effectiveness of medications including antibiotics, cough medicines, as well as drugs for arthritis, respiratory diseases, heart disease, and other serious diseases. It also helps increase the effectiveness of other spices. Turmeric, for example, is more potent medicinally if it is taken with black peppercorns. Peppers have been used therapeutically in dentistry as an antiseptic for tooth-decay and gum swellings. Peppercorns are also being used as

traditional medicines in treating flatulence and indigestion, however, there is little or no data to support these claims in modern medicine (Hai and Long An, 2015).

Health Benefits (Hai and Long An, 2015)

- **Alzheimer's disease:** In animal studies, researchers have found that piperine significantly improved the memory and neurodegeneration caused by Alzheimers.
- **Arthritis:** Researchers have been studying black pepper on both humans and animals and have found that the amazing chemical compound piperine reduces the cell compounds that make arthritic inflammation worse.
- **Cancer:** Piperine has been found to play an important role in both preventing and treating the following cancers: colon cancer, lung cancer, and breast cancer. Most research is only in the animal-study stage, but the prognosis is hopeful for the future ability for humans.
- **Dysphagia (difficulty swallowing):** After a stroke, many people have dysphagia, or difficulty in swallowing. Researchers have found that if you sniff black pepper oil for a minute, it helps improve the ability to swallow.
- **Hearing loss:** Piperine has been found to protect cells in the cochlea (an organ in the ear for hearing) from chemical damage.
- **Heart disease/High blood pressure:** In animal studies, researchers have found that piperine, when given with high fat foods, had less oxidation, a process that turns cholesterol into artery clogging junk. Their conclusion is that piperine reduces the oxidation stress on your cells. Piperine also has been found (so far in animal studies) to lower blood pressure.
- **Indigestion:** Black pepper has been found to speed up the time it takes for food to move through the digestive tract. Slow-moving digestion has been linked to many digestive problems including constipation, so black pepper is a positive thing for managing your digestion.
- **Smoking addiction:** Researchers have been studying smokers and have found that the craving for cigarettes decreases when smokers puff on a vapor that contains black pepper essential oil.
- **Vitiligo:** Vitiligo is a skin disease that results in abnormal patches of pale skin. Piperine has been found to promote the growth of melanocytes, which are the cells that produce pigment.

Safety profile: Consumption of dishes prepared with excessive amounts of black pepper can cause gastrointestinal irritation, and bleeding from the ulcer sites. Therefore, recipes prepared with pepper should be avoided in individuals with stomach ulcers, ulcerative colitis, and diverticulitis conditions (Hai and Long An, 2015).

Sensory quality: Pungent and aromatic. The pungency is strongest in white pepper and weakest in green pepper, while black and green peppercorns are more aromatic than the white ones. Green peppercorn have a somewhat immature, herbaceous fragrance. Red peppercorns combine a sugary-sweet taste with the mature pungency and flavour of black pepper (Katzer, 2024).

Ethnic/Cultural Info: The flavor and aroma of Black Peppercorns can vary greatly depending on the region in which they are grown. Peppercorns are a fruit, and their flavor is affected by climate, growing conditions, and soil compositions, much like grapes. These factors can also alter the acidity, sweetness, texture, and size of the peppercorns. Indonesian Lampong peppercorns have a strong and citrusy aroma with a slow-burning heat that intensifies over time, making them ideal for a richly marbled steak, like ribeye. The Tellicherry peppercorn from India, prized for its size and considered the best peppercorn in the world, has a piney and citrusy aroma with a sweet and fresh taste featuring more robust notes of fruit and grass. Peppercorns grown in Brazil have a strong scent that can clear the nose with a more subdued flavor and a quickly dissipating piquant kick. This bouquet and flavor profile is similar to the peppercorns grown in Vietnam, the world's largest supplier of the spice. These peppercorns had an intense aroma of fruit, citrus, and anise with a mild flavor marked with notes of smoke, wood, and gentle lingering heat. The varying flavors and aromas of Black Peppercorns add to the complexity of the spice. To get the perfect flavor and aroma for a recipe, combine peppercorns from different growing regions to create a custom blend (Invasive, 2024).

CULTIVATION

Propagation

With seedlings from seeds: Transplant the healthiest seedlings outside or to larger growing pots when they are 10- 15 cm high.

With seedlings from cutting stems: Transplant the healthiest seedlings outside or to larger growing pots when they have new roots and stems. The plants are propagated by cuttings about 40 to 50 cm long, tied up to neighbouring trees or climbing frames at distances of about 2 m apart; trees with rough bark are favoured over those with smooth bark, as the pepper plants climb rough bark more readily. Competing plants are cleared away, leaving only sufficient trees to provide shade and permit free ventilation (Hai and Long An, 2015). Black pepper seeds are only viable for a short time and don't store well over months. Choose fresh seeds from a healthy plant or from a local garden centre. Let the seeds soak overnight to soften their thick seed coats—this makes it easier for seedlings to sprout. Use a loamy soil high in organic matter and plant the seeds one-quarter-inch deep and three inches apart. Water the soil regularly, keeping the soil moist as the seeds sprout and grow leaves. Maintain temperatures around eighty degrees Fahrenheit. Germination can take up to a month. Once young plants are at least six inches tall, you can transplant them into your garden or into a container (Master, 2021). Cross pollination between various Piper 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 (Reshma *et al.*, 2022). Black pepper plants can be started from seeds. However, they are slow growing and can take up to 4 years before they will produce flowers and set fruit. For this reason, the preferred method of growing black pepper is from started plants that are already established. You can also grow black pepper plants via cuttings. These plants will naturally set roots wherever the vine touches the ground which makes it very easy to get cuttings to take root in your garden. If you happen to have a friend who likes to grow black pepper, then this may be a viable option for you to begin growing black pepper! (Klein, 2023).

Black pepper vines develop three types of aerial shoots, namely (a) primary stem with long internodes, with adventitious roots which cling to the standards (b) runner shoots which originate from the base of the vine and have long internodes which strike roots at each node and (c) fruit bearing lateral branches. Cuttings are raised mainly from runner shoots, though terminal shoots can also be used. Cuttings from lateral branches are seldom used since they develop a bushy habit. However, rooted lateral branches are useful for raising bush pepper (TNAU, 2024).

Traditional method: Runner shoots from high yielding and healthy vines are kept coiled on wooden pegs fixed at the base of the vine to prevent the shoots from coming in contact with soil and striking roots. The runner shoots are separated from the vine during February-March and after trimming the leaves, cuttings of 2-3 nodes each are planted either in nursery beds or in polythene bags filled with fertile soil. Adequate shade has to be provided and the polythene bags are to be irrigated frequently. The cuttings become ready for planting during May – June (TNAU, 2024).

Rapid multiplication method: An efficient propagation technique developed at Sri Lanka has been modified for adoption in India for quick and easy multiplication of black pepper vines. In this method, a trench of 45 cm depth, 30 cm width and convenient length is made. The trench is filled with rooting medium comprising of forest soil, sand and farm yard manure in 1:1:1 ratio. Split halves of bamboo with septa or split halves of PVC pipes of 1.25-1.50 meter length and 8-10 cm diameter provided with plastic septa at 30 cm intervals are fixed at 45° angle on a strong support. Rooted cuttings are planted in the trench at the rate of one cutting for each bamboo split. The lower portions of the bamboo splits are filled with rooting medium (preferably weathered coir dust-farm yard manure mixture in 1:1 ratio) and the growing vine is tied to the bamboo split in such a way so as to keep the nodes pressed to the rooting medium. The tying can be done with dried banana leaf sheath fibers or coir rope. The cuttings are irrigated regularly. As the cuttings grow, the bamboo splits are filled with rooting medium and each node is pressed down to the rooting medium and tied. For rapid growth, a nutrient solution of urea (1 kg), super phosphate (0.75 kg), muriate of potash (0.5 kg) and magnesium sulphate (0.25 kg) in 250 litres of water is to be applied @ 0.25 litre per vine at monthly intervals (TNAU, 2024). When the vine reaches the top (3-4 months after planting of the cutting) the terminal bud is nipped off and the vine is crushed at about three nodes above the base, in order to activate the axillary buds. After about 10 days, the vine is cut at the crushed point and removed from the rooting medium and cut between each node. Each cutting with the bunch of roots intact is planted in polythene bags filled with fumigated potting mixture. Trichodema @ one gram and VAM @ 100 cc/kg of soil can be added to the potting mixture. Care should be taken to keep the leaf axil above the soil. The polythene bags should be kept in a cool and humid place, or should be covered with thin polythene (200 gauge) sheet to retain humidity. The buds start developing in about 3 weeks and the polybags can then be removed and kept in shade (TNAU, 2024). The advantages of this method of propagation are rapid multiplication (1:40), well developed root system, higher field establishment and vigorous growth as a result of better root system (TNAU, 2024).

Trench method: A simple, cheap and efficient technique for propagating black pepper from single nodes of runner shoots taken from field grown vines has been developed at the institute. A pit of 2.0 meter x 1.0 meter x 0.5 meter size is dug under a cool and shaded area. Single nodes of 8-10 cm length and with their leaf intact, taken from runner shoots of field grown vines are planted in polythene bags (25 cm x 15 cm, 200 gauge) filled at the lower half with a mixture of sand, soil, coir dust and cow dung in equal proportion. The single nodes are to be planted in the bags in such a way that their leaf axil is above the potting mixture. The polythene bags with the planted single nodes are arranged in the pit. After keeping the bags in the pit, the pit should be covered with a polythene sheet. This sheet may be secured in position by placing weights on the corners. The cuttings should be watered at least five times a day with a rose can and the pit should be covered with the polythene sheet immediately after watering. It is advisable to drench the cuttings two-three times with copper oxychloride (2g/litre) (TNAU, 2024). After two-three weeks of planting, the cuttings will start producing roots which are visible through the polythene bags. After the initiation of roots the frequency of watering may be reduced to three-four times a day. After about one month, new shoots start emerging from the leaf axil. At this stage it is advisable to keep the pit open for about one hour per day so that the cuttings would harden and will not dry when they are taken out of the pit. The cuttings can be taken out of the pit after two months of planting and kept in a shaded place and watered twice a day. These cuttings will be ready for field planting after about 20 months. By this method 80-85 per cent success can be obtained. Foliar application of nutrient solution will also enhance the growth of the cuttings (TNAU, 2024).

Serpentine method: Cheaper propagation technique for production of rooted cuttings of black pepper is serpentine layering. In a nursery shed with roofing sheet or shade net, rooted black pepper cuttings are planted in polythene bags holding about 500 g potting mixture, which will serve as mother plants. As the plant grows and produces few nodes small polythene bags (20 x 10 cm) filled with potting mixture may be kept under each node. The node may be kept gently pressed in to the mixture assuring contact with the potting mixture with the help of a flexible twig such as mid rib of a coconut leaflet to enable rooting at that junction. Roots start growing from the nodes and the cuttings keep on growing further. The process of keeping potting mixture filled polythene bags at every node to induce rooting at each node is repeated. In three months the first 10 to 12 nodes (from the mother plants) would have rooted profusely and will be ready for harvest. Each node with the polythene bag is cut just below the rooted

node and the cut end is also buried into the mixture to induce more roots. Polythene bags filled with solarized potting mixture or soil, granite powder and farmyard manure in 2:1:1 proportion is recommended for producing disease free rooted cuttings. The rooted nodes will produce new sprouts in a week time and will be ready for field planting in two-three months time. Daily irrigation can be given with a rose can. On an average, 60 cuttings can be harvested per mother plant in a year by this method (TNAU, 2024).

Black pepper plants are most commonly propagated through vegetative cuttings rather than seeds, ensuring a more reliable growth process. To propagate, take cuttings from healthy, mature plants, making sure each cutting includes nodes that can develop roots. These nodes are essential for successful rooting and subsequent growth. By using vegetative cuttings, you maintain the genetic consistency of the parent plant, leading to more predictable and vigorous growth compared to seed propagation. This method not only expedites the growth process but also enhances the likelihood of producing strong, healthy pepper plants (Kelvine, 2024). Black pepper can be propagated using three main methods: dry seeds, cuttings, or stolons. Cuttings are the most common method for commercial production. They are typically taken from the secondary runners of the plant and should have one or two leaves. These cuttings are rooted in a seedbed and then transplanted when the plant has 4-7 new leaves. In cultivation, a trellis is used to support the plant, and the trellis should be at least 4 meters high. When planting, black pepper should be spaced at 8 meters × 8 meters, meaning 8 meters between individual plants and 8 meters between rows (Plantvillage, 2024). Black pepper vines produce three types of shoot, namely 1) Primary climbing shoot with long internodes having adventitious roots at nodes which cling to the supports/ standards; 2) Runner shoots which originate from the base of the vine and creep on the ground, have long internodes which strike roots at each node and 3) Fruit bearing lateral shoots. Cuttings are raised mainly from runner shoots, though terminal shoots can also be used. Cuttings from lateral branches develop a bushy habit. Rooted lateral branches are used for raising bush pepper. Though seeds (berries) are fully viable, they are not generally used for raising plantations as seedlings will not be genetically uniform (Vikaspedia, 2024).

Pruning and Training: To maintain the health and vigor of your black pepper plants, it's important to practice proper pruning and training techniques: Regular pruning is essential for removing dead or yellowing leaves and shaping the plant. This not only enhances the plant's appearance but also encourages bushier growth and improves air circulation around the foliage. Pruning also helps to remove any diseased or damaged parts of the plant, promoting overall plant health and vitality. Black pepper plants are climbing vines that benefit from support to guide their growth. Use a trellis or stake to provide support for the vines and help manage their growth direction. Training the vines also facilitates better light exposure, ensuring that all parts of the plant receive adequate sunlight for photosynthesis. Proper training helps prevent overcrowding and allows for efficient use of growing space (Kelvine, 2024).

Establishment of plantations: When black pepper is grown in slopes, the slopes facing south should be avoided and the lower half of northern and north eastern slopes are preferred for planting. This will prevent vines from the scorching effect of sun rays from southern direction during summer. With the receipt of the first rain in May - June, primary stem cuttings of shade trees *Eythrina* sp or *Garuga pinnata* or *Grevillea robusta* (silver oak) or seedlings of *Alianthus malabarica* (Matti) are planted in pits of 50 cm × 50 cm × 50 cm size filled with cow dung and top soil. The planting is done at a spacing of 3 m × 3 m which would accommodate about 1110 standards per hectare. The black pepper vines can be trailed on the standards after three years when they attain sufficient height. Whenever *E. indica* is used as standards, application of phosphorus 10 G* @ 30 g may be done twice a year (May/June and September/October) to control nematodes and stem and root borer. When *E. indica* and *G. pinnata* are used, the primary stems are cut in March/April and stacked in shade till the stacked stems start sprouting in May. The stems are planted in the edge of the pits dug for planting black pepper vines. (*banned in Kerala). Pits of 50 cubic centimeters at a distance of 30 cm away from the base, on the northern side of supporting tree are taken with the onset of monsoon. The pits are filled with a mixture of top soil, farmyard manure @ 5 kg/pit and 150 g rock phosphate. Neem cake @ 1 kg, *Trichoderma harzianum* @ 50 g also may also be mixed with the mixture at the time of planting. With the onset of monsoon, 2 - 3 rooted cuttings of black pepper are planted individually in the pits on the northern side of each standard. At least one node of the cutting should be buried in to the soil for better anchorage (Vikaspedia, 2024).

Cultural practices: As the plants grow, shoots are tied to the standard as often as required. The young vines should be protected from hot sun during summer by providing artificial shade. Regulation of shade by lopping the branches of standards is necessary not only for providing optimum light to the vines but also for enabling the standards to grow straight. Adequate mulch with green leaf or organic matter should be applied towards the end of north east monsoon. The base of the vines should not be disturbed so as to avoid root damage (Vikaspedia, 2024). During the second year, the same cultural practices are repeated. However, lopping of standards should be done carefully from the fourth year onwards, not only to regulate height of the standards, but also to shade the black pepper vines optimally. Lopping may be done twice (during June and September) in a year. Excessive shading during flowering and fruiting encourages pest infestations. From the fourth year, two diggings are usually given, one during May - June, and the other towards the end of south - west monsoon in October - November. Growing cover crops like *Calapogonium mucunoides* and *Mimosa invisa* are also recommended under West Coast conditions as an effective soil cover to prevent soil erosion during rainy season. During summer the cover crops dry up leaving thick organic mulch (Vikaspedia, 2024).

Harvesting: Black, white, green, and red peppercorns can all be harvested from *Piper nigrum*. A pepper plant can take three to four years to produce fruit from the time you plant the seed. Peppercorns can sometimes be harvested starting about one year after planting, but most will take 3 to 4 years to develop. Houseplants may never produce fruit. Peppers need a long, long growing season to produce peppercorns. Fortunately, the flowers are attractive in their own right and the foliage is glossy and evergreen. The cream, white, or yellow flowers appear from spring through summer, followed by the slow fruit production. The fruit will take

on slightly difference characteristic depending on when it is collected. For black peppercorns, the fruits can be collected at the earlier stages of ripeness. First, flowers will appear throughout the spring and summer. Fruit will begin to form shortly after in clusters. They will ripen from green to red and can be harvested at these different stages. Most gardeners will harvest peppercorns when they begin to turn red. Green and red peppercorn fruits are often found on the plant at the same time. The red fruit is the ripening fruit. The peppercorn can be picked whether the color is green or red depending on which type of peppercorn you desire. If you want black or green pepper as your final color then, harvest the peppercorn when it's green. If you want white or red pepper, then harvest the peppercorn when it is red. Peppercorns form in clusters of fruit that slowly ripen from green to red. They are usually harvested just as they reach the red stage. Once harvested, the red peppercorns are separated and dried, either in the sun or in a food dryer for about three days. The process is complete when the peppercorns are blackened and fully dry. At this point, they can be ground as black pepper. Dry peppercorns in the sun for about three days. They should turn black when completely dry. Grind them up to make black pepper. White peppercorn is made by removing the red hull. The remaining peppercorns are then dried and ground into a mild-tasting form of pepper. Finally, green pepper is made by harvesting the peppercorns while they are still green and drying them (Hai and Long An, 2015).

Immature peppercorn fruits grow in green clusters on the vine, gradually turning red as they ripen. Once the peppercorns have turned red, you can pluck them from the vine. (If you harvest the green peppercorns before they're ripe, you'll produce green pepper.) Separate the red peppercorns on a tray and let them dry in the sun (or in a food dehydrator) for at least three days. You'll know they're ready when they turn black and hard. (To produce white pepper, remove the red hulls from the peppercorns before drying them.) You can store whole peppercorns in an airtight container. When you're ready to add black pepper to a dish, grind the dried peppercorns in a pepper grinder or using a mortar and pestle. You can also grind the black peppercorns early and store the ground black pepper for later use (Master, 2021). Despite their contrasting appearances, black, white, green, and red peppercorns are all the same peppercorns! Black peppercorns are mature, dried fruit. These fruits will start green, then blush and turn red, and finally, they will grow black after they are picked and left to dry. White peppercorns are the inner portion of mature dried fruits. Black pepper is left to soak in water for days at a time, and then the outer husk is peeled away to reveal white pepper. Green peppercorns are immature fruits that taste more earthy and citrusy than when left to mature. They can be harvested immaturity, dried, and also produce green pepper! Pink peppercorns come from the Peruvian pepper tree, which is not the same as *Piper nigrum*. Once you have harvested your peppercorns, prune back the spent spikes to encourage more flower production (Klein, 2023).

The fruits are picked when they begin to turn red. The collected fruits are immersed in boiling water for about 10 minutes, which causes them to turn dark brown or black in an hour. Then they are spread out to dry in the sun for three or four days. The whole peppercorns, when ground, yield black pepper (Petruzzello, 2024). White pepper is obtained by removing the dark outer part of the pericarp, and the flavour is less pungent than that of black pepper. The outer coating is softened either by keeping the berries in moist heaps for 2 or 3 days or by keeping them in sacks submerged in running water for 7 to 15 days, depending on the region. The softened outer coating is then removed by washing and rubbing or by trampling, and the berries are spread in the sun to dry. Whole white pepper can also be prepared by grinding off the outer coating mechanically (Petruzzello, 2024). Harvest black pepper when the berries turn from green to red or yellow, depending on the variety. Avoid picking unripe or overripe berries. Handpick the berries or use tools like shears for larger harvests. Be gentle to prevent damaging the vines. Thresh the berries to separate them from the stems. Blanch, dry, clean, grade, and package the peppercorns for market distribution (Plantvillage, 2024). A single stem bears 20 to 30 fruiting spikes. The harvest begins as soon as one or two fruits at the base of the spikes begin to turn red, and before the fruit is fully mature, and still hard; if allowed to ripen completely, the fruits lose pungency, and ultimately fall off and are lost. The spikes are collected and spread out to dry in the sun, then the peppercorns are stripped off the spikes (Wikipedia, 2024).

Pepper vines start yielding usually from the 3rd or 4th year. The vines flower in May-June. It takes 6 to 8 months from flowering to ripening stage. Harvesting is done from the November to February in the plains and January to March in the hills. When one or two berries on the spikes turn bright or red, the whole spike is plucked. Berries are separated from the spikes by rubbing them between the hands or trampling them under the feet. After the separation, the berries are dried in the sun for 7 to 10 days until the outer skin becomes black and shrunken and assumes the characteristic wrinkled appearance of commercial black pepper (TNAU, 2024). For making good quality black pepper of uniform colour, the separated berries are collected in a perforated bamboo basket or vessel and the basket with the berries is dipped in boiling water for one minute. The basket is then taken out and drained. The treated berries are sun dried on a clean bamboo mat or cement floor (TNAU, 2024). White pepper of commerce is prepared by removing the outer skin and the pulp below it before drying the berries. Spikes with fully ripe berries are filled in gunny bags and steeped in flowing water for about 7 days. Outer rind of the berries is then removed by rubbing them with hands in a bucket of water and further cleaning the seeds with fresh water. The cleaned seeds are dried for 3 to 4 days. The seeds which are now dull white in colour are further cleaned by winnowing and polishing them by rubbing with a cloth. The recovery of white pepper is about 25 per cent of ripe berries while that of black pepper is about 33 percent (TNAU, 2024). Considerable advances have been made in recent years in the diversification of value and added processed products from the pepper which has great demand. They include 3 major groups *viz.*, (a) green pepper based products canned or bottled green pepper in brines, cured green pepper, frozen green pepper, freeze dried green pepper, dehydrated green pepper, green pepper pickles, green pepper flavoured products white pepper (whole) or powder etc., (b) black pepper based products-Black pepper powder, pepper oleoresins, pepper oils etc and (c) pepper by-products which have medicinal, culinary and industrial uses. These processed products earn more foreign exchange per unit weight /volume (TNAU, 2024).

Storing: Dry peppercorns in the sun for about three days. They should turn black when completely dry. Grind them up to make black pepper. Fruits collected after this stage at full ripeness will become white after drying. After collection, fruits can be placed on a screen and dried in the sun for several days, turning over periodically. Black pepper is available whole, crushed or ground into powder. To ensure best flavor, buy whole peppercorns and grind them yourself in a mill just before adding to a recipe. In addition to superior flavor, buying whole peppercorns will help to ensure that you are purchasing unadulterated pepper since ground pepper is oftentimes mixed with other spices. Whole peppercorns should be heavy, compact and free of any blemishes. Even through dried herbs and spices like black pepper are widely available in supermarkets, you may want to explore the local spice stores in your area. Often times, these stores feature an expansive selection of dried herbs and spices that are of superior quality and freshness than those offered in regular markets. Just like with other dried spices, when purchasing black pepper try to select that which is organically grown since this will give you more assurance that it has not been irradiated (among other potential adverse effects, irradiating black pepper may lead to a significant decrease in its vitamin C content.). Black pepper should be kept in a tightly sealed glass container in a cool, dark and dry place. Whole peppercorns will keep almost indefinitely, while ground pepper will stay fresh for about three months. Pepper can also be frozen although this will make its flavor more pronounced (Hai and Long An, 2015).

After harvesting from your garden, regardless of what stage (green or red), the peppercorns must be quickly blanched in boiling water to clean the exterior before drying. Once the peppercorns are fully dried, then they can be stored. If you'd like to save your seeds for future plantings, skip this blanching process as this will sterilize the seeds, and they will not produce more pepper plants. Whole peppercorns retain their flavor the longest, so storing them this way will give your harvest longevity. Grinding pepper should be reserved for just before you choose to utilize it. Pre-ground black pepper begins to lose its flavor at about 4 months because of its increased surface area and increased exposure to sunlight, oxygen, and moisture. It can even take on a bitter flavor. Store whole peppercorns harvested from your garden in an airtight container away from direct sunlight, such as in a pantry. If you have harvested fresh green peppercorns and chosen to pickle them, they will last for one month after opening and will need to be stored in the refrigerator (Klein, 2023).

Post harvest processing: Post harvest processing operations followed for black pepper involves threshing, blanching, drying, cleaning, grading and packaging. During processing care should be taken to maintain the quality at each step of operation (Vikaspedia, 2024). The berries are separated from the spike usually by trampling with human legs. This operation is crude, tedious and unhygienic. Chances of extraneous matter, soil particles and filth contaminating the produce are also high. Mechanical threshers with capacities varying from 50 kg/h to 2500 kg/h are available which can thresh quickly and provide cleaner products. Considering the shortage of human labour mechanical threshing can be popularized at cluster level (Vikaspedia, 2024). The quality of the black pepper can be improved by a simple treatment of dipping the mature berries taken in perforated vessel in boiling water for a minute before drying. This processing technique has several advantages: 1) Uniform coloured black pepper is obtained after drying. 2) Reduces the microbial load. 3) Pepper can be dried in 3 - 4 days as against 5 - 6 days required when following the traditional practice and 4) Removes the extraneous impurities like dust from the berries (Vikaspedia, 2024). Pepper has moisture content of 65% to 70% at harvest, which should be brought to safer levels of 10% by adequate drying. The green colour of matured pepper is due to the presence of chlorophyll pigment. During drying, enzymatic browning sets in and the phenolic compounds are oxidized by atmospheric oxygen under the catalytic influence of the enzyme phenolase and eventually turn black. Sun drying is the conventional method followed for drying of black pepper. The despiked berries are spread on concrete floor and dried under sun for 3 - 5 days to bring the moisture content below 10%. Dried black pepper with high moisture content (>12%) is susceptible to fungal attack. Mycotoxins produced by the fungal attack render the pepper unfit for human consumption. In order to achieve a quality dry product, pepper berries are spread on clean dry concrete floor / bamboo mats/ PVC sheets and dried in the sun for a period of 4 - 6 days. The average dry recovery varies between 33 - 37 per cent depending on the varieties and cultivars. Mechanical driers developed by various agencies are also used to dry black pepper. Models of varying capacities operated either electrically or by burning agricultural wastes are available for drying of black pepper by maintaining temperature below 55 ° C (Vikaspedia, 2024). The threshed and dried black pepper has extraneous matter like spent spikes, pinheads, stones, soil particles etc. mixed with it. Cleaning and grading are basic operations that enhance the value of the produce and help to get higher returns. Cleaning on a small scale is done by winnowing and hand picking which removes most of the impurities. Such units consist of a fan/ blower and a feeding assembly. The fan is placed at the rear end of the hopper. Cleaning is achieved by feeding the material through the hopper into a stream of air blowing in perpendicular direction. The lighter fractions (dust, immature berries, pin heads and spent spikes) are blown away. Grading of black pepper is done by using sieves and shifting black pepper into different grades based on size. The major grades of black pepper are Tellicherry Garbled Special Extra Bold (TGSEB) (4.8 mm); Tellicherry Garbled Extra Bold (TGEB) (4.2 mm); Tellicherry Garbled (TG) (4.0 mm); Malabar Garbled (MG grades 1 and 2) and Malabar Ungarbled (MUG grades 1 and 2) (Vikaspedia, 2024). White pepper it is generally prepared by retting (with frequently changing of water) fully ripened red berries for 7 - 8 days followed by removal of outer skin, washing and drying to a moisture level of 12%. White pepper is also prepared by fermentation using matured green pepper and black pepper (Vikaspedia, 2024). Organically grown black pepper should be packaged separately and labelled. Mixing different types of pepper is not good from a commercial point of view. Eco friendly packaging materials such as clean gunny bags or paper bags may be adopted and the use of polythene bags may be minimized. Recyclable/ reusable packaging materials shall be used wherever possible (Vikaspedia, 2024). Black pepper is hygroscopic in nature and absorption of moisture from air, during rainy season when there is high humidity may result in mould and insect infestation. Before storage it is to be dried to less than 10 per cent moisture. The graded produce is bulk packed separately in multilayer paper bags or woven polypropylene bags provided with food grade liners or in jute bags. The bags are arranged one over the other on wooden pallets after laying polypropylene sheets on the floor (Vikaspedia, 2024).

Grades: In trade, the pepper grades are identified by their origin. The most important Indian grades are *Malabar* and *Tellicherry* (*Thalassery*). The Malabar grade is regular black pepper with a slightly greenish hue, while Tellicherry is a special product (see below). Both Indian black peppers, but especially the Tellicherry grade, are very aromatic and pungent. In the past, Malabar pepper was also traded under names like Goa or Alleppey (the town is today named Alappuzha). The pepper trade center in India is in Kochi, still much known under its old name Cochin (Katzer, 2024).

Area and Production: The area, production and productivity vary among countries. Area varies from less than 100 ha to more than 2 000 000 ha, production also varies between less than 100 MT to more than 90 000 MT. International markets receive pepper from Vietnam, Brazil, Indonesia, India, Malaysia, Sri Lanka. India contributes around 10% to the world market (Krishnamoorthy and Parthasarathy, 2009). As of 2013, Vietnam was the world's largest producer and exporter of black peppercoms, producing 163,000 tonnes or 34% of the world total of 473,000 tonnes (table). Other major producers include Indonesia 19%), India (11%) and Brazil (9%) (table). Global pepper production may vary annually according to crop management, disease and weather. Vietnam dominates the export market, using almost none of its production domestically (Hai and Long An, 2015). In 2020, Vietnam was the world's largest producer and exporter of black peppercoms, producing 2,70,192 tonnes or 36% of the world total. Other major producers were Brazil, Indonesia, India, Sri Lanka, China, and Malaysia. Global pepper production varies annually according to crop management, disease, and weather. Peppercorns are among the most widely traded spice in the world, accounting for 20% of all spice imports (Wikipedia, 2024). Coastal areas where black pepper is grown in homesteads. Midlands and where black pepper is extensively cultivated on a plantation scale and hills at an elevation of 800-1500 m above sea level, where the crop is mostly grown on shade trees in coffee, cardamom and tea plantations (Vikaspedia, 2024).

Producers: The most important producers of black pepper used to be India and Indonesia. However, Vietnamese efforts to introduce pepper plantations to the country have proved very successful: Since about the turn of the millennium, Vietnam is main pepper producing country in the world, accounting for about one third of all pepper (90000 tons). India now comes second with about 50000 tons, followed by Brazil and former Number Two, Indonesia, whose production went into sharp decline in the 2000s. Note, however, that pepper production, trade volume and price show strong fluctuations, making the pepper business a rather volatile and unpredictable market (Katzer, 2024). India's main pepper product is black pepper. Yet the Malabar region also has a tradition for white pepper, and green pepper production has been introduced in the 1980s. In South East Asia, the most reputed provenances for black pepper are *Sarawak* in insular Malaysia and *Lamongong* from Sumatra/Indonesia. Both produce small-fruited black pepper that takes on a grayish colour during storage; both have a less-developed aroma, but Lampong pepper is pretty hot. Sarawak pepper is mild and often described fruity. Black pepper from other countries where it has been introduced to more recently is named after the trade center (Bangkok, Saigon); these provenances are less valued, as they vary in heat and lack the complex aroma found in Indian and (to lesser degree) Malesian cultivars (Katzer, 2024). The most important source of white pepper is the small Indonesian island Bangka, south east of Sumatra. The peppercorns are named *Muntok* after the island's main port. Smaller amounts of white pepper are produced in Sarawak, which is particularly light-coloured; the best quality is known as *Sarawak Cream Label*. There is also Brazil white pepper, but it has a poorer flavour and is, therefore, less reputed in the international trade. Brazil produces black, white and green peppercorns; the pepper is grown along the Amazon river in the state of Pará. Brazil almost held a monopoly for green pepper as the original production in Madagascar has declined, but the increasing Indian production has changed this picture. Brazil black and white pepper qualities are quite mild. All Brazil pepper is named after its main port, *Belém* (Katzer, 2024). Portuguese explorers took control of the spice trade from these islands before losing power to the Dutch. During this time, pepper plants were spread throughout Southeast Asia and Africa, increasing supply and reducing prices. Today, Black Peppercorns are widely cultivated throughout Indonesia and the tropical regions of Africa and the Western Hemisphere. Vietnam is the world's largest exporter of the spice, producing one-third of the world's supply and exporting over 130,000 tons of peppercorns each year. The other two-thirds of the world's supply is made mainly through India, Brazil, and Indonesia. Peppercorn trade accounts for 20% of the global spice trade, with the United States being the largest importer. Black Peppercorns can be found in the spice aisle of any grocery store worldwide (Invasive, 2024).

Pest and Disease Control: Black pepper has few insect pests. Mealy bug is the main culprit but only if other infected plants are nearby. In pests it can be attacked by aphids, slugs and scale insects. Also beware of red spiders during indoor cultivation. Outdoors, flea beetles or pepper weevils might bother young plants. The damage is rarely severe, although an application of rotenone can dispatch the pests. Indoors, you might notice aphids on the undersides of the leaves. Try spraying the leaves with a steady stream of water or applying an insecticidal soap or oil (Hai and Long An, 2015):

For most gardeners, the biggest challenge is simply providing enough heat and humidity for these tender plants. Pepper plants are not susceptible to many pests or disease if they are well taken care of. Plant them in high quality soil and do not over or under water. Blast off pests with a hose. Use organic sprays if bugs appear to be a nuisance. Remove diseased or infested foliage from the garden. Black spots on the backsides of the pepper leaves are totally normal. They are small crystalline balls that contain sugars called exudates. Over time, these balls turn black. They are sometimes mistaken for insects. They are not. Do not try to remove them. They are part of the plant's normal physiology and do not harm the plant. If your growing conditions are too cool and wet, then your pepper plant can be susceptible to root disease. The best way to prevent this problem is to grow the plant in a clay pot and allow the soil to dry out between waterings and make sure your daytime temperatures are above 70°F and your night temperatures don't drop below 60°F. Root rots can afflict pepper plants, but they are easily prevented by providing well-draining soil. Amend heavy soils with compost or grow peppers in raised beds. Most common disease that infect is root rot, which happens due to overwatering (Hai and Long An, 2015):

Certification: Certification and labelling is usually done by an independent body to provide a guarantee that the production standards are met. Govt. of India has taken steps to have indigenous certification system to help small and marginal growers and to issue valid organic certificates through certifying agencies accredited by APEDA. The inspectors appointed by the certification agencies will carry out inspection of the farm operations through records maintained and by periodic site inspections. The grower has to document all the details with respect to field map, field history sheet, activity register, input record, output record, harvest record, storage record, pest control records, movement record, equipments cleaning record and labelling records etc. Documentation of farm activities is must for acquiring certification especially when both conventional and organic crops are raised. Group certification programmes are also available for organized group of producers and processors with similar production systems located in geographical proximity (Vikaspedia, 2024).

Flavour: Pepper gets its spicy heat mostly from piperine derived from both the outer fruit and the seed. Black pepper contains between 4.6 and 9.7% piperine by mass, and white pepper slightly more than that. Refined piperine, by weight, is about one percent as hot as the capsaicin found in chili peppers. The outer fruit layer, left on black pepper, also contains aroma-contributing terpenes, including germacrene (11%), limonene (10%), pinene (10%), alpha-phellandrene (9%), and beta-caryophyllene (7%), which give citrusy, woody, and floral notes. These scents are mostly missing in white pepper, as the fermentation and other processing removes the fruit layer (which also contains some of the spicy piperine). Other flavours also commonly develop in this process, some of which are described as off flavours when in excess: Primarily 3-methylindole (pig manure-like), 4-methylphenol (horse manure), 3-methylphenol (phenolic), and butyric acid (cheese). The aroma of pepper is attributed to rotundone (3,4,5,6,7,8-Hexahydro-3 α ,8 α -dimethyl-5 α -(1-methylethenyl)azulene-1(2H)-one), a sesquiterpene originally discovered in the tubers of *Cyperus rotundus*, which can be detected in concentrations of 0.4 nanograms/liter in water and in wine: rotundone is also present in marjoram, oregano, rosemary, basil, thyme, and geranium, as well as in some Shiraz wines (Wikipedia, 2024). Pepper loses flavour and aroma through evaporation, so airtight storage helps preserve its spiciness longer. Pepper can also lose flavour when exposed to light, which can transform piperine into nearly tasteless isochavicine. Once ground, pepper's aromatics can evaporate quickly; most culinary sources recommend grinding whole peppercorns immediately before use for this reason. Handheld pepper mills or grinders, which mechanically grind or crush whole peppercorns, are used for this as an alternative to pepper shakers that dispense ground pepper. Spice mills such as pepper mills were found in European kitchens as early as the 14th century, but the mortar and pestle used earlier for crushing pepper have remained a popular method for centuries, as well (Wikipedia, 2024).

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