Recent scenario, advances and roadmap of 'king of spices': black pepper

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Abstract - Black pepper (*Piper nigrum* L.), a perennial evergreen climbing vine, belonging to the family Piperaceae, is cultivated for its fruit, that is usually dried and used as a spice and seasoning. It is considered as the 'King of Spices' due to its high demand in the global context and also referred as 'Black gold' due to its higher prized trade. It is economically the most important and the most widely used spice crop of the world. The spiciness of black pepper is due to the chemical piperine which exhibits diverse pharmacological activities like antioxidant, analgesic, anti-inflammatory, immunomodulatory and so on. Since black pepper occupies a prime position in the global market and has a high demand worldwide, there arises a need for increasing its production by adopting propagation techniques with high success rate, production of disease free and quality planting material as well as to focus on management of debilitating diseases like foot rot and slow wilt. Healthy and superior planting materials could be produced through tissue culture techniques whereas diseases like foot rot and slow wilt could be curbed through grafting with resistant rootstocks, application of plant growth promoting microorganisms and using resistant varieties. This review outlines the recent scenario, advances in production and propagation techniques, management of foot rot, slow wilt, moisture stress and roadmap of action in black pepper.

Index Terms - Black pepper, foot rot, propagation, rootstocks

I. Introduction

Black pepper (*Piper nigrum* L.) is a perennial evergreen climbing vine, belonging to the family Piperaceae having diploid chromosome number of 2n=52. It is originated in the Western Ghats of South India and is distributed widely in Kerala, Karnataka, Tamil Nadu, Andhra Pradesh and Assam. Its economic part is dried mature berries known as peppercorns which is used as a spice and condiment. Black pepper is referred to as the 'King of Spices' or 'Black gold' due to its high demand and price in the global context. There are several chemical constituents in black pepper. It contains alkaloids like piperine (5-9 %), piperidine, chavicine and piperitine. It also contains volatile oil (1-2.5 %). The main constituents of volatile oils are 1-Phellandrene and Caryophyllene. Apart from these, black pepper also contains pungent resin (6 %) and starch (30 %). Due to the presence of these wide array of chemical constituents, black pepper offers several health benefits like improvement in the functioning of immune system and digestive health, reduces blood pressure, preventing the risk of asthma and cancer and it also improves skin health and kidney functions.

II. Germplasm collection, accessions and varieties

In black pepper, 3466 accessions are maintained at the black pepper germplasm nursery at the experimental farm, Peruvannamuzhi, Kerala. The field genebank at Central Horticultural Experiment Station, Chettalli has 827 cultivar accessions. In 2019, forty accessions of black pepper were collected from the forests of Nagaland and 17 accessions from Andaman and Nicobar Islands. Five new Piper species viz. *Piper boehmeriaefolium*, *Piper makruense*, *Piper pothiforme*, *Piper rhytidocarpum* and *Piper diffusum* from Nagaland and two new species *Piper pedicellatum* and *Piper clypeatum* from Andaman and Nicobar Islands were identified. In 2020, high elevation species like *Piper schmidtii*, *Piper wightii*, *Piper mullesua* and *Piper pseudonigrum* were collected from the shola forests of Munnar and endangered species *Piper barberi* from Anakkulam forests.
A series of collections were planted at Regional Station, Appangala, and 31 collections in total were made. The most widely used cultivar, Karimunda, consistently produces yields throughout a range of agroclimatic conditions. Others like Aimpirian, Kottanadan, Neelamundi, Balankotta, Chumala, Narayakodi, Kalluvally, and Kuthiravally are popular. The cultivars Kottanadan, Kumbhakodi, and Aimpirian have significant oleoresin and essential oil content. Sreekara, Subhakara, Panchami, Pournami, IISR Thevam, IISR Malabar Excel, and IISR Shakthi are some of the improved black pepper varieties. Indian Institute of Spices Research found a natural triploid (2n (3x) = 78), Vadakkan bearing huge leaves and very bold fruits from the germplasm. The seeds of Panniyur-1 were given 0.05 % colchicine treatment, resulting in the development of an induced tetraploid (2n=104). In order to induce variability in Karimunda, Panniyur 1, Kuthiravally, Kalluvally (Pulpally), Kalluvally (Malabar), Thommankodi, and Aimpiriyan, Irulappan *et al.* (1982) and Ravindran *et al.* (1986) utilized 1-4 kr gamma rays. The germination of seedlings was significantly impacted by irradiation. Germination was delayed as the dose was raised. The M1 group displayed morphological anomalies include rosette leaves, twinned seedlings, and alterations in chlorophyll. In Sri Lanka and Malaysia, programs using ionizing radiation to create heterogeneity for the selection of superior genotypes are ongoing, and the results thus far are encouraging. Arka Coorg Excel, Panniyur-9 and Panniyur-10 are the recently released varieties of black pepper.

III. PROPAGATION

Black pepper is propagated by various methods which include traditional method, split bamboo method, serpentine method, trench method and column method. The traditional method of propagating black pepper involves taking cuttings from runner shoots and planting them in polybags filled with potting soil and irrigating them frequently until they become established. A quick way to multiply black pepper is to use the split bamboo method, which entails planting pepper vines in trenches that have been lined with rooting medium and split bamboo halves. The developing vine is connected to the bamboo split in such a way as to keep the nodes pressed to the rooting medium, and the lower regions of the bamboo splits are filled with rooting medium. Each single nodded cutting with the bunch of roots intact is cut and planted in polythene bags filled with potting mixture. The buds start developing in about three weeks and then the poly bags can be removed and kept in shade till main field planting.

The serpentine method involves planting mother plants, or rooted black pepper cuttings, in polythene bags that have been filled with potting mixture. Small polythene bags filled with potting mixture may be placed under each node as the plant develops and generates a few nodes. You can continue to gently press the node into the mixture. The nodes begin to produce roots, and the cuttings continue to expand. To encourage rooting at each node, the process of maintaining potting mixture-filled polythene bags at each node junction is repeated. In trench method, single nodded runner shoots are planted in polythene bags filled with potting mixture with their leaf axil exposed above the potting mixture. Trenches of the proper size are created, and the plastic bags are placed within them. The bags are then covered with polythene sheets.. The cuttings should be irrigated at least five times a day. New shoots start to emerge from the leaf axil after about a month. After two months of planting, the cuttings can be removed from the pit, stored in a shaded area, and watered twice daily. Growing black pepper cuttings on a vertical mesh column loaded with partially decomposed coir pith and vermicompost in a 3:1 ratio fortified with Trichoderma harzianum is known as the "column method of propagation." Each vertical column can have 8–10 black pepper plants wrapped around it. Polyhouses are then built to contain the columns. Cuttings on the column are permitted to trail, ensuring that every node makes touch with the medium. Once the vine reaches the top of the column, compost can be added in accordance. The vines can be taken for quick multiplication once they reach the top.

IV. RECENT SCENARIO

According to the latest statistical data of 2020, Vietnam is the largest producer and exporter of black pepper in the world and India accounts for the highest area under cultivation. About 49 % of world production of black pepper is from Vietnam. Apart from Vietnam, other major producers include India, Brazil, Indonesia and Sri Lanka. In 2020, a quantity of 2,85,292 tonnes of black pepper was exported from Vietnam. Other major exporters are Brazil, Indonesia, Cambodia and India. In India, Karnataka is leading in both area and production of black pepper. It has an area of 190.00 ha and production of 55.64MT. Next to Karnataka, the major producing states are Kerala, Tamil Nadu, Assam and Maharashtra. Analysis of trend in production of black pepper in India for the past ten years showed that there is a decreasing and fluctuating trend in production which could be attributed to the incidence of slow wilt and quick wilt diseases in black pepper. Apart from this, farmers are not receiving adequate income for their produce in the domestic market. These factors also contribute to decrease in export of black pepper from India and thus trade of black pepper in India is becoming more import oriented.

V. ADVANCES

Black pepper is one of the predominant spice crops cultivated worldwide. In order to increase its area and production there arises a need for production of good quality and disease free planting material. This can be achieved through micro propagation technique. In black pepper, an experiment on micropropagation to standardize the explant , media composition and sterilization protocol was done by Kadam *et al*. (2015). They observed that shoot apex was the best explant, MS media supplemented with 4.5 mg/l BAP + 1.0 mg/l IAA can be used as the media and dettol (1 %) (5 min) + Ethanol (50 %) (30 sec) + $HgCl_2$ (0.1 %) (2 min) can be used for sterilization for commercial micropropagation of black pepper. Hemant G H and Hulamani N C (1999) studied on developing a protocol for micro propagation in black pepper through axillary shoot multiplication as well as evaluated the different propagation structures and season of planting for rooting of cuttings. They revealed that Surface disinfection of shoot tip or nodal bud explants with sodium hypochlorite (2 %) for ten minutes was found optimum. The explants collected during February to May have better establishment. The young buds from the tip to the sixth nodal segment gave better establishment of cultures. MS semisolid medium with half the strength of its inorganic salts supplanted with BA 2 mgl^{-1} and 30 gl^{-1} sucrose was suitable for shoot establishment as well as shoot multiplication (5.13 buds / culture). The multiplication rate increased with repeated subculturing on media of same composition at 15 days interval. Rooting of *in vitro* derived shoots was achieved in *in vitro* conditions in medium supplemented with NAA 1 mgl^{-1} and 30 gl^{-1} sucrose. Pre-hardening treatments enhanced establishment of micropropagted plantlets. A potting mixture containing 1:1 and sand + coir pith was superior for establishment of plantlets. The propagation of black pepper by conventional means through cuttings was best in propagation frame or polyhouse during summer (94 %).

Thanuja T V and Hegde R V (1999) conducted a study on influence of vesicular *Arbuscular mycorrhizae* (VAM) on rooting and growth of black pepper cuttings. Rooting and other root characters such as number of primary roots per cutting, length of longest primary root, fresh weight and dry weight of roots were higher in VAM inoculated plants. *Acaulosphora laevis* was more efficient in inducing rooting than other VAM fungi and showed 171.5 % increase in rooting success over uninoculated plants. Compared to IBA treatment, *Gigaspora margarita* recorded 77.9 % increase in number of roots, 1.9 times and 1.7 times more fresh weight and dry weight of roots. *Glomus fasciculatum* showed 21.8 % increase in root length over IBA treated cuttings. *Acaulospora laevis* also resulted in earlier and higher number of sprouts. Orthotropic cuttings showed better response in rooting and root growth than runners on inoculation with VAM fungi. In establishment studies also mycorrhizae improved survival per cent and vegetative growth. All vegetative characters like number of leaves, shoot length and leaf area were higher on inoculation with *Alaevis* over IBA treated and uninoculated plants, both in greenhouse and field establishment studies. In another experiment to study the effect of VAM on growth or rooted pepper cuttings, inoculation of *Alaevis* resulted better growth response both in greenhouse and open condition. *Glomus* *fasciculatum* also enhanced the growth of pepper plants in greenhouse condition. The rapid vegetative growth achieved by mycorrhizal plants helped them to attain transplanting stage one month prior to uninoculated plants. Thus the study revealed that black pepper responded well to the inoculation of VAM fungi and indicated the usefulness of VAM fungi in reducing the nursery life of black pepper. Besides, when the planting material is in shortage, VAM inoculated orthotropic cuttings also can be used in getting elite planting material.

Another experiment on production of large scale planting material for black pepper was done by Kho Pei Ee and Chen Yi Shang (2017) at Malaysian Pepper Board. They developed an innovative cultivation method called W-Configuration planting method which enabled large scale production of runner shoots and contributed more income to the farmers. In order to determine the ideal cutting length (number of nodes) and growth regulator for quick rooting and subsequent root growth in stem cuttings of black pepper, Hegde G S and Rao M M (1981) carried out an experiment. They found that the three-node cuttings outperformed the one- and two-node cuttings in all root characteristics, and that the extent of rooted cutting survival, the length of new shoot, girth of new shoot, and number of new leaves produced were higher in the cuttings treated with IBA at 25 ppm or 50 ppm due to the development of a better root system. They came to the conclusion that, in situations when planting material is scarce, a small cutting might be utilized to propagate pepper vines with 25 ppm IBA. If the planting material is in a plenty, longer cuttings may be used for easier handling.

Foot rot is one of the major debilitating diseases in black pepper production which has completely wiped out almost the entire area of its cultivation. It is also called as quick wilt and is caused by the pathogen *Phytophthora capsici*. The development of workable strategies to eradicate this disease is still being researched. Sourabha *et al.* (2017) worked on response of different varieties of black pepper to wedge grafting using *Piper colubrinum* as rootstock. The observations of the experiment revealed that the varieties Panniyur-1 and Panniyur-3 showed better grafting response and maximum plant growth parameters. Chinnapappa *et al.* (2018) conducted an experiment to identify rootstocks resistant to root knot nematodes *Radopholus similis and Meloidogyne incognita* which are the responsible for slow wilt in black pepper. They evaluated *Piper colubrinum, Piper argyrophyllum* and the varieties IISR Sakthi, IISR Thevam, Panniyur-1 and Karimunda for their resistance to these nematodes. The results of this study showed that, IISR Sakthi was found to be highly resistant whereas *Piper colubrinum,* IISR Thevam and Karimunda were resistant to root knot nematodes and these cultivars can be used as a source of resistance. Hence, grafting with resistant varieties and species of black pepper could pave way for controlling the disease infestation in black pepper as well as improves the yield. Grafting of black pepper with *Piper colubrinum* as rootstock is practiced in University of Agricultural Sciences, Dharwad. It is resistant to foot rot but studies have revealed that it showed graft incompatibility and break down of graft union. Similarly, *Piper colubrinum* is less tolerant to drought, shows profuse suckering, water shoots production and susceptible to mealy bugs and hence has limitations. Therefore, grafting with alternative rootstocks should be done. In a study conducted by Janani *et al.* (2009) it was found that *Piper hymenophyllum* which is an indigenous species of black pepper showed higher percentage of grafting success (62.21 %) than *Piper colubrinum* (56.65 %). Thus *Piper hymenophyllum* could be used as a rootstock to overcome graft incompatibility in black pepper. Panniyur 8 which is a hybrid of Panniyur 6 and Panniyur 5, could be used as a rootstock as it is tolerant to foot rot and drought. Similarly, IISR Shakthi and IISR Thevam are resistant to foot rot. These could be exploited as rootstocks for grafting. Therefore, evaluation and application of rootstocks other than *Piper colubrinum* should be done inorder to overcome its limitations. Vithya *et al.* (2018) studied on the effect of different plant growth promoting micro-organisms in controlling foot rot pathogen. Among the various organisms studied, *Trichoderma harzianum* was found to be the best in terms of controlling the disease incidence by *Phytophthora capsici* as well as improving the growth characters of black pepper.

Another devastating disease in black pepper is slow wilt which is caused by the fungal- nematode complex including *Phytophthora capsici*, *Radopholus similis* and *Meloidogyne incognita.* Kumar *et al*. (2018) found out that an integrated approach involving the application of *Purpureomyces lilacinum* and *Trichoderma harzianum* in combination with neem cake and farm yard manure is highly useful in managing *Radopholus similis* and *Phytophthora capsici* wilt complex. Grafting in black pepper using *Piper colubrinum* rootstock is practiced as a method of managing foot root. In an experiment conducted by Aarthi S and Kumar N (2019) cutting and grafting was performed on rootstock simultaneously which was referred to as stenting method of propagation. In this study they evaluated the potentiality of *Piper hymenophyllum* as a rootstock for commercial propagation in black pepper. *Pochonia chlamydosporia* is a nematophagous fungus which helps in Phosphorous and Zinc solubilization, production of ammonia, siderophores and cell wall degrading enzymes like alpha amylase, cellulase and pectinase. The ability of *Pochonia chlamydosporia* to promote growth was investigated in 2019 at the Indian Institute of Spices Research using a pot culture trial of black pepper plants of the var. Sreekara with various potting medium, including sterilized soil, unsterilized soil, and vermiculite+farmyard manure. After inoculating black pepper plants with varying doses (1.0 g–5.0 g) of *Pochonia chlamydosporia* for six months, the growth was compared to that of uninoculated plants. It was revealed that *Pochonia chlamydosporia* considerably improved the shoot and root growth parameters of black pepper plants when administered at a dose of 5.0 g. The contents of major, secondary and micronutrients in both soil and plant were also increased.

In black pepper, several drought tolerant varieties have been developed which could withstand water stress conditions. But some of these varieties might be inferior in terms of quality. On the other hand, cultivars that were superior in quality but unable to endure drought stress conditions may be promoted to flourish effectively. Super absorbent polymers (SAPs) are one such technique that could work as a soil conditioner by absorbing and retaining water and limiting the problems associated with water scarcity during drought periods.In this context, a study was conducted by Rasanjali *et al.* (2019) to evaluate he efficiency of super absorbent polymers and irrigation intervals in the growth of black pepper. They concluded that 2 g of super absorbent polymer and irrigation intervals of 8 days improved the plant growth parameters and survivability percentage. Thus application of super absorbent polymers could be used as a novel technology to mitigate water deficit in black pepper growing areas. Subila *et al.* (2020) isolated *Pythium deliense* for the first time from the root and soil samples of black pepper cultivated in major parts of Kerala and Karnataka. The pathogen caused yellowing and wilting symptoms in black pepper vines. Therefore, the ongoing research studies should focus on preventing the pathogen spread.

Radopholus similis gene silencing research was carried out in 2021 at the Indian Institute of Spices Research. Using double-stranded RNAs (dsRNAs) as triggers, the effects of silencing on seven genes (Rs-AB, Rs-Ac16, Rs-CDh, Rs-VpSA, Rs-GH, Rs-PL, and Rs-ReCa2) of *Radopholus similis* were examined. Many of the nematodes lost their characteristic body shapes after soaking in dsRNA, and as compared to untreated nematodes, they exhibited a typical locomotory behavior. The expressions of the Rs-GH, Rs-AB, and Rs-PL genes were drastically decreased following treatment with dsRNAs. This work reveals that responses of various genes to RNAi suppression may have varied outcomes; as a result, a thorough assessment of target genes as nematode control via RNAi targets is essential.

An experiment was conducted in 2021 at Indian Institute of Spices Research with five different concentrations of PEG-6000 (5, 8, 10, 12, 15 %) along with a control in black pepper cv. Panniyur-1, IISR Thevam, IISR Sreekara and IISR Girimunda inorder to standardize the concentration of PEG-6000 for moisture stress tolerance. According to the findings, seedling survival was lowered by about 50 % when PEG-6000 concentrations were set at 8 % in Panniyur-1 and 10 % in IISR Thevam, IISR Sreekara, and IISR Girimunda. Seedling survival percentage further reduced above 10 % PEG concentration. However, at 10 % PEG, a significant increase in proline was recorded. In response to moisture stress, proline builds up in plants, maintaining cell turgor and stabilizing cell membranes to stop the loss of water and electrolytes from the cells. Therefore, 10 % PEG-6000 might be utilized as the optimal concentration for testing the susceptibility of different genotypes of black pepper to moisture stress. Another experiment was carried out in 2021 at the Indian Institute of Spices Research to assess the effectiveness of various *Trichoderma spp.* in reducing moisture in black pepper. *Trichoderma harzianum* (NAIMCC-SF-0049), *Trichoderma lixii* (IISR KA15), *Trichoderma asperellum* (IISR TN3), *Trichoderma harzianum* (IISR KL3), *Trichoderma erinaceum* (IISR APT1), and *Trichoderma atroviridae* (IISR APT2) were the various isolates employed in the experiment. The variety IISR Sreekara was used in the experiment, which was conducted *in vitro*. The results of the experiment showed that black pepper plants inoculated with *Trichoderma asperellum* (IISR TN3) and *Trichoderma atroviridae* (IISR APT2) showed the highest leaf proline content and lipid peroxidation. Proline is an amino acid which usually get accumulated under moisture stress conditions in plants to help them to cope up the situation. From this study, it can be inferred that *Trichoderma asperellum* (IISR TN3) and *Trichoderma atroviridae* (IISR APT2) have the potential to induce moisture stress tolerance in black pepper by encouraging root and shoot growth as well as by activating defense mechanisms that prevent oxidative damage.

Pooja *et al.* (2022) conducted an experiment to find out the predominant form of breeding system in black pepper by conducting open pollination, autogamy, geitonogamy, xenogamy and apomixis as different treatments in selected black pepper plants. They found that geitonogamy was the most effective breeding system in black pepper and apomixis didn't contribute to fruit set. Paul *et al.* (2022) studied on the effect of bacterial and fungal endophytes in the management of foot rot. They found that treating black pepper plants with combination of *Piriformospora indica* and *Rhizobium radiobacter* PCRE10 was effective in managing the symptoms caused by *Phytophthora capsici* and also improved the growth characters in black pepper.

VI. ROADMAP

Screening of improved varieties with resistance to biotic and abiotic stresses with biotechnological approaches involving Marker Assisted Selection, cloning of defence genes from these resistant sources and identification of gene sequences could develop a divergent mapping population for gene tagging in black pepper. Surveillance of newly emerging disease, diagnostics, development of disease forecasting models, identification of resistant accessions and novel bio control agents and biomolecules, developing integrated pest and disease management for different cropping systems could lead to increase in productivity of the spice. Application of GIS in conservation of exotic germplasm and indigenous genetic resources, bar-coding of promising accessions, registering of unique genotypes, development of c DNA library, databases and catalogues. Studies should focus on incorporation of the therapeutical potential of piperine into health enhancing medical formulations, chemo profiling and identification of new flavour compounds, bio active principles for patenting. Development of databases, prediction models, production strategies and market intelligence-use of GIS & bioinformatics tools in pepper cultivation, marketing and trade.

VII. CONCLUSION

Black pepper is a highly valued spice crop in the domestic as well as international market. Currently, the trade of black pepper in India is becoming more import oriented. The fluctuations in area and production of the spice made India to import black pepper from the top producing countries in the world. Research areas on black pepper should focus on area expansion as well as increase in production by eradicating some of the causes like quick wilt and slow wilt. This could bring about a huge change and India could succeed in becoming the major exporter of black pepper in the world. Identification of novel thrust areas in crop improvement, biotechnological approaches, exploitation and practical applications of minor alkaloids and flavour compounds could lead to a new phase of the crop. Development and validation of these techniques will be able to maintain the global demand, trade flow and value of black pepper for yet another hundred years.

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