OVERVIEW OF BLACK PEPPER RESEARCH AND DEVELOPMENT PROGRAM IN INDIA

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Black pepper (*Piper nigrum* L.) known as the "King of Spices" is one of the oldest spices known to the world. Native to the India, black pepper has played a very important role throughout history and has been a prized spice since ancient times. The major commercial producers of black pepper are India, Vietnam and Malaysia. Besides, Indonesia, Brazil, Thailand and Sri Lanka are the other countries producing black pepper substantially (Table 1).

Presently it is grown in 26 countries with a production of 369587 MT from 467708 ha having a production of 790.2 kg ha^{-1} (FAOSTAT, 2004). Steady increase in area (R^2=0.8958) and production (R^2=0.8714) was noticed from year 1961 to 2004. However, perceptible variation in productivity was not observed during this period.

In India, Kerala, Karnataka, Tamil Nadu, Pondicherry and Andaman & Nicobar Islands are the black pepper producing states. Kerala alone accounts for 94% of the total area and 96% of the total production of black pepper in India, followed by Karnataka, Tamil Nadu, Pondicherry and Andaman & Nicobar Islands.

The productivity of black pepper is declining due mainly to prevalence of diseases, pests and drought. This results in increased use of biocides thus contaminating the produce as well as the environment with residues of pesticides. 'Clean spices' is a concept that is catching up and this is achieved through integrated approaches for pest, disease and nutrient management involving resistant varieties, biocontrol, botanicals and organic farming. This also reduces soil degradation.

The yield reduction is also due to unattractive prices which reduces farmer's interest in caring black pepper crop.

A brief overview of black pepper research and development program in India is mentioned hereunder:

A. Crop improvement

1. Genetic resources- Conservation and documentation

The Indian Institute of Spices Research (IISR), Calicut, Kerala, India maintains world's largest collection of black pepper germplasm containing local cultivars and 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 besides 9 exotic collections maintained in India. These collections have been 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.

2. Genetic improvement

2.1 Conventional approaches

Domestication of black pepper started thousands of years back. Today more than 100 traditional black pepper cultivars are prevalent in India mainly in the states of Kerala and Karnataka. Clonal selection, open pollinated progeny selection and hybridization are the major approaches followed in genetic improvement of black pepper (Ravindran and Sasikumar 1993, Sukumara Pillai et al., 1994, Ravindran et al., 2000). 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, any breeding method should also ensure this heterozygosity. The breeding strategies followed in black pepper are described below.

2.1.1 Clonal selection

Wide variability for yield and quality characters, occasionally even within a cultivar, is common in black pepper. Ibrahim et al. (1985) studied genetic variability in black pepper cultivars. Selection within the popular clones like 'Karimunda', 'Kuthiravally', 'Thevanmundi' and 'Kottanadan' has resulted in evolving superior varieties (Ratnambal et al., 1985; Ravindran et al., 1997).

Sreekara and Subbakara are the two high yielding varieties evolved based on clonal selections from 216 accessions of the local cultivar "Karimunda" conserved and characterized at IISR, Kozhikode, India. On the fifth year the highest yield (fresh) recorded per plant was 7.5 kg (dry) in the case of Sreekara and 7.9 kg (dry) in the case of Subhakara.

Panniyur-4 is an improved variety from the clones of c.v. Kuthiravally based on the selection carried out by the Pepper Research Station, Panniyur, Kerala Agricultural University. PLD-2 is a selection from cv. Kottanandan.

Panchami and Pournami and IISR Thevam are selections obtained from the germplasm collections of the IISR. Panchami is high yielding line from an elite mother vine of cv. Aimpiriyan, and Pournami is cv. Ottaplackal (named after the house of the farmer from where this cultivar was collected). Panchami and Pournami have good yield contributing characters (Nirmal Babu and Ravindran. 1992). The improved variety Pournami was found to be tolerant to root knot nematode- *Meloidogyne incognita.* The performance of these two cultivars was much superior to the prevailing varieties (Ravindran et al., 1992a, b). IISR Thevam is selection from the local cultivar Thevanmudy which has shown field tolerance to *Phytophthora* foot rot coupled with high yield (Sasikumar et al., 2004).

2.1.2 Open pollinated progeny selection

Selections from open pollinated seedlings of popular varieties have also yielded very good segregants. Even though the mode of pollination in black pepper is geitonogamy, there is a certain percentage of crossing and it is possible to locate useful genotypes in open pollinated progenies. In Sarawak, Malaysia Sim (1993) identified five promising genotypes from the third generation open pollinated progenies of cvs. *Balankotta, Cheriyakaniyakkadan* and *Kalluvally*, introduced from India to Malaysia. Three black pepper varieties, Panniyur 2, Panniyur 5 and IISR Sakthi have been released in India through open pollinated progeny selection.

2.1.3 Hybridization

Genetic improvement of black pepper through hybridization involves three steps *viz.,* selection of parents, developing progenies from the parents and selection of superior varieties from the progenies and their clonal multiplication. The Pepper Research Station, Panniyur are the pioneers to start black pepper breeding in India way back in 1950s. Many inter varietal hybrids were produced involving popular varieties as parents and evaluated for yield and quality attributes. So far four hybrids, Panniyur-1, Panniyur-3, IISR Girimunda and IISR Malabar Excel have been released for cultivation. Their important characters are given in Table 2.

Sasikumar et al. (1999) reported the first successful production of inter specific hybrids from the crosses of *P. nigrum* x *P. attenuatum* and *P. nigrum* x *P. barberi*. The hybrids were distinct in anatomical and morphological features with chromosome number 2n= 26. Isozyme studies revealed hybrid specific as well as male parent specific bands. Later, Vanaja et al. (2008) developed a partly fertile interspecific hybrid resistant to *Phytopthora* foot rot disease using a cultivated *P. nigrum* and *P. colubrinum*- an exotic wild species resistant to foot rot disease, as parents. Morphological, anatomical and molecular were used for confirmation and this hybrid can be considered as a successful breakthrough for introgression of resistance to the cultivated species

2.1.4 Polyploidy breeding

Black pepper is a diploid (2n=52). However, an induced tetraploid (2n=4x= 104) of the black pepper hybrid, Panniyur-1, was evolved at the IISR by treating fresh seeds of Panniyur-1 with 0.05% colchicine (Nair and Ravindran 1992). Nair et al. (1993) reported a natural triploid (2=78) among the black pepper cultivars. This triploid cultivar is characterized by very bold berries, loose setting and large leaves. Progenies of this triploid exhibited wide variation for somatic chromosome number and morphology (Nair et al., 1993; Nair and Ravindran, 1992).

The varieties/ hybrids developed/released through the above strategies in India and their salient features are given in Table 2.

2.1.5 Breeding for nematode, disease and insect resistance

Phytophthora foot rot (quick wilt) is the major disease of black pepper in all pepper growing countries, resulting in heavy crop losses. New varieties IISR Thevam and IISR Shakthi are highly tolerant to foot rot. Burrowing nematode (*Radopholus similis*) and root knot nematode (*Meloidogyne incognita*) are serious problems in some black pepper tracts. A Root knot nematode tolerant cultivar 'Pournami' has been developed through germplasm selection.

Pollu beetle is a major insect pest of black pepper in India. At IISR, evaluation of the germplasm accessions resulted in the identification of four accessions of cultivated black pepper *viz.,* Acc. No. 816, 841, 1084 and 1114 to be relatively resistant to '*pollu*' beetle (*Lanka ramakrishnae*). Incorporation of '*pollu'* beetle resistance through interspecific hybridization involving *P. attenuatum* and *P. barberi* with *P. nigrum* has been achieved (Sasikumar et al., 1999).

2.1.6 Breeding for drought tolerance

Screening of germplasm against moisture stress has resulted in identifying few promising Karimunda lines *viz.,* KS 69, KS 51 and KS 114, Acc. 813, 931and 1495. These drought tolerant lines are undergoing yield evaluation.

2.1.7 Breeding for high altitude

Black pepper grows well in altitudes up to 3000 ft MSL. Most of the black pepper varieties are not specifically bred for high altitudes, where it can be grown either as a monocrop or as an intercrop on the shade trees of tea or coffee or cardamom estates. Evaluation of 100 hybrids at Valparai (3000 ft above MSL), Tamil Nadu, India has helped in identifying 2 hybrids *viz.,* HP-813 and HP-105, which were for released as 'IISR Malabar Excel' and 'IISR

Girimunda' respectively. 'IISR Thevam' is another variety performing well at higher altitudes. The identified lines with resistance to biotic and abiotic stresses were involved in breeding programmes to bring these characters in a single genotype**.**

2.1.8 Breeding for high quality

Black pepper cultivars rich in piperine, oleoresin and essential oil are in great demand in the value added produce industry. Screening of the germplasm has resulted in identifying some cultivars with high piperine, oleoresin and oil content. The Indian cultivars 'Kottanadan', 'Kumbakodi', 'Kuthiravally' and 'Nilgiri' are rich in piperine and oleoresin whereas 'Balankotta', 'Kaniyakadan' and 'Kumbakody' are rich in essential oil. Sreekara and Subhakara varieties have high oil content (>6%). Zachariah (1995) observed variability for essential oil and major oil constituents in 42 accessions of black pepper. Gopalam and Ravindran, (1987) also reported variability for quality traits in black pepper cultivars. These high quality lines are being used in hybridization programme to evolve high quality, high yielding cultivars. 'IISR Malabar Excel' (HP 813) and PLD 2 are improved hybrids rich in oleoresin (above 12%).

Among the five varieties of black pepper *viz.,* Panniyur-1, Panniyur-2, Panniyur-5, Sreekara, and Subhakara, the variety Subhakara had the highest amount of berries of size between 3.8 to 4.8 mm (33.3 %) which belongs to TGSEB (Tellicherry Garbled Special Extra Bold) grade. Panniyur-1, Panniyur-2 and Panniyur-5 had more than 60 % of its berries under the grade TG (Tellicherry Garbled). Bulk density ranged from 450 to 571 g/l. Bulk density increased with increase in size. However, bulk density was found to decrease when the berry size was above 4.8 mm. The primary metabolites like starch increased as the grade size increased where as protein and crude fibre did not show any consistent trend. The secondary metabolites like oleoresin and piperine content were highest for the lower grade (< 3.5mm) but the essential oil content did not vary with respect to grade in all the varieties (Jayashree et al., 2009).

Based on GIS studies of the species of Western Ghats, Utpala Parthasarathy et al. (2006) reported that *Piper nigrum* L. has great adaptability to a wide range of climatic and soil conditions, which leads to inter-species diversity. Gas chromatography detected 7–15 compounds from volatile oil in different accessions and maximum variability was observed with respect to β-caryophyllene and nerolidol in the leaf oil and the influence of location on these components was found to be significant (Utpala Parthasarathy et al., 2008)

The composition of essential oil of 17 cultivars of Kerala indicated the presence of 69.4-85.0% monoterpene hydrocarbons and 15-27.6 % sesquiterpene hydrocarbons. The major monoterpene hydrocarbons *viz.,* α-pinene ranged from 5.9-12.8%, β-pinene 10.6-35.5% and limonene 22-31.1%. The major sesquiterpene hydrocarbon, β-caryophyllene, ranged from 10.3 to 22.4 % (Zachariah and Parthasarathy 2008). Analysis of four new genotypes of pepper (Panniyur-1, Panniyur-2, Panniyur-3 and Panniyur-4) by a combination of GC-MS and Kovats indices revealed that the three Panniyur genotypes contained α-pinene in the range of 5.07-6.18%, β-pinene 9.16-11.08%, sabinene 8.50-17.16%, and limonene 21.06-22.71% and β-caryophyllene 21.57-27.70%. The oil from *Panniyur*-4 contained α-pinene 5.32%, β-pinene 6.40%, sabinene 1.94%, myrcene 8.40%, p-cymene 9.70%, limonene 16.74% and caryophyllene 21.19% (Zachariah and Parthasarathy 2008). Zachariah et al. (2005) conducted a study on the effect of grafting *P. nigrum* on *Piper colubrinum* as

rootstock. The cultivars used for grafting were Panniyur-I, -II, -III, -IV and -V, Malligesara, Pournami, Sreekara, Poonjaranmunda, Kuthiravally, and Balankotta. The major essential oil constituents in grafts and non-grafts of pepper cultivars were pinene, sabinene and β-caryophyllene. Caryophyllene content varied from 12 to 27% in graft and 7 to 29% in non-graft. Limonene content varied from 13 to 24% in graft and 13 to 22% in non-graft.

2.1.9 Grafting with resistant root stocks

Phytophthora foot rot and slow decline are the major maladies for black pepper. To overcome this, *P. colubrinum* an exotic wild species of *Piper* is effectively utilized as a rootstock for grafting black pepper to control foot rot and nematodes in addition to adaptability to marshy situations. The plant has been found to be immune to the foot rot and resistant to nematodes. Five month old seedlings or rooted cuttings of *P.colubrinum* are used as rootstock. Grafting at 50 cm height is needed to avoid splashing of soil, debris, that contains fungal spores to the pepper vine and also to have more aerial roots growing into the ground. Several methods of grafting were tried and the best performance was seen with double rootstock method. Shoots taken from runner vines trailing on the ground that arise from mature vines were used as scions. Each scion has either a node with leaf or 2-3 nodes without leaves. Ideal time for grafting is during rains. Sprouting is observed 20 days after grafting and the union is complete after three months when the plastic wrapping around graft union can be removed. A yield of about 1.0 kg (dry)/graft can be obtained by the third year from the grafts. The evaluation of grafts in field indicated that they remained healthy even nine years after planting. The rootstock did not have any influence on qualities of the berries.

2.2 Biotechnological approaches

2.2.1 Micropropagation

In vitro propagation of black pepper has been reported using shoot tips, nodal segments and apical meristems. Multiple shoots can be induced using BA in the culture medium either alone or in combination with auxins. *In vitro* developed shoots could be easily rooted using growth regulator free basal medium (Rema et al., 1995, Nirmal Babu et al., 2001).

Micropropagation coupled with virus indexing and genetic fidelity testing is a good technology for obtaining disease and virus free planting materials. In India tissue cultured black pepper plants fortified with biocontrol agents like VAM and *Trichoderma viride* and PGPR were evaluated in over 100 ha in comparison with rooted cuttings and the tissue cultured plant showed better establishment, better growth, early flowering and low disease incidence.

Protocols for plant regeneration were standardized and plants were regenerated from shoot and leaf derived callus cultures (Nirmal Babu et al., 2000; Nazeem et al., 1993, Bhat et al., 1995). The plants could be established in the field. Micro propagation through direct somatic embryo genesis and subsequent cyclic secondary somatic embryogenesis was developed by Nair and Dutta Gupta (2003, 2006).

2.2.2 Protoplast culture

Shaji et al. (1996) reported high frequency isolation of viable protoplasts from *in-vitro* derived leaves of *P. nigrum* and *P. colubrinum*. Regeneration and development of protoclones were observed only in *P. colubrinum* protoplast cultures.

2.2.3 Genetic transformation

Preliminary reports are available on *Agrobacterium*- mediated gene transfer system in *P.nigrum*. Primary transformants for kanamycin resistance in the cotyledons were obtained using *Agrobacterium tumefaciens* binary vector strains LBA4404 and EHA105. Sim et al. (1993) cultured explants from leaf, petiole and stem explants from axenic seedlings of black pepper inoculated with the *A. tumefaciens* strain LBA4404 containing vectors carrying the *nptII* and *gus* [*uid A*] genes in callus inducing medium in the dark at 28^0C . At ten days after inoculation with the *A. tumefaciens* explants were sampled for GUS expression by X-gluc staining. Expression of the *gus* gene confirmed gene transfer to recipient tissue.

2.2.4 Molecular markers

Molecular profiling of important cultivars, released varieties and related species were done to study inter relationships and molecular markers were used to study the genetic similarity/variability of major accessions, hybrids and their parents. Pradeepkumar et al. (2001, 2003) studied 24 black pepper (*P.nigrum*) accessions, including nine advanced cultivars and 13 landraces using RAPD markers. Good variability was observed among *P. nigrum* cultivars. Genetic proximity among *P. nigrum* cultivars could be related to their phenotypic similarities or geographical distribution. Greater divergence was observed among landraces than among advanced cultivars. Cultivar-specific bands were obtained for all cultivars tested except for Panniyur-3.

An assessment of genetic relationships among thirty popular and agronomically important cultivars of black pepper using AFLP analysis was reported by Nisha et al. (2007). The dendrogram derived by unweighted pair group method analysis (UPGMA) grouped the accessions into three major clusters and four diverse cultivars with only 30% similarity. Karimunda, a widely grown and popular cultivar was unique in the fingerprint profiles obtained. Nazeem et al. (2005) used both RAPD and AFLP analysis to assess the variability and inter- relationships among 49 cultivars of black pepper. Two selections from the variety Karimunda, namely Sreekara and Subhakara, together formed a single cluster with almost 92 percent similarity. But Panniyur 1 and Panniyur 3 which are the progenies of the same parentage were distinctly dissimilar. Sreedevi et al. (2005) used RAPD to characterize seven new high yielding lines of black pepper and developed a bar code to identify the varieties. Nirmal Babu et al. (2003) used morphological characters coupled with RAPD, ISSR profiles to estimate the genetic fidelity of micropropagated plants pepper cv. Subhakara and Aimpiriyan. They observed that the micropropagated plants are genetically stable and the micropropagation technology can be used for commercial cloning of black pepper.

2.2.5 Gene isolation

Efforts are being made for the discovery of plant genes that are up regulated during resistant interactions between *P. colubrinum* and *P. capsici*. Differential display RT-PCR was carried out using RNAs isolated from *P. colubrinum* (resistant to *Phytophthora*) to tag genes expressed on *P.colubrinum* in response to *Phytophthora* inoculation (unpublished). Two cDNAs corresponding to differentially expressed genes in *P. colubrinum* were cloned and the 3'end of the gene was sequenced.

2.3 IISR initiatives towards developing varieties resistant to biotic and abiotic stresses

Black pepper hybrids/varieties combining disease and pest resistance with high yield and quality is the need of the hour. Field screening of black pepper germplasm resulted in the

identification of resistant/tolerant lines against various biotic and abiotic stresses (Table 3) However, most of these accessions are not high yielders. Efforts have been initiated to transfer these features to improved cultivars through inter cultivar hybridization using the improved variety Subhakara as female parent.

2.4 Registration of germplasm

Registration of valuable and important germplasm will meet the requirement of the intellectual property right and released issues, breeders' right, farmers' right, etc. In this endeavor, IISR Calicut has registered four unique black pepper germplasm (Table 4) with unique characters

2.5 Distinctness, Uniformity and Stability *(DUS) testing*

In the IPR regime it is important to protect the rights of farmers and breeders who develop improved genetic stocks. Accordingly the Government of India has established Plant variety Protection and Farmers' Right Authority (PPV & FRA). PPV & FRA in consultation with all the stake holders developed guidelines for distinguishing the varieties having DUS for different crops. The Indian Institute of Spices Research, Calicut is identified as the DUS test center for the spices *viz.*, Black pepper, Cardamom, Ginger and Turmeric. The institute in consultation with the task force members (Task force 7/2007) has developed DUS test guidelines for black pepper with IISR Chelavoor as main test center. The DUS test guidelines for black pepper consists of 10 essential characters supported by 12 other characters for assessing DUS. Farmers can protect their variety (candidate variety) by registering it with PPV & FRA. The varieties which have been released during the last 15 years are eligible for protection. The registrar, PPV & FRA will register every extant varieties within three years from the date of notification under the Act with respect to the genera and species eligible for registration subject to conformity to the criteria of distinctness, uniformity and stability as laid down under the legislation (Section 24, PPVFR rules). The registration is valid for 18 years and will be renewed after nine years if found fit will be extended for the remaining period.

Crop production

1. Techniques for production of planting material

1.1 Split bamboo method

Rapid multiplication technique utilizing bamboo splits is recommended for large-scale production of planting materials. A suitable area having good drainage is selected and leveled. Overhead shade is provided by using 50% shade net or thatched coconut leaves. Trenches of 30 cm width, 45 cm depth and of convenient length are taken and filled with soil, sand and farmyard manure (1:1:1). Bamboos of 8-10 cm diameter are selected and cut into 1.25-1.50 m long pieces and split into halves keeping the septa intact. Coal tar is smeared to prolong the life of bamboo splits. The bamboo splits are arranged at an angle of 45^o alternatively either side on straight wooden poles or strong supports fixed on small supports from ground and tied to each other with coir rope at the free end. Rooted cuttings are planted in the trench, one for each bamboo split.

As the cuttings start growing, the bamboo splits are filled with rooting mixture composed of farmyard manure, coir dust and sand in equal proportions. Each tender node is tied carefully to the bamboo using banana fibre, so that every node is in contact with the rooting medium. For rapid growth, daily irrigation through rose-can is essential. Vermiwash may be applied (50 ml per plant) at monthly intervals. When the vines reach to the top of the bamboo, the tip is nipped off and the vine is crushed at the base of 3rd or 4th node from the ground, to activate the buds. After 7-10 days, the vine is cut at the crushed point and removed from the bamboo with the roots intact and with the adhering soil. The vine is cut into single nodded pieces and each cutting is planted in a polythene bag filled with fortified potting mixture of soil, sand and farmyard manure (2:1:1) or solarized soil enriched with biocontrol agents or vermicompost.

After planting in the bamboo, the first harvest of cuttings can be done after 3-3½ months and the subsequent harvest at every 2-2½ months. Each rooted vine can give about 10 cuttings in one harvest and about 40 cuttings will be obtained in a year. A shed of 6 m x 24 m would accommodate 600 bamboo splits. On an average 20,000 cuttings can be produced annually by this method. The method is thus advantageous for producing a large number of rooted cuttings within a short period, throughout the year. The cuttings are also robust due to the abundance of roots leading to more than 90% establishment in the field.

1.2 Serpentine method

Three node cuttings planted in polythene bags are kept in an end of the nursery. When the plant develops two leaves they are trailed horizontally in polythene bags containing solarized potting mixture fortified with VAM (100cc/kg potting mixture) and Trichoderma (1g/kg potting mixture). Each node should be pressed into the mixture with polythene bags with 'V' shaped midribs of coconut leaves. As new shoots arise these are to be trailed horizontally in polythene bags containing potting mixture. Once 20 nodes get rooted, the first 10 polythene bags with the rooted nodes should be separated by cutting at the inter nodes. The internodal stub should be pushed back into the potting mixture. These stubs also produce a secondary root system. Daily irrigation is to be given using a rose -can. Application of vermiwash or *Pseudomonas* @ 25ml/plant encourages the growth of the cuttings. After 3 months these

cuttings are ready for planting in the field. On an average 60 cuttings can be obtained in a year by this method from each mother cutting. Cuttings raised in media consist of coir pith compost and, granite powder in 2:1 proportion with *Azospirillum* and *Phosphobacteria* as nutrient source yields higher biomass production.

2. Studies on climate change

2.1 Relationship between weather parameters and black pepper yield

An exhaustive analysis of climate change and spice production is provided by Parthasarathy et al. (2010). The rainfall pattern and pepper yields of during two extremely adverse years (1980-81 and 1986-87) were compared to that of a favourable year (1981-82) by Pillay et al. (1988) and it was found that during both adverse years, there was a distinct break in the rainfall during critical period following flower initiation. The break was experienced at two different times and therefore at different stages of the crop during the two years, but in both cases, the pepper yields were as low as 24.3% of the normal years yield. On the contrary, during 1981-82, the favourable year, the precipitation remained steady without any break and the pepper yields were high. The further reported that rainfall of 70 mm received in 20 days during May–June has been sufficient for triggering off flushing and flowering process in black pepper, but once the process is set off there should be continuous shower until fruit ripening. Any dry spell even for few days, within this critical period of 16 weeks (flowering to fruit ripening) would result in low yield. Mathai (1983) has observed high dry matter accumulation in branches just before shoot elongation and flowering during April-May.

The correlation between black pepper yield and climate parameters was worked out by Krishnamurthy et al. (2010). The climate and black pepper production data for the past two decades (1984 to 2004) were used for the purpose in most of the pepper growing areas of the country. In Ambalavayal (Wayanad, Kerala, India), December rainfall showed negative correlation with productivity. Tmin (minimum temperature) during March and January showed significant positive correlation with productivity while Tmax (maximum temperature) did not show significant correlation. In Nilgiris (Tamil Nadu, India), rainfall during December and January had negative correlation with black pepper productivity. Number of rainy days during May had positive influence while that of January was negatively correlated. Tmin showed significant positive correlation with pepper productivity during March, April, July, August and October months. In Panniyur (Kerala) also, rainfall and Tmax during December showed negative correlation with productivity and Tmin from August to December also showed significant negative correlation with productivity while in Trichur (Kerala), Tmin during January and Tmax during May and July had significant negative influence on productivity. In Pampadumpara (Kerala), October rainfall was positively correlated while June, July and September rainfall had negative influence on productivity whereas, in Valparai (Tamil Nadu) none of the climatic parameters showed significant correlation with productivity. It is seen that the response of black pepper yield to weather parameters was mixed for different location.

The correlation between climatic parameters and productivity shows that in plains (Trichur and Kannur, Kerala, India) Tmin and Tmax are negatively correlated while in the higher elevations (Wayanad & Pampadumpara of Kerala and Nilgiris of Tamil Nadu,) Tmin is positively correlated with productivity. Tmax does not seem to have much influence on

productivity in higher elevations. This implies that climate change especially the increase in minimum temperature may have positive influence on productivity in higher elevations while the same may have negative influence in plains. Increased rainfall during December and January tend to decrease productivity.

Sunil et al. (2010) reported that temperature and amount of rainfall received during second fortnight of March determined the productivity of black pepper in Wayanad. Increase in Tmax (18 March to 31 March) had a significant positive correlation and resulted in good yields whereas, the amount of rainfall adversely affected the yield. The yield was further reduced considerably if it is followed by a dry spell. Ankegowda et al. (2008) reported that March, April and May rains had positive impact on black pepper production in Kodagu District (Karnataka, India) in Robusta coffee and shade regulated Arabica coffee mix cropped with black pepper in Karnataka.

Parthasarathy et al. (2010) have brought out the magnitude of association of weather parameters with black pepper yield and it was in the order, rainfall> Tmin > Tmax. The effects of change in weather variables in successive weeks were not abrupt or erratic. The maximum annual growth of black pepper i.e., new flushes initiation and its growth, spike emergence and development coincides with the peak rainy period. Total rainfall and its distribution play an important role in black pepper production. An annual rainfall of around 2000 mm with uniform distribution is ideal. In India, black pepper growing areas receive annual rainfall of 1500 mm to more than 4000 mm. The nature of relationship indicates that rainfall beyond normal during initial period of annual cycle (i.e., 5 -11 March to 25 June – 01 July) was harmful or would reduce the yield.

Trend analysis for the effects of past changes in climate of black pepper growing areas such as Wayanad, Calicut, Panniyur, Pampadumpara and Trichur in Kerala; Valparai and Nilgiris in Tamil Nadu and Coorg in Karnataka on black pepper productivity has been done (Table 5). The data on rain fall, Tmax and Tmin were collected from these places for the past two decades (1984-2004). The black pepper productivity data was also collected for the corresponding period from these regions. In general, rainfall and productivity showed decreasing trend while Tmax and Tmin showed an increasing trend (Krishnamurthy et al. 2010).

2.2 Geographical Information System (GIS) studies

GIS was used at IISR to analyze the effect of change in the climatic parameters on black pepper. The study revealed that with an increase of temperature by 2ºC, most of the areas where the crops are being cultivated may become unsuitable and some new areas may become suitable for cultivation. In case of black pepper, North Eastern Himalayas show very less change in optimum climatic parameters while in Western Ghats the climate will tend to change from excellent to marginal. These shifts would lead to the erosion of native genotypes or wild types endemic to this region.

3. Tree supports for black pepper

Around 31 tree species which support the growth of black pepper have been identified under homestead agroforestry in Kerala, India (Salam et al., 1991). Among these, the most popular live stakes used on a plantation scale in the lower elevations are *Ailanthus triphysa* (Dennst.)

Alston., *Erythrina variegata* L., *Gliricidia sepium* (Jacq.) Steud. and *Garuga pinnata* Roxb. (Nair, 1993). Also, non-living stakes made of granite or reinforced cement concrete are sometimes used to support black pepper. While silver oak (*Grevillea robusta* A.Cunn. ex R.Br) is the common support used in the higher elevations, *Gliricidia sepium* (Jacq.) Steud. and to some extent *Erythrina variegata* L., are commonly used as supports of black pepper (Dinesh et al., 2005).

An evaluation of seven selected MPTs as support trees for black pepper vine was carried out at the Livestock Research Station, Thiruvazhamkunnu, Palakkad, Kerala, India (http://www.nrcaf.ernet.in/aicrpaf/pdf/kautra.pdf accessed on 26 October 2010). The results showed that *Acacia auriculiformis* and *Artocarpus heterophyllus* are promising especially when grown in high density (3 x 3m spacing) block plantations. Furthermore, they showed better response to pruning. Other trees species involved in the study were *Casuarina equisetifolia, Grevellia robusta, Macaranga peltata,* and *Ceiba pentandra*. Black pepper (var. *Karimunda*) was trailed on all support trees from the second year of tree planting. This study also revealed that *Acacia auriculiformis* was the best support tree with regard to pepper yield (1.98 t ha^{-1} of dried pepper). The second best was *Artocarpus heterophyllus*, a common species in the homegardens of Kerala but not widely used as standard for intensive pepper cultivation.

A study was conducted by IISR to assess whether the four commonly used support trees of black pepper (*Ailanthus triphysa* (Dennst.) Alston., *Erythrina variegata* L., *Gliricidia sepium* (Jacq.) Steud., and *Garuga pinnata* Roxb.,) had species-specific effects on an array of soil properties that provide a better indication of their rhizosphere health. The impact of these tree species on soil biochemical and microbial properties was also studied (Dinesh et al., 2010). The results revealed that among the tree species, greater levels of soil organic C were registered in the rhizosphere of *G. sepium* (26.5 g kg^{-1}), while the lowest level was registered by *A. triphysa* (21.6 g kg^{-1}). Greater levels of dissolved organic-C, -N, and mineral N also corresponded to the rhizospheres of *G. pinnata* and *G. sepium*, while the lowest level was registered by *E. variegata* and *A. triphysa*. Bray P level was markedly greater in the *G. pinnata* rhizosphere (8.4 mg kg^{-1}) and least in the *E. variegata* (5.2 mg kg^{-1}) rhizosphere. The levels of exchangeable-K, -Ca and -Mg in the tree rhizospheres were, however, not always higher than the control. Greater accumulation of microbial biomass- C (C_{MIC}), -N (N_{MIC}) and –P (P_{MIC}) was observed in the tree rhizospheres compared to the control. Among the tree species, C_{MIC} levels were greatest in the *G. sepium* and *G. pinnata* rhizospheres (474.0 and 454.0 μg g^{-1} respectively) and least in the *E. variegata* rhizosphere (415.0 μg g^{-1}). However, N_{MIC} and P_{MIC} levels did not vary markedly among the tree rhizospheres. Soil respiration rates did not vary significantly among the tree species (22.0-25.0 μg CO_2-C $g^{-1}day^{-1}$) and the lowest soil respiration (17.0 μg CO_2-C $g^{-1}day^{-1}$) was registered in the control. Contrarily, metabolic quotient (qCO_2) was greatest for control (83.0 mg CO_2-C (g biomass C)$^{-1}$ day^{-1}) and least for the tree species (51.0-59.0 mg CO_2-C (g biomass C)$^{-1}$ day^{-1}). The tree rhizospheres also positively affected the activities of enzymes like dehydrogenase, urease, acid phosphatase, aryl sulphatase and β-glucosidase. The results implied that among the tree species studied, *G. sepium* and to some extent *G. pinnat*a can be used as live supports for the restoration of degraded black pepper plantations and overall improvement in soil quality in the plains of the tropics.

3. Intercropping in black pepper gardens

Intercropping involves the growing of two or more crops in the same field- in sequence, in combination or both. The crops are mixed to form an ecologically sound system designed to maximize production. This system which has been commonly practiced by millions of farmers in the tropics for centuries may be particularly beneficial to cash- or credit-poor farming families. Most subsistence farmers prefer to plant at least two crops in the same field, thereby minimizing the risk of total crop failure. When the crop species complement each other in growth rhythms, rooting depths, nutrient uptake and use of water and light, production is maximized. Intercropping produces a combination of vegetation which permits little room for weeds either to invade or survive, and the efficiency with which many crop mixes use light, water and nutrients leaves precious little for the weeds. Intercropping also brings benefits through changes in the microclimate, reduces soil erosion, and helps to bind the soils due to increased rooting. Multistorey crop combinations such as coconut-black pepper- cacao-pineapple are now becoming more common place in the effort to produce as much as possible from a unit of land (Crump, 1993).

However, studies on intercropping in black pepper gardens are few. Trials conducted at IISR explored the possibility of growing cowpea, black gram, horse gram, amorphophallus, coleus, yam, turmeric, and ginger as intercrops. Also, medicinal plants such as *Desmodium gangeticum*, *Pseudarthria viscida*, *Adathoda vasica*, *Plumbago rosea*, *Piper longum*, *Gymnema sylvestre*, *Hemidesmus indica* and fodder crops such as congo signal grass, guinea grass, hybrid napier grass (CO-3) were tested (Thankamani, 2008). In the evaluation of legumes, the maximum shoot mass noted in Mimosa (25.81g/plant) whereas root mass was more in *Crotalaria striata* (11.3g/plant) after six months of growth. Nitrogen content was maximum in *Clitoria* spp (2.44 %). Yield recorded for ginger, turmeric, coleus, amorphophallus and tapioca in 5 year old black pepper garden was 5kg /bed, 7kg/ bed, 3kg/ bed, 1kg/ plant, and 1kg/ plant respectively. In the case of vegetables, yield obtained was, amaranthus green 200g/plant, amaranthus red 80g/plant, Brinjal 100g/plant and chillies 50g/ plant under rain fed condition planted during January. Average yield recorded for black pepper at RARS Ambalavayal was 5kg/ plant. In juvenile black pepper garden, yield recorded was higher than that in 5 year old garden. Recorded yields in juvenile garden were 7kg/ bed, 8kg/ bed, 4 kg/ bed, 1.5 kg/plant, 1.5 kg/plant and 1.7 kg/ plant respectively for ginger, turmeric, amorphophallus, tapioca, coleus and yam. In the case of vegetables, yield obtained was amaranthus green 500g/ plant, amaranthus red 300g/ plant, brinjal 750g /plant, chillies 200g/ plant and bhendi 150g/ plant. Among the various crops tried for a period of three years, crops such as ginger (Varada), tapioca (Sreejaya), coleus (Nidhi), amorphophallus (Gajendran) and hybrid napier (CO-3) were found suitable for intercropping in black pepper garden which is more than 15 years old (Thankamani, 2009).

4. Nutrient management

7.1 Nutrient requirement and removal

Major nutrients (nitrogen, phosphorus, potassium), secondary nutrients (calcium and magnesium) and micro nutrients especially Zn are the most important nutrients essential for black pepper growth, development and yield. Studies on nutrient removal by black pepper plants showed that three months old cuttings with four to five leaves removed 64.8, 3.3, 54.8,

24.5, 11.2, 8.1 mg of N, P, K, Ca, Mg and S respectively. Among the major nutrients studied, uptake of N was highest followed by K and Ca and among micro nutrients iron uptake was the highest. The magnitude of the nutrients removed was in the order: N>K>Ca>Mg>P>S.

Sadanandan (2000) reported a higher uptake of N and K up to the magnitude of 183-292 kg ha^{-1} and 313-337 kg ha^{-1}, respectively by eight year old yielding vines of pepper with a population of 1000 vines ha^{-1}. The P uptake was in the range of 21.4-24.5 kg ha^{-1}. Nutrient uptake sometimes varies with varieties. For instance, the variety Panniyur-I removed higher N, P and K compared to the variety Karimunda. When fertilizer inputs are added the uptake of nutrients was also appreciably higher.

Numerous studies have been made in pepper growing soils to evaluate the nitrogen status and uptake and dose of nitrogen to be applied for getting optimum black pepper yield. Sadanandan (1993) found that varieties like Panniyur-1 and Karimunda removed 292 and 183 kg ha^{-1} $year^{-1}$ of N respectively. For Panniyur-1, N at 50 kg along with 100 kg of P_2O_5 and 150 kg of K_2O are reported to be optimum in a laterite soil (Pillai et al., 1987). The availability of phosphorus depends on fixation and release in the soil. Besides, soil pH and organic matter content play vital roles in regulating P availability. Sadanandan (2000) reported a removal of 24.6 and 21.4 kg P ha^{-1} by Panniyur-1 and Karimunda varieties of which 50-62% of removal was constituted by the leaves followed by stem (16-24%), root (11-16%) and berries (8-10%). Among the sources of P, bone meal and mussoorie rock phosphate were found to be better P sources in an acid soil for the pepper varieties Panniyur-1 and Karimunda than super phosphate with higher cumulative yield and relative agronomic efficiency (Sadananadan and Hamza, 1995).

Black pepper requires large quantities of K for growth and fruiting and K requirement is related to the content of other nutrients in the plant, mainly nitrogen. A soil fertility survey carried out in the major pepper growing tracts in the states of Kerala and Karnataka in India indicated that 10% of the gardens surveyed were low (< 120 kg ha^{-1}), 31% medium (120-280 kg ha^{-1}) and 59% high (> 280 kg ha^{-1}) in available K status. Pillai et al. (1987) worked out an optimum K dose of 200g of K_2O $vine^{-1}$ for variety Panniyur-1, whereas Sadanandan (1993) optimized a dose of 270 kg K_2O ha^{-1} for high yield.

In case of secondary nutrients, Sadanandan (1994) reported the positive effects of Ca and Mg application at 50 kg each ha^{-1} levels. Yield response can be expected for pepper when sulphur content in the soil is less than the threshold value of 6 mg kg^{-1}. Hardly any response was seen as sulphur gets supplemented through super phosphate source which makes up the crop requirement (Sadananadan, 2000). Among micronutrients, zinc, molybdenum and boron are likely to become deficient in acid soils by leaching or precipitation. Studies on nutrient removal by black pepper plants showed that about three months old cuttings with four to five leaves removed 981, 19, 128 and 451 mg of Fe, Mn, Zn and Cu respectively. The magnitude of the nutrients removed was in the order: Fe>Cu>Mn>Zn.

7.2 Integrated nutrient management

Integrated nutrient management with annual application of NPK at the rate of 100:40:140 kg ha^{-1} and organics like FYM at the rate of 5.0 kg $vine^{-1}$ enhanced the fertility of soils under black pepper. Application of organics like castor and cotton cakes @ 1-2 kg per plant or

poultry waste @ 1-2 kg or cattle manure @ 3-5 kg, 200 to 300g NPK (12:12:17) mixture, 500g of lime and 300g thermo phosphate per plant per year in addition to foliar sprays of micro nutrients are the general practice followed by the growers. From a four year study conducted in 162 locations, Sadanandan and Hamza (2002) reported an increase in almost all the nutrients and yield due to the adoption of integrated nutrient management involving recycling of FYM.

A five year study on optimizing inorganic nutrient use in black pepper involved substitution of 50% of the recommended inorganic fertilizer dose with FYM on equivalent N basis and the remaining 50% of the dose was met either through inorganic N and P, inorganic N + Phosphobacterium (PB) + Vesicular Arbuscular Mycorrhiza (VAM) or inorganic P + Azospirillum. The study revealed that inorganic nitrogen and phosphorus dose could be reduced by 50% in black pepper by substituting with FYM (Mathew and Nybe, 2004).

A study by Stephen and Nybe (2003) indicated that treatments involving complete organic (FYM, ash) and biofertilizer (Azospirillum, AMF, phosphobacteria) + organic + inorganic combinations exhibited higher values of soil nutrients (N, P, K, Ca, Mg). Nybe et al. (2004) suggested manuring @ 10 kg cattle manure/ compost/ green leaves with NPK @ 50:50:150 g vine^{-1} year^{-1} and liming @ 500g vine^{-1} in alternate years during April-May in plant basins at 50-75 cm radius for higher yield. Hamza et al. (2004) reported that integrated plant nutrition management by combined application of FYM, leaf litter and chemical fertilizers are good for maintenance of soil fertility. Srinivasan et al. (2005) recommended application of coir pith compost at 1.25 t ha^{-1} integrated with half the recommended fertilizer dose and *Azospirillum* sp. @ 20 g vine^{-1} for higher yield and fertility build up in black pepper gardens.

Mathew and Nybe (2006) observed that combined application of 50% N as FYM + Azospirillum + 50% P as inorganic + Phosphobacteria + 100% K as inorganic resulted in highest berry yield comparable with 50% N and P as inorganic + biofertilizers + 100% K as inorganic and recommended dose of chemical fertilizers. The foliar and soil NPK contents also showed higher status with 50% N and P as inorganic + biofertilizers + 100% K as inorganic.

7.3 Organic nutrition

In recent years, organic agriculture has gained considerable importance and many farmers are switching to this traditional method of cultivation as a means to produce safe food and preserve the environment. Organic farming favors lower input costs, conserves nonrenewable resources, high-value markets and boosts farm income.

For nutritional management under organic management system, a judicious application of a combination of organic manures such as farm yard manure 5 kg, neem cake 1 kg and vermicompost @ 1 kg per vine per year can be made during May-June. Biofertilizers *viz.,* Phosphobacteria and *Azotobacter* are also applied @ 100g/vine mixed with farm yard manure in the second year of planting. Application of FYM (10 kg), burnt earth (10 kg) or wood ash (2 kg) and *Azospirillum* (50g) or Phosphobacteria (50g) per vine increased the yield by 37-173% over control (AICRPS, 2005). The studies at IISR showed that soil P, Ca, Mg, Zn and Cu availability increased significantly under organic system of black pepper cultivation with highest average fresh yield of 2.9 kg vine^{-1} as compared to integrated and inorganically

managed systems. The available soil N and K levels of organic sites were comparable with that of integrated nutrient management sites (Table 6).

Several PGPRs (plant growth promoting rhizobacteria) isolated from the rhizosphere of black pepper were found growth productive, disease suppressive and are efficient P solubilizers. Leaf compost and vermicompost supplementation supported significantly highest population of free-living N-fixing bacteria and phosphate solublizing bacterial populations (Parthasarathy et al., 2006). Biofertilizers like Azospirllum, Azotobacter, phosphobacteria etc are also widely used in black pepper plantations. Bopaiah and Khader (1989) reported increased shoot and root weight of cuttings of pepper by dipping in a peat based culture slurry of *Azotobactor, Azospirillum* and *Glomus mosseae* (VAM). Kandiannan et al. (1994, 2000) reported enhanced growth of pepper in the nursery due to application of 10g *Azospirillum* into the growing medium and significant enhancement in plant height, leaf area, biomass and dry matter production and nutrient content of black pepper cuttings due to combined application of *Azospirillium*, phosphobacteria and VAM.

Application of *Pseudomonas fluorescens* and inclusion of *Trichoderma harzianum* in potting mixture for rooting black pepper cuttings were found to increase the biomass production by influencing nutrient uptake through P solubilization (Thankamani et al., 2005), increased feeder root production and thereby enhancing the absorptive surface area (Anandaraj and Sarma, 2003) and phytohormone and siderophores production (Diby Paul et al., 2001; Diby et al., 2005a). Diby et al. (2005b) reported significant uptake of nitrogen (N) and phosphorus (P) and enhanced vigour of black pepper when inoculated with *Pseudomonas fluorescens* strains, due to higher root proliferation and nutrient mobilisation especially that of P in the rhizosphere. *P. fluorescens* strains enhanced P uptake by 122% over control (non bacterised plants) and N uptake by 65% over control resulting in increased root growth and biomass production.

Experiments conducted at various locations like Panniyur, Yercaud, Ambalavayal and Sirsi in India revealed that inoculation of Azospirillum (50g vine^{-1}) along with 10 kg FYM and 100% recommended inorganic N dose yielded 4.8 kg vine^{-1} recording 44% increased yield over control. Similarly phosphobacteria (50g vine^{-1}) inoculation with 10 kg FYM and 75% recommended inorganic P fertilizer dose recorded 185% increased yield (6.0 kg vine^{-1}) over control (2.1 kg vine^{-1}; AICRPS, 2005).

5.Crop physiology

Black pepper is a day neutral plant. It is a crop of humid subtropics and a shade loving plant. Vijayakumar et al. (1985) found that black pepper vines exposed to direct solar radiation developed physiological disorders. Even under favourable soil moisture conditions, black pepper vines kept under shade (7% incident light) remained green and healthy whereas those exposed to sunlight turned yellow and developed necrotic patches during summer (Vijayakumar and Mammen, 1990).

The rainfall requirement of the crop varies from 2000-3000mm. Tropical temperature and high relative humidity with little variation in day length through out the year is relished by the crop. It does not tolerate excessive heat and dryness (Sivaraman et al., 1999). In India

black pepper growing areas receive 1500 mm to more than 4000 mm rainfall. Rainfall after stress induces profuse flowering (Pillay et al., 1988). A relative humidity of 60-95% is optimum at various stages of growth. The crop tolerates temperature between 10^0C-40^0C. The ideal temperature is 23^0C-32^0C with an average of 28^0C.

One of the drawbacks of pepper production is the indiscriminate use of varieties irrespective of the prevailing agroclimatic conditions. In a state like Kerala with diverse climatic and soil conditions, identification and popularization of location specific varieties are important steps in increasing the production and productivity (Nybe et al., 1999). Sainamole kurian et al. (2002) reported a significant variation in performance of black pepper varieties in plains and high ranges owing to the differences in environmental conditions of these two regions, which provides evidence for climate change effects.

8.1 Light

The availability of light plays an important role in the productivity of black pepper. In a study on the influence of light availability on the productivity of black pepper, Mathai and Sastry (1988) reported that higher light availability during pre-flowering growth produced greater leaf area and more compact canopy structure with shorter lateral shoots resulting in more productivity of the vine. In an experiment to study the yield response of black pepper varieties to varying growth light regimes, Mathai and Chandy (1988) reported that the productivity of vine decreased with decreasing light interception from tip to bottom of vine.

Adequate sunlight in the pepper plantation is essential for proper vine growth, development of fruiting shoots and berry development. The average yield of the vines of 3.086 kg could be increased to the levels of potential yield of 10.345 kg per standard by adopting optimum plant spacing and better cultural and management practices (Nawale and Salvi, 1990). Shade regulation of live standards is an important cultural practice during rainy / cloudy weather to allow sufficient light for crop growth; if not, the yield will be reduced to 50% or more (Ramadasan, 1987).

Korikanthimath and Ankegowda (1999) reported that yield of black pepper was significantly higher in vines trained on *Terminalia bellerica* indicating the total surface area available for support and distribution of light through the canopy were important factors affecting the yield. In a study on bush pepper, maximum dry matter production and nutrient uptake were observed in bush pepper grown under 50 % light (Devadas et al., 2000). Vijayakumar and Mammen (1990) reported 44% more chlorophyll content in leaves exposed to full sun than that of leaves kept in shade.

8.2 Production physiology

Black pepper is a shade tolerant / shade loving crop and is normally grown under the shade of support trees. Higher light availability during pre flowering (March to April) produced greater leaf area and a more compact canopy structure. As a result, vines accumulated more metabolites, leading to greater production of lateral shoots during second flush, more flowers, spikes, greater number of berries per vine and higher dry matter accumulation in berries (Mathai and Sastry, 1988). A drastic reduction in leaf area of black pepper lateral after 60 days of spike initiation affected the yield attributes severely due to limitation in the availability of current photosynthates (Mathai et al., 1988). Berry set percentage was significantly reduced due to 75 % leaf area reduction of subtending leaves (Krishnamurthy et

al., 2000b). Low yielding cultivars accumulated 80 % of dry matter in laterals where as high yielding cultivars accumulated only 50 % in laterals and more dry matter in berries.

Leaf photosynthesis, nitrate reductase (NR) activity and stomatal conductance showed significant positive correlation while leaf temperature had significant negative correlation with productivity. High yielders maintained significantly higher NR activity, stem and leaf carbohydrate content and photosynthetic rate compared to low yielders during juvenile stage and these traits showed significant positive correlation with yield indicating their utility in screening germplasm for higher productivity in seedling stage itself (Krishnamurthy and Chempakam, 2009). Germplasm accessions from juvenile stage including the accessions shortlisted for various characters such as drought tolerance, nematode resistance, pollu beetle resistance etc. were screened for high yield based on carbohydrates, photosynthetic rate as well as NR activity. Accessions were ranked based on these three parameters and those which show high NR activity, carbohydrates and high photosynthetic rate were identified. Among 145 accessions screened for productivity, Acc 1395 and 898 figured in top 10 for all the three parameters.

8.3 Spike shedding

The spike shedding in black pepper may be due to several factors such as pollu producing fungus or insect or due to a prolonged spell of rainless days after the vines have started flushing and begun to put forth spikes or due to complete non-pollination of flowers. These factors may act singly or in combination. Low N and K levels in shoots and low soil moisture content during November and December also leads to spike shedding (Geetha and Nair, 1989). In var. Panniyur 1, spike shedding is highest in June, least in May and nil during September. In relation to plant development stages, it was highest during first month of fruit set and least during fourth month (Menon and Nair, 1987). Kumar and Sathiamoorthy (2002) reported that the number of developed berries per spike and the total number of berries per spike were highest with the application of 50 ppm NAA. Berry set was highest with the application of 150 ppm NAA, whereas green berry yield was highest with the application of 50 ppm NAA.

8.4 Water stress

Black pepper is a weather sensitive crop and yield is influenced considerably by environmental factors. Total rainfall and its distribution play an important role in black pepper cultivation and productivity. Annual rainfall of 2000 mm with uniform distribution is ideal. Rainfall of 70 mm received in 20 days during may- June is sufficient for triggering flushing and flowering process in the plant, but once process is set off there should be continuous showers until fruit ripening. Any dry spell even for a few days within this critical period of 16 weeks (flowering to fruit ripening) will result in low yield (Pillay et al., 1988)

Significant correlation were obtained between rainfall received (amounts to 100 mm to attain field capacity during first half of May) with yield in black pepper (r=0.75) and also with rainfall received during the second half of June and yield (r=0.90) (if preceded by rainfall in the first half of May) (Pradeepkumar et al., 1999). It was also found that 82.43% total annual growth of fruiting branches was required in June-July coinciding with peak period of Monsoon for better yield. High dry matter accumulation was observed in branches just before shoot elongation and flowering during April-May (Mathai and Sastry, 1988).

Intensive shedding of berries in the advanced stage of fruit development is thought to be due to physiological disturbance in the plant caused by prolonged spell of drought or heavy rains or the sharp and sudden alteration of the two. Intensive shedding occurs during years in which heavy North East monsoon showers are received after a spell of dry period followed by SW monsoon (Sukumara pillay et al., 1977).

Carotenoid ratio can be used as an index for stress studies in black pepper (Vasantha et al., 1989). Chlorophyll a, chlorophyll b and total chlorophyll content decreased with severe water stress. However the wax content of the leaf was found to be increased under water stress (Thankamani and Ashokan, 2002). During water stress relative water content decreased and cell membrane leakage increased. The decrease in relative water content and increase in membrane leakage intensified with stress intensity.

Water stress reduced the activity of catalase and acid phosphatase and increased the activities of peroxidase and polyphenol oxidase enzymes. Catalase activity was negatively correlated while peroxidase activity was positively correlated with membrane damage (Krishnamurthy et al., 2000a). Days taken for wilting showed a significant positive correlation with relative water content, significant negative correlation with peroxidase activity and membrane leakage and no significant correlation with catalase and SOD activities. Among the species studied, *P. colubrinum* wilted fast, showed high membrane leakage, very high peroxidase activity and low relative water content during stress period compared to other species indicating that it is very susceptible while *Piper chaba* was relatively tolerant (Krishnamurthy and Saji, 2006). Higher percentage increase in the enzyme activities of peroxidase and superoxide dismutase was observed in drought resistant cultivars on exposure to water stress. Lipid peroxidation was high in drought susceptible cultivars compared to tolerant cultivars (Thankamani et al., 2003).

B. Crop protection

The productivity of black pepper is considerably low in India due to various factors among which infestation by pests and diseases is a major factor. The major pests and diseases affecting black pepper in India include *Phytophthora* foot rot and slow decline diseases, *pollu* beetle, scale insects, and plant parasitic nematodes. The pests and diseases which are emerging as serious threats to black pepper in recent years include stunt and anthracnose diseases, root mealybugs and *Erythrina* gall wasp on *Erythrina* standards. Adoption of integrated pest management schedules is important in black pepper since the spice is high-value and export-oriented in nature and excessive use of pesticides could lead to pesticide residues in the produce and other ecological hazards. The major research initiatives being undertaken at IISR and KAU for the management of these pests and pathogens are highlighted here.

1. Phytophthora foot rot

Phytophthora foot rot caused by *P. capsici* is the most devastating disease of black pepper in India and is reported to cause a crop loss of over 1000 tonnes annually at Kozhikode and Kannur districts in Kerala. The disease which is common during the monsoon period culminates in death of the vine. The strategies developed for the management of the disease include: phytosanitation, cultural practices, biological control, including application of

antagonistic micro-organisms such as VAM fungi, *Trichoderma harzianum* and *Pseudomonas fluorescens*, cultivation of resistant varieties such as IISR-Shakthi and need-based application of chemicals such as Bordeaux mixture 1%, copper oxychloride 0.2%, potassium phosphonate 0.03% or metalaxyl-mancozeb 0.0125% (IISR, 2005; KAU, 2007). Since *Phytophthora* foot rot is a serious concern in black pepper production, research on management of the disease utilizing resistant varieties, newer biocontrol agents and biotechnological approaches is being given major emphasis.

1.1 Resistance

Efforts are being made to locate resistance to *P. capsici* in the germplasm collections, and a large number of cultivars, hybrids and related *Piper* species were screened and promising lines identified. A *Phtophthora* tolerant line namely, IISR Shakti, was released based on screening open pollinated seedling progenies of various cultivars and evaluation in the field. Another open pollinated progeny [P 24-04-1] was also identified as resistant and is under field evaluation. Evaluation of *P. nigrum* on the resistant rootstock *P. colubrinum* is in progress in the field. An inter-specific hybrid (*P. nigrum* x *P. colubrinum*) partially resistant to *Phytophthora* foot rot has also been developed (Nybe, 2001; Bhai, 2007, Vanaja et al., 2008, Suseela Bhai et al., 2010).

1.2 Biological control

Several strains of biocontrol agents such as VAM fungi, *Trichoderma* spp. and *Pseudomonas fluorescence* were identified as efficient in protecting black pepper from root rot caused by *P.capsici.* Mass multiplication techniques were also standardized using coconut water, sorghum meal, coffee husk and pulp, tea waste and decomposed coir pith. A bioconsortium was also developed with potential rhizosphere bacteria namely, IISR-6, 8, 13, 51, 151 and PB-21C and found effective under field conditions. Promising endophytic bacteria such as *P. aeruginosa*, *P. putida* and *Bacillus megaterium* were identified from black pepper and proved effective against the disease in greenhouse studies and are being evaluated in the field (Sivaprasad et al., 1995; Anandaraj and Eapen, 2006; Dinu et al., 2007).

1.3 Biotechnological approaches

A mapping population involving Panniyur 1 x Subhakara was developed and the inheritance pattern of *Phytophthora* resistance in the mapping population was studied. Successful *Agrobacterium* mediated transformation with osmotin gene was also achieved for disease resistance in black pepper. The enzyme chitinase involved in disease resistance was identified in *P. colubrinum* and the gene was cloned which showed similarity to known chitinase gene from plants. SCAR markers for Phytophthorta resistance have also been developed (IISR, 2007; Anandaraj et al., 2008).

2. Slow decline

Slow decline is caused by the association of plant parasitic nematodes such as *M. incognita* and *R. similis* and also *P. capsici*. The affected vines exhibit mild to moderate foliar yellowing initially and with depletion of soil moisture during the post monsoon season, they show defoliation and die-back leading to loss of vigour, yield and finally death of the vine. Yield losses ranging from 39% to 65 % have been reported when black pepper vines were inoculated with *R. similis* and *M. incognita* under simulated field conditions.

Nematode management in black pepper warrants a sustainable approach integrating several strategies to bring down nematode populations below economic injury levels. The strategies developed for the management of the disease include: phytosanitation, biological control, including application of antagonistic microorganisms such as, *Trichoderma harzianum*, *Pochonia chlamydosporia* and *Bacillus macerans* and need-based application of chemicals such as phorate or carbofuran (KAU, 2007; IISR, 2005). Research on management of the disease utilizing resistant varieties and newer biocontrol agents is being given major emphasis.

2.1 Resistant lines

A number of black pepper germplasm accessions, including wild types, were screened against *M. incognita* and *R. similis* and *a* cultivar, which was resistant to *M. incognita* was released as 'Pournami' for cultivation in root knot infested areas. *Piper hymenophyllum, P. colubrinum, P. attenuatum* and accessions like HP-39 and C-820 were resistant to *R. similis*. *P. colubrinum* is now widely used as a root-stock to graft cultivated pepper plants (Nybe, 2001; Eapen, 2006).

2.2 Biological control

Biological control initiatives to manage nematode pests of black pepper include use of antagonistic microorganisms such as *P. chlamydosporia*, *T. harzianum* and *B. macerans*. There are only very few successful attempts to control *R. similis* by using fungal bioagents, probably due to the migratory endoparasitic nature of this nematode. Recently, two promising endophytic bacteria namely, *Bacillus megaterium* and *Curtobacterium luteum* suppressing *R. similis* have been identified and are being evaluated in the field (Sivaprasad et al., 1990; Eapen, 2007; Aravind et al., 2010).

3. Pollu beetle

The *pollu* beetle (*Lanka ramakrishnae=Longitarsus nigripennis*) is the most destructive insect pest of black pepper in India. The pest infestation is higher in the plains and midlands in Kerala and in endemic areas up to 40% of the crop is lost due to the pest infestation. The adult *pollu* beetle feeds on tender shoots, leaves and spikes whereas the larva bore into tender spikes and berries and feed on the internal contents. An integrated strategy involving regulation of shade and spraying of insecticide (quinalphos 0.05%, dimethoate 0.05% or cypermethrin 0.01%) and neem-based product is to be adopted for the management of *pollu* beetle (IISR, 2005; KAU, 2007). Since very few natural enemies have been recorded on pollu beetle, identification of resistant lines and utilization of plant products is being given emphasis in the research programmes of the institute.

3.1 Resistance

Black pepper cultivars show wide variation in their reaction towards *pollu* beetle in the field. Four cultivars resistant to the pest under field conditions were identified from the germplasm collections of IISR, Calicut. Six wild species of *Piper*, namely, *P. colubrinum*, *P. chaba*, *P. longum* , *P. attenuatum*, *P. barberi* and P. *hymenophyllum* have also been identified to be resistant to the pest. Interspecifc hybrids of black pepper such as *P. nigrum* x *P. attennuatum* and *P. nigrum* x *P. barberi*, were less preferred for feeding by adult *pollu* beetle. These

resistant lines are being utilized in breeding programmes for developing resistant varieties against the pest (Sasikumar et al., 1998).

3.2 Plant products

Extracts of various plant species have been screened for antifeedant activity, among which leaf extracts of *Chromolaena odorata*, *Azadirachta indica* and *Strychnos nux-vomica*, neem oil, neem seed kernel extract and custard apple (*Annona squamosa*) seed extract were promising indicating their potential in utilizing them in IPM schedules (Devasahayam, 2005).

4. Scale insects

Scale insects are major insect pests of black pepper at higher altitudes in Kerala, Karnataka and Tamil Nadu. Among the various species of scale insects recorded on the crop, the mussel scale (*Lepidosaphes piperis*) and coconut scale (*Aspidiotus destructor*) are the most common feeding on the sap of various tissues. The management strategies developed against the pest includes cultural practices such as clipping off and destroying severally affected branches, and spot application of insecticide such as dimethoate 0.1% (IISR, 2005; KAU, 2007)

4.1 Natural enemies

Various predators and parasites have been recorded on scale insects in the field among which predatory beetles such as *Chilocorus* spp. and *Pseudoscymnus* spp. (Coccinellidae), and hymenopterous parasitoids such as *Aphytis* sp. and *Encarsia* spp. (Aphelinidae) were identified as major natural enemies. Methods have been standardized for mass rearing of *C. nigrita* and *C. circumdatus* in the laboratory. Evaluation of these predators in the field indicated that their release brought down the population of *L. piperis* and *A. destructor* (Selvakumaran et al., 1996; Devasahayam, 1998).

4.2 Plant products

Neem products such as neem oil 0.3% or Neemgold 0.3% or natural products such as fish oil rosin 3% are also promising for the management of scale insects and are safer to the coccinellid predators (Devasahayam, 1998).

5. Emerging insect pests and diseases

5.1 Stunt disease

Stunt disease caused by caused by *Cucumber mosaic virus* (CMV) and *Piper yellow mottle virus* (PYMoV) are becoming serious in recent years in Kerala and Karnataka especially at higher altitudes. The diseased vines exhibit shortening of internodes and the leaves become small and narrow with varying degrees of deformation and appear leathery, puckered and crinkled with chlorotic spots and streaks. The incidence of the disease was higher (45.4%) in Wayanad District in Kerala and the yield loss due to the disease in infested vines, varied from 16%-85% (Bhat et al., 2005; Bhat, 2008).

Two viruses *viz*., CMV and PYMoV virus were associated with the disease. The mealy bugs *Ferrisia virgata* and *Planococcus citri*, commonly found associated with black pepper was found to transmit PYMoV. DAS-ELISA based methodology was developed for the detection of both the viruses in nursery and plants. A protocol for isolation and simultaneous detection of both the viruses infecting black pepper based on Multiplex RT-PCR method was also developed. Planting materials of black pepper are being screended for these viruses before multiplication and distribution to various agencies (Bhat, 2008).

5.2 Anthracnose

Anthracnose disease caused by *Colletotrichum gloeosporiodes* is also referred to as *pollu* disease indicating the hollow nature of infested berries. The disease is increasingly becoming serious at higher attitudes in Kerala and Karnataka. The crop loss due to anthracnose was reported to be up to 67% in Kerala when the berries were infected at an early stage; the crop loss was higher when the spikes were affected.

Trials conducted at Kodagu District (Karnataka) revealed that irrigation of vines 4-5 times at an interval of 5-7 days commencing from the third week of March, followed by shade regulation of support trees was optimum for managing spike shedding. Phytosanitory, prophylactic sprays with Bordeaux mixture 1% and nutrition management practices are also necessary for holistic management of the disease (IISR, 2004; KAU, 2007). Studies on epidemiology of the disease in various cropping systems, screening of black pepper cultivars and fesibility of utilization of biocontrol agents for the management of the disease is being undertaken at the institute.

The emerging insect pests which are becoming serious especially at higher altitudes include root mealybugs on black pepper and *Erythrina* gall wasp on *Erythrina* standards. Colonies of root mealybugs (*Planococcus* spp.) are observed at the basal portion of the stem under the soil and on roots causing yellowing, wilting and mortality of younger vines. The pest infestation is more common at higher altitudes in Wayanad (Kerala) and Kodagu (Karnataka) districts and is more severe on vines affected with *Phytophthora* sp. and nematodes. Root mealybugs can be managed by planting pest-free cuttings, removal of weeds in the interspaces of black pepper vines during summer and drenching chlorpyriphos 0.075% and also by undertaking management schedules against *Phytophthora* and nematodes (IISR, 2005; Devasahayam, 2006; KAU, 2007; Devasahayam et al., 2009) .

The *Erythrina* gall wasp (*Quadrastichus erythrinae*) is a new invasive pest infesting *Erythrina* spp. in all black pepper areas. The pest infestation results in the formation of galls on tender shoots and leaves leading to stunting and death of standards. A viable long-term strategy for the management of the pest would be planting other standards such as *Ailanthus malabaricus*, *Garuga pinnata*, *Graevillea robusta*, *Gliricidia sepium,* for trailing black pepper. The relative incidence of the pest in various species / types of *Erythrina* spp. and the natural enemies associated with the galls are being documented to evaluate their suitability in the management of the pest (Jacob and Devasahayam, 2009).

C. Conclusions

With the present pace of research and developmental efforts, India would remain a key player in black pepper trade at the global level. Major efforts are focused on identifying core issues and developing strategies for increased productivity through development of high yielding and high quality varieties resistant to biotic and abiotic stresses (Table 7)

While conventional breeding remains a basic strategy, exploiting appropriate biotechnological approaches like molecular breeding are of high priority. Characterization of germplasm through conventional methods and DNA profiling should be a major thrust area in crop improvement programme to safeguard against biopiracy and to identify useful genes. Various approaches are greatly increasing our ability to characterize and manipulate the genes responsible for many agronomic characters especially disease resistant genes. Molecular markers are allowing the effective deployment of resistance genes to enable more stable resistance and providing the opportunity for transgenic disease control. Another focus area should be breeding black pepper varieties resistant to *pollu* beetle, *Phytophthor*a, nematodes and viruses through both conventional and biotechnological approaches.

Since the crop is grown in a wide range of soils, it is essential to develop location-specific fertilizer recommendations based on soil fertility levels. The need is to develop soil test kits and decision support aids on the one hand and farmers' capacity to adopt and utilize these in field fertility management on the other. Hence, development of decision support software, which imbibes a fertilizer recommendation program based on soil series and soil testing will be imperative. In the growing crop, leaf colour charts are known simplified tools to adjust site specific nutrient applications.

Nutrient uptake and response to fertilizer application is decided by the genetic makeup, root and shoot habits of the crop. Hence, screening the different cultivars/ varieties for their efficiency under nutrient deficient conditions will help in identifying ideal varieties for different soil types.

It is vital to evolve techniques and technologies that integrate native and synthetic inputs with natural resources. The need is to broaden the scope and depth of integrated nutrient management systems. The response to organic nutrition and role of biological agents and its sustainability have to be extensively studied to determine the feasibility of low input agriculture and to design sustainable organic farming systems for black pepper.

Future studies on black pepper physiology should aim at quantification of water requirement especially during summer to obtain maximum benefit with minimum expenditure, identification of varieties adaptable to climate extremities, understanding the mechanism of abiotic and biotic stress tolerance and adaptation/mitigation strategies to overcome the ill effects of these stresses. Regulation and physiological basis of flowering and spiking is another important area for investigation.

A comprehensive understanding of the molecular mechanisms of host-pathogen interactions is imperative. This could augment the development and utilization of diagnostics for management of pests and diseases. Another area that needs attention is the use of genomic tools for diversity studies and characterization of pathogens and biocontrol agents of pests and diseases. It is also essential to develop sustainable IPM strategies including cultural

methods, resistant lines, biocontrol agents, botanicals, microbial metabolites and need-based application of pesticides. More importantly, it is critical that we strengthen our capacity to develop strategies to manage new and invasive insect pests and diseases of black pepper.

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Table 1. **Black pepper production from major producing countries (tonnes)**

Country	**Brazil**	**India**	**Indonesia**	**Malaysia**	**Sri Lanka**	**Vietnam**	**Others**	**Total**
1997	18,000	60,000	43,200	18,000	4,470	25,000	22,930	191,690
2000	26,385	58,000	77,500	24,000	10,670	36,000	27,535	260,090
2001	43,000	79,000	59,000	27,000	7,800	56,00	36,395	308,195
2002	45,000	80,000	66,000	24,000	12,600	75,000	38,460	341,060
2003	50,000	65,000	80,000	21,000	12,660	85,000	48,500	362,160
2004	45,000	62,000	55,000	20,000	12,820	100,000	51,659	346,479
2005	35,000	70,000	35,000	19,000	14,000	90,000	31,720	294,770
2006	44,500	55,000	20,000	19,000	14,330	100,000	36,400	289,230
2007	35,000	69,000	25,000	20,000	14,640	90,000	36,400	271,040

Source: Sreekumar, 2008

Table 2. Improved varieties of black pepper from India and their salient features

Name	Pedigree	Released from	Average yield. Dry (kg/ha)	Oleo-resin (%)	Pip-erine (%)	E. oil (%)	Remark
Panniyur-1	F_1 of 'Uthirankotta' x 'Cheriyakaniy-akadan'	Pepper Research Station, Panniyur, Kerala Agriucultural 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'	-do-	2570.0	10.9	6.6	3.4	Reported to be shade tolerant.
Panniyur-3	F_1 of 'Uthirankotta' x 'Cheriyakaniy-akadan'	-do-	1953.0	12.7	5.2	3.1	Late maturing. Suited to all pepper growing regions.
Panniyur-4	Clonal selection from 'Kuthiravally'	-do-	1277.0	9.2	4.4	2.1	Stable yielder.
Panniyur-5	Open pollinated progeny selection of 'Perumkodi'	-do-	1098.0	12.3	5.5	3.8	Tolerant to nursery diseases and shade.
Panniyur-6	Clonal selection of 'Karimunda'	-do-	2127.0	8.3	4.9	1.3	Suited to all pepper tracts.
Panniyur-7	Open pollinated progeny of 'Kalluvally'	-do-	1410.0	10.6	5.6	1.5	Suited to all pepper tracts.
Subhakara	Clonal selection from 'Karimunda'	IISR, Calicut, Kerala, India.	2352.0	12.4	3.4	6.0	Suited to all pepper growing regions.
Sreekara	Clonal selection from 'Karimunda'	-do-	2677.0	13.0	5.1	7.0	Suited to all pepper growing regions.
Panchami	Germplasm selection	-do-	2828.0	12.5	4.7	3.4	Late maturing type suited to all pepper growing areas.
Pournami	Germplasm selection	-do-	2333.0	13.8	4.1	3.4	Tolerant to root knot nematode (*M. incognita*).
PLD-2	Clonal selection from 'Kottanadan'	IISR, Calicut 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' x Panniyur-1	-do-	1065.0	13.5	2.96	3.2	Suited to high altitudes and rich in oleoresin.
IISR Girimunda	F_1 of 'Narayakodi' x 'Neelamundi'	-do-	2112.0	9.65	2.2	3.4	Suited to high altitudes
IISR Sakthi	Open pollinated progeny of 'Perambramundi'	-do	5.17**	10.2	3.3	3.7	Tolerant to foot rot disease in the juvenile phase

(Source: Parthasarathy 2008)

Table 3. Black pepper accessions shortlisted for breeding objectives

Sl. No	Trait	Germplasm accessions shortlisted

1	Tolerance/ resistance to foot rot disease	IISR, Thevam, IISR Shakti
2.	Resistance to "pollu" beetle	Acc. No. 816 (Neyyatinkara mundi), 841 (Veluthakaniyakadan), 1084(Cheppukulamundi) and 1114(Kumbhachola).
3.	Tolerance/ resistance to slow wilt (Nematodes)	Pournami, Acc. 820 (Perumkodi) & Hybrid 39 (Irumaniyan X Karimunda)
4	Tolerance to drought	Karimunda selections (KS) 69, KS 51 and KS 114, 813 (Ottaplackal-II), 931(Kalluvally) and 1495 (Kottanadan).
6	High caryophyllene content	Acc. No 840 (Vattamundi), 971 (Balankotta), 1019 (Vellamunda) and 1022 (Karimunda).

Table 4. List of germplasm registered

Sl. No	Crop	Year	Reg. No	Coll. No	Traits
1	Black pepper	2003	INGR 03091	1041	Field tolerance to foot rot disease
2	Black pepper	2004	INGR 370011	5455	High oleoresin and bold berries
3	Black pepper	2006	INGR 06026	1019	High caryophyllene
4	Black pepper	2008	INGR 8100	IC 563950	Novel spike variant with 100% proliferating spikes

Table 5. Trends in climate and black pepper yield at different black pepper production centres

Place	Rainfall	Tmax	Tmin	Productivity
KERALA				
Ambalavayal	Decreasing	Increasing	Increasing	Decreasing
Pampadumpara	Decreasing	-	Increasing	Increasing
Calicut	Decreasing	-	-	Decreasing
Panniyur	Decreasing	Increasing	Increasing	Decreasing
Trichur	Dccreasing	Decreasing	No trend	Decreasing
TAMILNADU				
Valparai	No trend	No trend	Decreasing	No change
Nilgiris	Increasing	Increasing	No trend	Decreasing
KARNATAKA				
Kodagu	Decreasing	-	-	Decreasing

Source: Parthasarathy et al. (2010)

Table 6. Effect of different management systems on soil nutrients under black pepper

Management systems	pH (1:2)	OC %	N	P	K	Ca	Mg	Fe	Mn	Zn	Cu
			(mg/kg)								
Organic	4.92	2.44	134.8	5.63	177.4	658.5	116.8	43.8	4.7	3.61	25.31
Inorganic	4.63	2.43	117.0	3.08	169.3	388.1	79.3	43.2	6.9	2.90	3.80
Integrated	4.70	2.45	140.9	3.10	206.0	434.1	88.6	44.7	6.4	1.37	4.58
CD (5%)	0.19	NS	8.8	1.03	28.6	74.9	18.2	NS	0.99	0.86	1.43

NS- non significant; unpublished data.

Table 7. Issues and Strategies

Issues	Strategies
1. Non-availability of genes characterized for desirable traits such as yield and quality, disease, pest and drought tolerance for pyramiding in a single cultivar	• Broadening the genetic resources, their conservation, documentation and preparation of catalogues • Locating the sources of resistance for stresses using conventional and biotechnological tools
2. Lack of quality disease free planting material and certification standards	• Production of disease free quality planting materials of HYVs and its distribution
3. Crop loss by pest and diseases and emergence of new pest and diseases	• Development of IPM practices for increasing the productivity
4. Pesticide residues in spices	• Development and popularization of Good Agricultural Practices (GAP) for spices
5. Non-availability of methods to control post harvest losses and aflatoxin contaminations	• Developing suitable on-farm processing techniques • Developing storage and packaging system to suit HACCP norms
6. Poor adaptability of nutrient management practices by farmers	• Dissemination of technologies to the farmers and industry
7. Lack of resistant lines against biotic and abiotic stresses	• Breeding varieties for high yield and resistance to biotic and abiotic stresses
8. Lack of proven organic farming technology	• Development of location specific technology package for organic farming
9. Reduction in quality of spices due to mixing up with other inferior varieties imported into the country	• Developing varieties with specific qualities such as oleoresin and essential oil contents
10. Lack of technology for marginal and small farmers.	• Development of cost effective agricultural practices.
11. WTO implications	• Genetic finger printing of germplasm and patenting technologies related to spices