PHYSIOMORPHOLOGICAL AND BIOCHEMICAL RESPONSES OF BLACK PEPPER (*Piper nigrum* L.) TO IRRIGATION, PRUNING AND HORMONE APPLICATION FOR FLUSHING, FLOWERING AND BERRY SET

By

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THESIS

Submitted in partial fulfilment of the requirement for the degree of

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DECLARATION

I hereby declare that the thesis entitled **"Physiomorphological and biochemical responses of black pepper (*Piper nigrum* L.) to irrigation, pruning and hormone application for flushing, flowering and berry set"** is a bonafide record of research work done by me during the course of research and the thesis has not previously formed the basis for the award to me of any degree, diploma, associateship, fellowship or other similar title of any other university or society.

22.08.2003
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CERTIFICATE

Certified that the thesis entitled **"Physiomorphological and biochemical responses of black pepper (*Piper nigrum* L.) to irrigation, pruning and hormone application for flushing, flowering and berry set"** is a record of research work done independently by **Mrs. T.V. Thanuja** under my guidance and supervision and that it has not previously formed the basis for the award of any degree, diploma, associateship or fellowship to her.

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We, the undersigned members of the Advisory Committee of **Mrs. T.V. Thanuja,** a candidate for the degree of **Doctor of Philosophy in Horticulture**, with major field in Plantation Crops and Spices, agree that the thesis entitled **"Physiomorphological and biochemical responses of black pepper (*Piper nigrum* L.) to irrigation, pruning and hormone application for flushing, flowering and berry set"** may be submitted by Mrs. T.V. Thanuja in partial fulfilment of the requirement for the degree.

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22.08.2003

Thanuja

T.V. Thanuja

Affectionately Dedicated to
My
Beloved Parents
&
Loving Husband

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Introduction

1. INTRODUCTION

Black pepper (*Piper nigrum* L.), which rules the spice trade of our country, enjoys a unique and foremost position in the agricultural scenario of Kerala as well as India. It is often referred as the black gold of our country due to its international trade importance. Black pepper alone accounts for about 50 per cent of the total export earnings from spices in India. The annual export earnings from pepper has been reported to be Rs. 212 crores (Sivaraman *et al.*, 2002).

In India, the crop is cultivated in an estimated area of 1.92 lakh ha with an annual production of 58,290 t (Sivaraman *et al.*, 2002). Kerala, Karnataka and Tamil Nadu are the major pepper growing states, among which, Kerala alone accounts for 96 per cent of area (1.84 lakh ha) and 97 per cent (56,430 t) of the production (Sivaraman *et al.*, 2002).

Though India is a major producer of black pepper, productivity of the crop is lower (315 kg ha^{-1}) compared to other pepper producing country like Thailand (4000 kg ha^{-1})(Ghosh *et al.*, 1999). Several reasons like existence of senile vines, uneconomic and poor varieties, incidence of pests and diseases and want of timely scientific management practices are attributed to the low productivity of pepper vines in our country. In the present day situation, international trade of black pepper is facing a strong competition from other pepper producing countries like Sri Lanka, Vietnam and Brazil, which has resulted in a fall of pepper export leading to a low market price of black pepper in India. In order to withstand the competition and to capture the world market, India has either to produce more or to improve the export quality of pepper.

In Kerala, black pepper is mainly grown as a rainfed crop. The stand of the crop and yield are highly dependent on the quantity and distribution of rains. Although Kerala receives a high amount of rainfall (3000 mm per year), due to uneven distribution of rains the crop is subjected to moisture stress from December to April. The periodic water stress during the above period is regarded as the major constraint in increasing the productivity of black pepper in the state (Vasantha *et al.*, 1989). The present study aimed to elucidate the effect of dry spell on subsequent season's yield and

quality by substituting irrigation at systematic intervals during the drought period. The proposed study can also help in the optimization of irrigation schedule for the drought period to obtain maximum yield in pepper.

The exogenous application of growth regulators is reported to increase the yield and quality attributes of crop plants (Gurumurty *et al.*, 1985; Guardiola *et al.*, 1992; Khurshid *et al.*, 1992). Use of growth regulators is one of the options to increase the productivity in pepper. Very little is known about the effect of growth regulators on yield attributes of pepper. The present investigations were envisaged to study the role of growth regulators on enhancing the yield and quality parameters of black pepper.

Pruning is an important practice in perennial horticultural crops, to attain higher level of productivity and quality. It is particularly effective in crop plants, which bear fruits on new shoots. Since pepper bears on the current season laterals and each leaf axil is potentially productive, there is better scope for pruning to improve the productivity in black pepper. Hence, an experiment was conducted to study the effect of pruning of laterals on the subsequent flushing and yield of pepper.

The productivity of black pepper is primarily dependent on growth and flowering behaviour of the vine. The flowering in pepper occurs only on the current season's growth of the lateral shoots. The main yield components in black pepper are determined during flushing and flowering. Hence to exploit the full production potential in black pepper, a detailed understanding of growth and flowering characters is of importance. Morphological characters are accounted generally to judge the overall productivity of a plant. Although this can furnish a general assessment, a sound knowledge of causal mechanisms at cellular or molecular level is necessarily warranted for any kind of manipulations. The monitoring of biochemical and physiological mechanisms, which determine the yield potential of a crop at important physiological stages attains importance at this point. A fundamental knowledge on these factors is highly essential to elucidate the factors governing as well as limiting the yield under a particular situation or a cultural practice and will be useful to define the requirement of cultural practices.

In the light of the above facts, the investigations reported herein were undertaken with the following objectives:

To elucidate the effect of dry spell on subsequent flushing and yield characters of pepper vine by substituting irrigation at periodic intervals from December to April. Biochemical and physiological analysis with respect to flushing, flowering and berry set are also envisaged.

To study the effect of application of growth regulators at spike initiation on the yield and quality parameters of black pepper and to assess the biochemical and physiological changes during flowering and berry set.

To investigate the effect of pruning of laterals on the growth and yield characters of subsequent year and to analyze the various biochemical and physiological characters during flushing and flowering and also at berry set.

To correlate the influence of morphological, biochemical and physiological parameters with yield and to assess the contribution of these traits towards productivity in black pepper.

Review of Literature

2. REVIEW OF LITERATURE

Black pepper being an evergreen perennial vine, its pattern of vegetative and reproductive growth is controlled by a combination of physiological, biochemical and environmental factors. The crop regulation or management practices like irrigation during drought period, exogenous application of growth regulators and pruning after harvest in black pepper may affect its productivity by affecting the different aspects of crop phenology through various physiological and biochemical factors. The research work done on these aspects in black pepper is reviewed here. Since work done in black pepper is scanty, information available in other perennial horticultural crops has also been incorporated for better understanding, under following heads:

2.1 GROWTH AND DEVELOPMENT IN BLACK PEPPER

2.1.1 Vegetative Growth

Black pepper is a climbing evergreen hardy vine growing to a height of 10 metres or more. Based on the growth habits, morphological characters and biological functions, the shoot system of a pepper vine exhibits five distinct types of growth like main stem, plagiotropes or fruit bearing laterals, top shoots or orthotropes, hanging shoots or geotropes and runners. Among these, 'black pepper', the economic product of a pepper vine is produced on the lateral that grows more or less right angles to the main stem. The emergence of new shoots from the previous season growth of laterals with the onset of monsoon is referred to as flushing in pepper. Since flower buds are borne on the newly formed flushes of the laterals, their number and growth characters are closely related to the productivity of pepper vine.

The new growth in black pepper was found to initiate in late May and continued to mid August with maximum growth occurring in June-July (Nalini, 1983; Menon and Nair, 1989; Mathai and Nair, 1990). The total annual extension growth of laterals in the variety Panniyur 1, varied from 5.28 to 12.04 cm of which 82.43 per cent was recorded in June-July (Menon, 1981). However, any variety may putforth new flushes during any time of the year if sufficient rains are received after a dry spell. A

second flush is also commonly noticed in pepper cultivars during the North East monsoon period (Nambiar *et al.*, 1978; Kurien and Nair, 1988). The main lateral produces primary, secondary and tertiary branches and grows to a maximum length of 50-75 cm depending up on the variety and soil fertility. The angle of insertion of laterals to the main stem, vary from variety to variety to the tune of 45 to 130 degrees. As a result, some of the varieties have drooping laterals, some have well arranged horizontal laterals and others have somewhat erect laterals. Chandy and Pillai (1979a) observed that the drooping, horizontal or erect nature of the laterals determined the photosynthetic efficiency of pepper vine.

2.1.2 Reproductive Growth

2.1.2.1 Flowering

Flowering in black pepper coincides with the onset of South West monsoon in Kerala. Nalini (1983) and Rajan (1985) reported a spurt in flower bud differentiation activity immediately after the receipt of premonsoon showers with maximum differentiation in June – July (40 to 95 per cent) and the process was completed with in 20 to 25 days of commencement. The flowering in pepper was confined to four months from May onwards and followed a pattern similar to the growth of shoots with maximum in July (50.3 per cent) followed by June, May and August (Menon, 1981). Flowers in pepper are borne opposite to the leaves on laterals in pendant spikes of 5 to 25 cm length with up to 150 flowers. The spikes emerged are covered in sheaths of green to pink or even violet colour. Normally, a spike takes 20-25 days from the time of its emergence from sheath for its full development and to attain maximum length (Chandy and Pillai, 1979a). The spike length is a character of importance, which controls the yield in pepper along with increased fruit set.

2.1.2.2 Fruit Set

The pollination of flowers on the spike is mainly through self pollination with the help of rain water (geitenogamy). Pollination and berry development in pepper vine start soon after the anthesis and it requires about 150 days for complete maturity.

Availability of photosynthates, which is controlled by light, decides the formation of developed berry number per spike, which is an important criterion that determines the yield (Mathai, 1983).

2.2 FACTORS INFLUENCING GROWTH AND YIELD OF BLACK PEPPER

Black pepper being an evergreen perennial crop, its pattern of vegetative and reproductive growth is controlled by a combination of environmental, biochemical and physiological factors.

2.2.1 Environmental Factors

The effect of environmental stress on phenology could adversely affect the final yield in the same year or the following years depending up on the type of the crop. Among the environmental factors, weather plays an important role in determining the growth, development and production of any crop. In a perennial crop like black pepper, the influence of weather on yield is rather decisive. The variation in weather parameters affecting growth and yield will finally be reflected in terms of yield. Weather variables, which mainly influence the growth and yield in pepper, are rainfall, light and temperature.

2.2.1.1 Rainfall and its Distribution

Rainfall appears to be the most important weather element, which determines crop growth and development in black pepper. The flowering and fruiting in the plant synchronise with the rainy season, indicating the importance of rainfall in pepper cultivation.

The shoot growth in plagiotropes of pepper is closely related with the pattern and the quantity of rainfall received. Pillai *et al.* (1987) reported that, a pepper vine could be induced to flush and putforth new shoot growth if 70-100 mm of rainfall is received or an equivalent quantity of water is given to the plant within a period of about three weeks. The time taken from the receipt of the trigger of showers to the early stages

of fruit development (about six weeks), which is considered as critical period in the reproductive phase of a pepper plant. They observed that if the daily mean rainfall during a week in the critical period is less than 10 mm, spike elongation and fruit set in pepper are adversely affected. It resulted in less spike length and poor berry development and consequent reduction in the yield up to 76 per cent. A continuously drizzling and wet atmosphere throughout the critical period seems to be an optimum condition for maximum productivity of pepper.

The intensity and distribution of summer showers in any year determined the crop aspects of pepper to a considerable extent in that particular year. Nalini (1983) reported that receipt of the premonsoon showers after the dry spell during December to April triggered the flower bud differentiation activity in pepper. In a year of poor or no summer showers pepper yield was satisfactory, while fairly high summer rains resulted in low yield of pepper (Kannan *et al.*, 1987). John *et al.* (1999) highlighted the importance of a stress period in pepper after harvest of the previous crop as a physiological need for a better crop production during the particular season. Rainfall initiated from February to March onwards without providing a stress period to pepper accelerated the vegetative growth of the vines. It adversely affected the spike initiation and thereby reduced the yield by 25 per cent compared to previous season. They also observed that about 7.5 cm rainfall with in a period of 20 days is sufficient to trigger off the flushing and flowering process in black pepper. Rao (2001) also reported that rainfall during summer months is detrimental to black pepper production.

The distribution of rainfall in a year is also having a significant relation with the vine yield. Spike yield in pepper is highly dependant on the quantity and distribution of rains during May-June period (Nalini, 1983). Sadanandan (1996) observed a significant correlation between the rainfall received (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 second half of June (if preceded by the rainfall in the first half of May) and yield ($r=0.9$) which pinpoints the importance of rainfall in flowering and production of pepper. The rainfall in March, extending up to second half of April reduced the yield in black pepper whereas, a well distributed monsoon rainfall during June and September found to affect the yield of black pepper positively (Sajith *et al.*, 2001).

2.2.1.2 Light

In any cropping system, light appears to be one of the most limiting factors in the productivity of crops. The productivity of a plant depends on its capacity to harvest the solar energy efficiently for the metabolic production and the partitioning efficiency of the same for higher productivity. Since pepper is a traditionally shade grown perennial vine, the light availability to various parts is an important factor which controls the productivity.

Light interception is the amount of available light intercepted by a plant canopy, which can affect the productivity of crop plants (Jackson, 1980). It is a fundamental parameter in any crop model for estimating canopy photosynthesis. A check in the availability of solar radiation due to the wide spread foliage of the live standards can possibly affect the productivity characters of pepper vines trailing on that. Wide differences have been reported among varieties in their response to intensities of light. The light requirement of Panniyur 1 is reported to be more compared to other varieties of pepper (Mathai, 1983).

Chandy *et al.* (1984) reported the indirect influence on productivity by certain leaf and vine characters, which determined the effectiveness of light interception. Five cultivars of black pepper were evaluated for eight growth and eleven yield attributes at harvest by Mathai *et al.* (1991). Vines with smaller leaves, shorter internodes, vigorous branching and smaller canopy surface received increased sunlight penetration and air movement within the canopy. Such condition reduced the number of lateral branches but increased the number of productive laterals and number of spikes on each lateral.

Leaf lamina is the major photosynthetic organ of the plant to intercept sunlight and productivity of the plant directly depends on the chlorophyll bearing surface area, irradiance and its potential to utilize carbon dioxide (Edwards and Walkers, 1983). Evidences suggest that leaf production, leaf area index, leaf orientation and other factors have major influence on radiation harvesting process. The partial or total removal of bract leaf significantly reduced spike length, number of berries and

berry weight in Panniyur 1 (Kumar and Sreedharan, 1984). The reduction in source area by 62 per cent after 60 days of spike initiation, affected the yield attributes and photosynthetic accumulation in black pepper (Mathai *et al.*, 1989).

Mathai and Sastry (1988) reported that highest light availability during pre flowering (March to April) produced greater leaf area and more compact canopy structure with shorter lateral shoots. This allowed the vines to accumulate higher levels of metabolites which led to greater production of lateral shoots during the second flush, more flowers, spikes, greater number of berries per vine and higher dry matter of berries per vine. The vines under high growth light regime were found to produce more number of berries per unit surface area and it was low under low growth light regime (Mathai and Chandy, 1988). They attributed the lower productivity at the lower parts of the canopies to low light availability to the vines, which in turn can hinder the production of photosynthates and also partitioning. Satheeshan (2000) compared light compensation point in Panniyur 1 to Karimunda and found that Panniyur 1 can fix increased carbon at higher light intensities, supporting its high productive nature under increased illumination. Also, the laterals in Panniyur 1 is likely to receive more light at all canopy levels as it is having less compact canopy and the laterals are more protected and exposed to light compared to Karimunda.

2.2.1.3 Temperature

Temperature relations have been found to be important among the factors governing the pattern of flowering and fruit set in a wide variety of crops. The temperature affects the rate of physiological and biochemical processes of plant growth or the timing of developmental events in crop plants.

Nalini (1983) observed high mean temperature at peak period of flower bud differentiation in pepper. Rajan (1985) also reported that maximum and minimum temperature in the preceding summer and subsequent monsoon showers played important roles in triggering the flower bud differentiation activity. Maximum temperature observed during the first fortnight of April was found to affect the yield of

pepper positively as an increasing trend in yield was observed with rising temperature during the period (Sajith *et al.*, 2001).

2.2.1.4 Moisture Stress or Drought

Generally, water stress or drought affects several physiological processes in plants leading to a reduction in crop yield. However, in pepper there are contradictory reports on the effect of drought period (December to May) on the flowering and consequent yield of the crop. Ridley (1912) reported about the profused blooming and fruiting of pepper vines in Sumatra after a continuous dry period of eight months while, Dewaard (1969) attributed higher yield in Malaysia to the widely distributed rainfall prevailing there and the dry spell, which seldom exceeds 10 days. In Kerala, black pepper is grown mainly under rainfed condition where the plants are subjected to water deficit during the period from December to May due to uneven distribution of rains. Vasantha *et al.* (1990) reported that water stress during the period as a major constraint in increasing the productivity of pepper in Kerala.

Pillai *et al.* (1985) necessitated the importance of a short spell of drought in pepper during summer months preceding to flowering in June-July. Sadanandan (1994) also reported that some amount of stress is needed during April for the induction of flowering in pepper. This support the observation made by Rao *et al.* (1998) that, pepper gave higher yield in drought years while it gave low yield in good premonsoon years. Similarly a temporary water stress prior to flower bud differentiation was found to be beneficial in several other crops like peach (Aldrich and Work, 1934), citrus (Abbot, 1935), grapes (Balasubrahmanyam, 1971), and cardamom (Vasanthakumar, 2001).

The moisture stress during other important stages of physiological development also adversely affects the yield in black pepper. The critical periods of moisture stress in black pepper are flushing, flowering and fruit set (Sadanandan, 1994). Mathai *et al.* (1988) observed reduced carbon fixation during the advanced stage of berry development resulting from stomatal closure due to water stress, which pinpointed

the fact that moisture stress free situation is a must also during berry development stage in the crop.

2.2.2 Biochemical Factors

The transformation from vegetative to reproductive phase has been reported to change the status of biochemical constituents in plants. Analysis of plant extracts for various biochemical parameters therefore help in better understanding of the metabolism, since the levels of these biochemical constituents in plant tissues at any given time is the outcome of their biosynthesis, accumulation and metabolism. Biochemical methods are increasingly used to evaluate the crop variety, to change methods of management and to predict the performance of the plant as such.

2.2.2.1 Leaf Chlorophyll

A positive correlation between leaf chlorophyll content, photosynthesis and biomass production has been reported in several crops (Agarwal and Prakash, 1980; Naidu and Swamy, 1995). In coconut, Mathew and Ramadasan (1975) reported higher chlorophyll content in high yielding hybrids compared to West Coast Tall. Anakaiah and Rao (1991) stated that chlorophyll content of mature cashew leaves would give a fair indication of the bearing capacity of the tree and significant difference in chlorophyll content was observed between high and poor yielders.

Chlorophyll content in leaves varies with day length, irradiance, quality of light, temperature, water and nutrient status of soil (Lewandowska and Jarvis, 1977). In black pepper, a reduction in chlorophyll and carotenoid pigments were observed due to higher temperature (Vasantha *et al.*, 1989; Vijayakumar and Mammen, 1990). Reduction in total chlorophyll content in the moisture stressed leaves of pepper, was also observed by Kurup and Vijayakumar (1987) and Thankamani (2000). The chlorophyll content of the pepper leaves exposed to sun was 44 per cent of that of leaves grown in the shade (Vijayakumar and Mammen, 1990). Similarly in grapes also, shade grown vines exhibited highest chlorophyll content (Cartechini and Palliotti, 1995).

The chlorophyll content in the leaves of crop plants varies with respect to the physiological stages of development. Kumari and Sinha (1972) reported that leaf chlorophyll content at pod development decreased in chickpea compared to flowering stage. No definite trend in the chlorophyll production in leaves during the different stages of development of laterals in pepper was observed (Satheeshan, 2000). Spike bearing laterals recorded higher chlorophyll content than those without spike. In mango, there was no variation in the chlorophyll content between flowering and fruit development stages (Jyothy *et al.*, 2000). However, during the fruit development stage, chlorophyll 'a' recorded higher in 'off' year trees compared to 'on' year trees. The chlorophyll content in the reproductive flushes of cashew after fruit set was found to be higher compared to the chlorophyll content at panicle development (Pushpalatha, 2000).

The chlorophyll content was also found to vary with leaf age, leaf position, and management practices. Schubert *et al.* (1996) in grapes reported that leaf chlorophyll content per unit leaf area was highest in the leaves of intermediate age (40-60 days) whereas, Lovisolo *et al.* (1997) reported higher chlorophyll content in 20 to 30 days old leaves. In ginger, Xizhen *et al.* (1998) observed that leaf chlorophyll content and photosynthetic rate increased with increased leaf expansion and reached a peak in 15 days old leaves after that both declined gradually. Significant increase in leaf chlorophyll content was noticed only up to 17 days after unfurling of the leaves in banana (Thomas and Turner, 1998). Severely defoliated leaves in grape vine appeared to contain more chlorophyll than those of the lightly defoliated and control vines (Hunter and Visser, 1989). Chlorophyll content decreased as leaves were situated progressively deeper into the canopy. No consistent relationship between chlorophyll concentration, light intensity and photosynthetic activity could be found for the different leaf position.

2.2.2.2 Phenols

Some of the phenolic compounds are analogous to plant hormones and some may function as growth inhibitors as they invoke enhanced enzymatic oxidation of indole acetic acid (IAA), which is reported to influence the flowering process (Bernier *et al.*, 1981). Earlier studies have indicated that certain phenolic acids induce flowering

under non-inductive conditions (Nanda *et al.*, 1976; Kumar *et al.*, 1978; Tayal and Sharma, 1982). Khurana and Maheshwari (1986) showed induction of 80 per cent flowering under strict non-photo inductive condition by a polyphenol, tannic acid.

The main phenolic constituent of reproductive organs in a wide range of flowering plants have been identified as hydroxy cinnamic acid amides. Its increase in apical part at the time of floral induction and absence in leaves and stems were noticed in tobacco plants (Martintangue *et al.*, 1978). The phenolic substances affect the physiological process by interfering with IAA biosynthesis and by IAA oxidase activity (Balasimha and Subramanian, 1983). In mango cv. Alphonso, phenolic content of the fruit buds during fruit bud differentiation increased steadily but remained stable in undifferentiated buds or scar buds (Patil *et al.*, 1992). Sreehari (1995) also observed higher levels of phenols in the shoots with differentiating fruit buds than non-differentiating shoots during fruit bud differentiation. In cashew, Sherlija and Unnikrishnan (1996) reported marked increase in phenol content during transition from vegetative to reproductive phase. Phenolic compounds are present in black pepper as secondary metabolites, which were reported to have active roles in the biosynthesis of essential oil and piperine content of the berries (Shaukathali, 1997). Satheeshan (2000) observed higher phenol content in the laterals with spike compared to laterals without spikes. The phenol content did not record marked difference between growth stages except berry maturity.

2.2.2.3 Polyphenol Oxidase Activity

Polyphenol oxidases (PPO) are copper proteins of wide occurrence in nature, which catalyze the aerobic oxidation of certain phenolic substrates to quinones, which are auto oxidized to dark brown pigment known as melanin. It plays a vital role in higher plants and the activity varies with respect to different physiological stages of development.

The activity of PPO was higher before and during the fruit bud differentiation than afterwards, in the fruit buds of mango cv. Alphonso (Patil *et al.*, 1992). In grape vines, Sharma and Sharma (1999) reported that the polyphenol content

and the related activity decreased as the shoots developed from the sprouts. The activity was considerably higher at the initial stages of plant growth, which dropped markedly at later stages. In coffee, PPO activity was higher in the early developmental stages of leaves (Muzzafera and Robinson, 2000). Sharma *et al.* (2001) reported a strong negative correlation between PPO activity and number of panicles in mango. The activity was inversely related to flowering and regular bearers exhibited low enzymatic activity.

2.2.2.4 Peroxidase Activity

Peroxidase enzyme appears to be a key enzyme involved in several biochemical pathways. It catalyses the dehydrogenation of a large number of organic compounds such as phenols, aromatic amines, hydroquinones and also takes part in the synthesis of lignin (Kosuge, 1969). Peroxidase enzyme is also involved in several plant reactions such as, IAA oxidation (Hinnmann and Lang, 1969), cell elongation (Goldberg *et al.*, 1986) and *in vitro* rhizogenesis of explants (Mato *et al.*, 1998).

Golodriga and Pucao (1963) reported that peroxidase activity in the leaves was associated with early berry growth in grapes. Increased enzymatic activity during inflorescence formation in grape vines was also reported (Srinivasan and Rao, 1971). Vora and Vyas (1974) reported higher peroxidase activity whenever there was differentiation. In mango cv. Alphonso, a highly significant association between peroxidase and yield of fruits was observed (Vijayalakshmi and Srinivasan, 2001). The activity registered a peak during flowering with a gradual decline and a low value at the time of harvest. In Satsuma mandarin, peroxidase activity was found higher in the leaves of flowering trees compared to nonflowering trees (Monerri and Guardiola, 2001).

Nie *et al.* (1991) reported a significant correlation between the leaf peroxidase activity and length of the shoots and internodes in orange. The higher activity was observed in shorter shoots and thus suggested leaf peroxidase activity as a biochemical index for the early selection of short shooted forms.

2.2.2.5 *Nitrate Reductase Activity*

The nitrogen metabolism in plants involves the reduction of nitrate to nitrite, which is catalyzed by nitrate reductase enzyme, and then to ammonia before it is converted to amino acids. In green tissues, assimilation of nitrate is intimately linked with photosynthetic reactions. Activity of the enzyme varies widely in different tissues and is influenced by several factors such as growth of the plants, substrate concentration, light intensity and moisture regime etc. The level of nitrate reductase activity (NRA) in many crops has been positively correlated with their productivity (Deckard *et al.*, 1973; Oh *et al.*, 1980; Thomas, 1990). High NRA was found necessary to impart better nitrogen use efficiency in cashew plants (Pushpalatha, 2000).

Raju and Rajagopal (1988) studied the NRA in the flag leaves and berries of black pepper during growth and development. The activity of the enzyme in the berry increased while that of flag leaf declined with the time of development. Irrespective of the age, the flag leaf had higher NRA during early stages of berry development and it decreased with the maturity of berries. The mature leaves from the runner shoots showed higher NRA per leaf than the young leaves, though the latter showed higher activity on unit weight basis. They also studied the diurnal fluctuation of NRA in leaf. The activity in the leaves of runner shoots was found to be high during daytime and negligible during night. Thomas (1990) reported that NRA in black pepper leaf in the range of 0.67 to 1.68 m mol nitrite per gram fresh weight per hour. Seasonal influence in the NRA was also observed with highest activity during November and lowest during April. Higher enzymatic activity was observed in runner shoots and low in the main shoot and laterals. There was an increase in NRA with increase in light intensity. The mean activity was significantly higher at 60 and 100 per cent light. There was a decrease of around 40 per cent in NRA at 10 to 30 per cent light intensities compared to that at 100 per cent light.

The nitrate reductase activity was found to be higher in flowered branches of cashew and mango compared to unproductive branches (Devi and Tyogi, 1991). At different stages of growth in mango, significant difference in the activity of nitrate reductase was observed (Vijayalakshmi and Srinivasan, 2001).

2.2.2.6 C:N Ratio

Carbon is the most abundant element in plant on the basis of percentage of dry weight. The carbon and oxygen together account for 88 per cent of the dry weight that remains after water is removed from the plant tissues. In black pepper no work is done earlier on the total C content of the leaves. But 43.6 per cent of C by dry weight was reported in maize (Noggle and Fritz, 1989). The total C content of leaves may differ at different physiological stages due to the difference in C assimilation, accumulation and translocation at these stages.

Nitrogen is one of the most important plant nutrient influencing vegetative growth and yield in crop plants. Sobrado (1994) indicated a linear relation between foliar N and leaf photosynthetic rate.

Pillai and Sasikumar (1976) reported 2.66 to 2.83 per cent N content in pepper leaves. Productive laterals showed high N content during flowering and spike development period (Geetha, 1981). The foliar N showed peak at flowering in July and gradually decreased to berry maturity in November (Kurien, 1982). Nybe *et al.* (1989) also observed maximum content of N in June, which coincided with the peak flower bud differentiation activity in black pepper.

In banana, highest N content was observed during flower bud differentiation (Fayek *et al.*, 1983) whereas in cashew, it was maximum at flushing and flowering phase and lowest at fruiting and maturity phases (Latha, 1992; Bhaskar, 1993). The 'on' year trees of mango, recorded low N in leaves during fruit bud development and flowering. In 'off' year trees, N rose during the stage corresponding to fruit bud differentiation stage of 'on' year trees and declined gradually (Jyothi, 2001).

The pioneering report on the C:N balance as a factor governing flower bud initiation was proposed by Krans and Kraybill (1918). Consequently, several workers have contributed to the relationship between C:N ratio and flowering. In mango Sen *et al.* (1963) reported that higher C:N ratio favoured flower initiation. But in grapes,

Chitkara *et al.* (1972) failed to get any correlation between flowering and C:N ratio. Similar observation was reported in mango by Veera and Rao (1977) also. But they observed a higher C:N ratio during 'on' year. Carbon-nitrogen ratio had a favourable influence on the differentiation of flower buds in black pepper (Nalini, 1983). It exhibited two peaks, the first synchronizing with the commencement of the differentiation process and the second with the spurt in the flower bud differentiation activity.

2.2.2.7 Essential Oil, Oleoresin and piperine

These are the quality parameters in black pepper. The oleoresin of pepper is heterogenous, partly liquid with an upper oily layer and lower crystalline layer of piperine, which account for about half the weight (Mathew and Sankarikutty, 1977). The content of piperine was less during early stages and reached a maximum at 210 days after flowering. Volatile oil in berries declined with maturity while oleoresin showed about 50-60 per cent increase in 180 days after flowering (Chempakam *et al.*, 1998).

2.2.3 Physiological Factors

2.2.3.1 Photosynthesis

Crop productivity depends on canopy size, photosynthetic efficiency of individual leaf and the extent of partitioning of photosynthates to economically important parts. Photosynthesis is the sole mean for dry matter accumulation in plants and it shows a close positive relationship with yield in many crop plants. (Du and Haung, 1988; Edson, 1991; Muthuchellian, 1992; Faville *et al.*, 1999; Bai and Kelly, 1999).

2.2.3.1.1 Plant Factors and Photosynthesis

Mathai (1983) observed maximum photosynthetic rate of pepper in June and high CO_2 fixation under higher light illumination in Panniyur 1. Mathai *et al.* (1988)

reported that black pepper variety Panniyur 1 translocated higher percentage of photosynthates to the developing berries and recorded higher photosynthetic rate resulting in higher yield than other cultivars. They also observed that 45 days old pepper berries depend more on stored photosynthates while berries older than 45 days depends more on current photosynthates for its dry matter accumulation and attributed the reduction in yield to the reduced availability of current photosynthates. Influence of source area on photosynthetic accumulation and yield attributes in laterals, was investigated by Mathai *et al.* (1989). The removal of lower leaves from laterals after 60 days of spike initiation in Panniyur 1 reduced the average source size (leaf area) by 62 per cent. This severe limitation of area for the production of current photosynthates reduced the extension of spike length by 18 per cent, the number of developed berries per spike by 39 per cent and individual dry berry weight by 22 per cent. These reductions were considerably less than the reductions in leaf area, suggesting partial compensatory mechanism in photosynthesis. In pepper, the photosynthetic rate of spike bearing laterals was found to be higher at all phenological stages (Satheeshan, 2000). The average photosynthetic rate was 2.00 μ mol m^{-2} s^{-1} in Panniyur 1 and it recorded higher in the upper canopy levels. The periods of flushing and flowering were coincided with maximum photosynthetic rate.

In grapes, the leaves on fruiting shoots had higher photosynthetic rate than those on non bearing shoots (Wen and Liu, 1989; Albuquerque and Regima, 1995; Edson *et al.,* 1995). Intrieri *et al.* (1992) observed maximum photosynthetic rate of grape leaves at full leaf expansion (35-40 days of age) stage and decline there after. But leaves older than four months maintained 70 per cent of their maximum assimilation rate. However, Schubert *et al.* (1996) reported maximum photosynthesis in 20-40 days old leaves. At lower light intensity (150 μ mol m^{-2} s^{-1}), photosynthesis reached a maximum in 50-60 days old leaves. The leaves that were fully expanded at flowering showed highest rate of net photosynthesis in grapes (Jianhua *et al.*, 1996) and the highest rate of CO_2 assimilation and carboxylation efficiency were shown by lateral leaves (Schultz *et al.*, 1996). No correlation between photosynthetic parameters and leaf shape was observed in grapes (Shiraishi *et al.*, 1997).

Palanisamy and Yadukumar (1993) reported that in field grown cashew trees, maximum net photosynthetic rate was found in the leaves of middle portion of the tree. The photosynthetic rate was positively correlated with yield in cashew (Palanisamy *et al.*, 1994). Net photosynthesis was found to be highest at the beginning of shoot growth and lowest at the cessation of shoot extension in tea (Botwright *et al.*, 1998). In banana, (Thomas and Turner, 1998) reported that net photosynthetic rate of the second leaf from top reached a maximum of 20-25 μ mol CO_2 m^{-2} s^{-1} at ninth day after unrolling of the leaf.

Since CO_2 fixation is enzymatically controlled, the leaf temperature is also one of the factors that can affect photosynthesis.

2.2.3.1.2. Light and Photosynthesis

The photochemical reaction of photosynthesis is dependent on light fluctuations. With gradual increase in light intensity, there is a relatively larger increase in photosynthesis up to light compensation point. With further increase in light, there is a relatively small increase in the photosynthetic rate of C_3 plants (Wahid *et al.*, 1997).

Photosynthetically Active Radiation (PAR) is the component of intercepted light, which is capable of carrying out photosynthesis in crop plants. Satheeshan (2000) observed that photosynthetic response in black pepper was saturated at low light intensity and PAR below 300 μ mol m^{-2} s^{-1}, which indicated the adaptability of pepper leaves to low light or shaded situations. The higher PAR was intercepted by the leaves of Panniyur 1 compared to Karimunda, and the top canopy level recorded maximum. The spike bearing laterals recorded higher PAR compared to lateral without spikes. The higher PAR recorded in the leaves of the upper canopy may be because the vines are more exposed in the top canopy and they are subjected to more light compared to lower levels. Similar observations were also made in rubber (Satheesan *et al.*, 1984) and cashew (Palanisamy and Yadukumar, 1993).

Photosynthetic efficiency of cardamom was found to be more under subdued light intensities (30.86 – 106.63 μ E $s^{-1}m^{-2}$). A negative correlation was observed

between the CO_2 fixed by cardamom leaves at different intervals during a day and the light intensities that prevailed at that time. (Vasanthakumar *et al.*, 1989). Shade grown vines of grapes (60 per cent and 30 per cent sunlight) in the field recorded significantly lower photosynthetic rate (Cartechini and Palliotti, 1995) and increase in light intensity was found to increase the rate of photosynthesis (Shiraishi *et al.*, 1997). Pathirathna *et al.* (1998) investigated the effect of shade on photosynthesis of cinnamon leaves. Photosynthetic rate at light saturation increased from 5.14 to 7.25 μ mol m^{-2} s^{-1} as growth irradiance increased from 12-100 per cent daylight.

2.2.3.1.3 Stomatal Factors and Photosynthesis

Stomatal conductance plays a major role in the photosynthesis. Occurrence of a positive correlation between photosynthetic rate and stomatal conductance was observed among various species and among different physiological treatments (Ehleringer and Bjorkman, 1978). When the stomatal conductance is lower, the capacity of assimilation also tends to be lower (Wong *et al.*, 1978).

In cashew, Palanisamy *et al.* (1994) observed a positive correlation between stomatal conductance and yield. Yem *et al.* (1998) reported that stomatal conductance increased rapidly as irradiance increased in ginger and was saturated at relatively low light intensity (400 μ mol m^{-2} s^{-1}). Stomatal conductance was relatively insensitive to increased soil moisture availability until a threshold was reached with increasing transpiration. In pepper variety Panniyur 1, Satheeshan (2000) observed higher stomatal conductance in spike bearing laterals compared to laterals without spikes. It recorded highest at flushing and flowering stage compared to other physiological stages. There was a general declining trend in stomatal conductance as the season advanced towards December.

Stomatal resistance is an important selection criterion for drought tolerance in plantation crops. In black pepper, stomatal resistance recorded maximum at lower canopy levels. It fluctuated between different crop stages and was lowest towards berry maturity stage (Satheeshan, 2000).

2.2.3.1.4 Biochemical Factors and photosynthesis

Certain biochemical factors are also found to affect photosynthetic rate in crop plants. The amount of chlorophyll present in leaves has a direct relationship with the rate of photosynthesis (Gerasimenko *et al.*, 1993). Pande and Sinha (1972) reported that plant hormones like gibberellic acid and cytokinins increase the photosynthetic rate and carboxylating activity in plants.

2.2.3.2 Transpiration Rate

In pepper, increased stress intensity gradually reduced the transpiration rate and drought tolerant accessions expressed a low transpiration rate (Krishnamurthy *et al.*, 1998). Vasantha (1996) and Thankamani (2000) reported that Panniyur 1 showed higher transpiration rate compared to other varieties indicating its inability to respond to relatively severe stress. The transpiration rate of Panniyur 1 and Karimunda was found to vary at different stages of crop growth but the variation was not consistent indicating the seasonal and climatic effects (Satheeshan, 2000). Seasonal variation in transpiration was reported in cocoa also (Balasimha, 1999).

2.2.3.3 Leaf Water Potential

Leaf water potential is an important quantitative character used to assess water status of plants. It varies greatly depending up on the species, type or varieties of the plant and the environmental conditions. The leaf water potential in a plant is controlled by the availability of water from the soil, demand for water imposed by the atmosphere and the resistance to water movement within the plant. Cell growth, photosynthesis and enzyme activities are affected when leaf water potential goes below 1.5 M Pa in most of the mesophytes (Hsiao *et al.*, 1976). Plants under normal water supply maintain high leaf water potential whereas, with the development of moisture stress in field it shows a gradual reduction. Thus the ability of plants to maintain a positive or even constant turgor potential, as water potential decreases is considered as an important adaptation to drought (Turner and Jones, 1980). Drought tolerant cultivars

were reported to maintain high leaf water potential in rubber (Rao *et al.*, 1982), tea (Handique and Manivel, 1986) and cocoa (Balasimha *et al.*, 1988).

Vegetative growth rate in coffee with or without irrigation did not show a direct relation with leaf water potential (Barros *et al.*, 1997). Latha (1998) observed a decrease in water potential of cashew seedlings with increase in duration of stress. Leaf water potential was lower in exposed leaves of cocoa compared to shaded leaves (Balasimha, 1999).

2.3 IMPROVEMENT OF YIELD IN BLACK PEPPER

The yield in pepper can be improved by the practices like irrigation during summer period, and methods of crop regulation like exogenous application of growth regulators and pruning of laterals after harvest. The literatures available in this regard are cited hereunder different sections.

2.3.1 Irrigation

There are several reports available in black pepper on the yield improvement by irrigation during summer months. Sadanandan (1996) reported that summer irrigation of pepper vines at IW/CPE ratio of 0.25 increased the yield by 90 per cent. The depth of irrigation was 10 mm (100 litres of water at an interval of 8-10 days). Irrigating black pepper vines trailed on *Erythrina* with seven litres of water plant^{-1} day^{-1} during October to May enhanced the pepper yield (4.07 kg vine^{-1}) over unirrigated control (1.33 kg vine^{-1}) (IISR, 1997). The basin irrigation during December to March at 0.25 IW/CPE ratio and withholding irrigation there after significantly increased the green pepper, dry pepper and oleoresin yield in Karimunda while all the irrigation treatments were on par in the variety Panniyur 1 (Satheeshan *et al.*, 1998). The yield contributing characters like number of spikes, length of spike, number of berries, hundred berry weight, berry volume, green and dry berry yield and oleoresin content were found to be maximum in plants irrigated with eight litres drip and least in two litres drip for three year old bush pepper variety Karimunda grown in coconut garden (Thankamani, 2000). A drip irrigation trial conducted at Panniyur during December to

April showed that irrigation level @ two litres per vine can enhance the yield (AICRPS, 2001). Total number of spikes, spike yield, developed and undeveloped berries and spike length were higher in irrigated vines though the data were not statistically significant.

Similar reports are available in coffee also. Awatramani *et al.* (1973) and Raghuramulu *et al.* (1996) reported that irrigation throughout dry period in coffee increased its vegetative growth, hastened ripening and increased yield up to 95 per cent. Irrigation for blossom and backing shower was also reported to improve the yield up to 57 per cent. Flower opening in coffee was stimulated by irrigation after a period of water deficit while frequent irrigation was found to prevent flowering (Crisoto *et al.*, 1992). Marimuthu (1996) observed that giving two irrigations in coffee, in December and March under adequate water availability and one irrigation in February under water scarcity condition, improved flowering and fruit setting. Mild moisture stress followed by irrigation increased the intensity of flushing and flowering in acid lime (Singh and Chadha, 1988).

2.3.2 Growth Regulators

The metabolic reactions in plants are controlled both by the supply and conversion of nutrients and by their endogenous hormonal pattern (Halmann, 1990). The use of plant growth regulators enables rapid changes in the phenotype of the plant with in one season to achieve desirable results. The plant growth regulators are synthetic chemical substances other than nutrients, which can modify the growth when added in small amounts, usually by stimulation or inhibiting the endogenous plant hormones. They regulate cell division, cell enlargement, organ development, rate of growth, nutrient mobility, abscission, flowering, fruit set and development. Thus they promote rooting, lengthen the leaf area duration, suppress the photo respiration and unwanted growth, increase the harvest index, withstand stress and enhance the quality of the produce. The major groups of growth regulators include auxins, gibberellins and cytokinins.

2.3.2.1 Auxins

Flowering requires a certain level of endogenous auxins in the leaves or meristems of a plant (Lang, 1962). The activity of endogenous auxins were reported to be high during flowering and initial fruit growth period in several crops (Chacko *et al.*, 1972; Nimi *et al.*, 1977). The control of flowering and fruit set by the application of auxins has been the subject of numerous investigations on a large number of plant species. The wider use of auxins in enhancing flowering and fruit set has been published earliest by Zimmerman and Hitchcock (1944). The exogenous application of naphthalene acetic acid (NAA), an important auxin was found to improve the flowering, fruit set and yield in may crops.

Pillai *et al.* (1977) had reported that application of Planofix (90,120 and 150 ppm) enhanced the berry size in black pepper. The number of berries per unit length of spike, berry volume and berry weight were increased and spike shedding decreased by 52.2 per cent with the application of 50 ppm Planofix (Geetha, 1981). She also observed increased oleoresin content with 150 ppm of NAA. Ponnuswami *et al.* (1982) reported increased number of berries per spike and five times higher yield in pepper with the application of Planofix (20, 40 and 60 ppm). The application of NAA was also found to reduce the harvesting duration in pepper (Salvi and Desai, 1989). It took minimum number of days (eight) from first picking to last picking as against 15 days in the control. The green berry weight and dry recovery percentage of berries also increased with the application of NAA (10 ppm and 100 ppm respectively).

Reports are also available in various horticultural crops on the effect of NAA on flowering and yield. In mango, application of NAA was reported to result enhanced fruit set, fruit retension, fruit weight, fruit length, fruit diameter, fruit volume and quality (Singh and Ram, 1983; Baghel *et al.*, 1987; Suma, 1987; Sharma *et al.*, 1990; Sharma *et al.*, 1993). Application of 20 ppm NAA decreased the IAA oxidase activity which led to high auxin content during flowering, resulting in high flowering and fruit set during off years in mango (Vijayalakshmi and Srinivasan, 2000). Jogdande *et al.* (2000) observed highest activity of endogenous auxins at the time of initiation of flush in off year shoots of Alphonso. The high requirement of auxins needed for the flower

bud differentiation, can be manipulated by sprays of synthetic substances at appropriate intervals to induce flowering in off season mango (Jogdande and Choudhari, 2001).

Application of 50 ppm NAA increased the number of flowers per inflorescence in ginger (Usha, 1984). In cardamom, NAA 40 ppm was found to enhance the yield by improving panicle length, number of flowers and reducing the capsule dropping (Gurumurthy *et al.*, 1985; Vasanthakumar, 1986). The highest retention of fruits was recorded in coffee plants with 10 ppm NAA (Raghuramulu *et al.*, 1990). In cashew, Mariappan *et al.* (1995) observed decreased number of male flowers and increased number of hermaphrodite flowers per panicle, number and weight of nuts per shoot in cashew with the application of 200 ppm NAA. In grapes application of 25 ppm NAA resulted in highest bunch weight, number of berries per bunch, bunch width, berry diameter and berry weight (Farooq and Hulamani, 2000). In mandarins, 300 ppm NAA decreased the fruit number and increased the fruit size without affecting the total yield (Greenberg *et al.*, 2000).

The regulatory role of plant hormones on enzyme synthesis and activity is very complex. The range of different enzymes affected by the hormones is large and they cover a wide spectrum of metabolic activities in the plants. The plant hormones result in the synthesis, degradation, activation and inactivation of enzymes. Auxins were found to inhibit the peroxidase activity in tobacco pith (Galston *et al.*, 1968) and sugarcane (Glasziou *et al.*, 1968). Vijayalakshmi and Srinivasan (2000) reported that foliar spray of 20 ppm NAA increased the peroxidase and nitrate reductase activity, which led to increased chlorophyll metabolism there by enhanced yield in off season mango.

The growth regulators can also affect the physiological process like photosynthesis. Auxins were reported to enhance the photosynthetic rate in cotton (Lohot, 2000).

2.3.2.2 Gibberellins

The gibberellins are the only group of chemicals known to evoke flowering in a wide range of plant species. Since they influence several cellular processes, it is

possible to initiate flowering in different photoperiodic response groups. Gibberellins cause flower initiation indirectly through the production of other flower promoting factors. However, the effect is almost restricted to long day and biennial plants that grow as rosettes in short days and flowering is signaled by elongation of the stem. In crop production programmes, gibberellins are mainly used for manipulating production practices and insuring the quality of high value crops. In pepper, the application of Gibberellic acid (GA_3) (25, 50 and 75 ppm) was found to increase the berry weight (Salvi and Desai, 1989). The works reported in pepper are scanty. Hence, the relevant works done in other crops with GA_3 are reviewed.

Among the various horticultural crops, the most important one in which man has exploited the full potential of GA_3 is grapes. In grapes, the application of GA_3 for different economic characters had revolutionized the grape industry it self. There are umpteen number of reports by several workers on the effect of GA_3 in grapes for enhancing the yield characters viz; bunch length, bunch weight, cluster length, cluster weight, rachis length, flower number, berry length, berry weight, berry size, berry diameter, berry firmness, shelf life and quality parameters like total soluble solids, anthocyanin and acidity (Khan and Singh, 1989; Qadir *et al.*, 1989; Colak and Guven, 1991; Uarma, 1991; Kashyap *et al.*, 1992; Khurshid *et al.*, 1992; Hammady and Hamid, 1995; Hodairi *et al.*, 1995; Shehata and Barbary, 1996; Hammady *et al.*, 1998; Farooq and Hulamani, 2000).

The GA_3 application also enhanced the vegetative characters like internodal length and leaf area in grapes (Mahmoud, 1989). The response of crop plants to growth regulators can vary with the stages and concentrations of the chemical applied. Reduction in leaf number (Khurshid *et al.*, 1992), cluster compactness, berry adherence (Hammady *et al.*, 1998) and yield (Shehata and Barbary, 1996) was also reported with the exogenous application of GA_3.

In citrus, application of different concentrations of GA_3 improved the vegetative characters like number of shoots, shoot length, tree height, tree spread, trunk diameter, and leaf area (Inoue, 1990; Cuello *et al.*, 1991; Thukral *et al.*, 1994). Enhancement of economic characters like number of fruits, fruit size, fruit weight, yield

and quality with application of GA_3 was also reported in citrus (Tafazoli *et al.*, 1989; Cuello *et al.*, 1991; Ghosh and Chattopadhyay, 1994; Greenberg *et al.*, 1995; Liang *et al.*, 1999). Reduction in the number of flower buds, fruit weight, fruit size, and yield were also observed in citrus with GA_3 application (Tafazoli *et al.*, 1989; Inoue, 1990; Takahara *et al.*, 1990; Greenberg *et al.*, 2000). Informations are also available on the beneficial use of GA_3 in improving the various vegetative and yield characters in mango and coffee (Suma, 1987; Rajput and Singh, 1989; Yamdagni and Khangia, 1989; Schuch *et al.*, 1990; Singh and Rajput, 1990; Raghuramulu *et al.*, 1996; Turnbull *et al.*, 1996).

The application of GA_3 has also been reported to affect several biochemical and physiological parameters in crop plants. The foliar application of GA_3 enhanced the chlorophyll content in many crop plants including chickpea (Bishnoi and Krishnamoorthy, 1992), mustard (Saran *et al.*, 1992), maize (Goswami and Sarma, 1994) and aonla (Dhankar *et al.*, 1997). However, contradictory reports are also available in tea (Pillai and Kulasegaram, 1981) and watermelon (Gobbur, 1997). Henry and Jordan (1977) reported that GA_3 depressed the activity of PPO in excised apical section of pea whereas, Jennings and Duffus (1977) observed enhanced activity by GA_3 in de-embryonated grains of wheat. They also noticed that the application of GA_3 inhibited the PPO activity in two barley cultivars.

The enhanced peroxidase activity with the application of GA_3 was observed in dwarf corn (Mc Cune and Galston, 1959), barley and wheat aleurone cells (Harvey and Murray, 1968) and mango (Panday and Sharma, 1984). Catalfamo *et al.* (1978) reported neither inhibited nor enhanced isoperoxidase activity in pea internodes whereas, reduced activity of peroxidase by GA_3 was reported in pea (Ockerse and Mumford, 1973), *Phaseolus radiatus* (Ram *et al.*, 1976) and beans (Shanan, 1976). Rothbejerano and Lips (1970) observed enhanced activity of nitrate reductase in tobacco leaves. Enhancement of photosynthesis by the application of GA_3 has also been reported in several crops viz., red clover (Treharne and Stoddart, 1968), castor bean (Scala *et al.*, 1969) and water melon (Gobbur, 1997).

2.3.2.3 *Cytokinins*

The higher amount of endogenous cytokinins during flowering and initial fruit set stage in crops like apple (Luckwill and White, 1968), mango (Dutt and Dhillon, 1981) and citrus trees (Hernandez *et al.*, 1989; Murti, 1989) signifies the role of cytokinins in flowering and fruiting. The literature available on the use of cytokinins in pepper is nil. However, informations are available in several other crops.

Exogenous application of cytokinins enhanced fruit set in crops like figs (Crane and Vanoverbeak, 1965), and grapes (Weaver *et al.*, 1966). The treatment with 100 ppm 6- benzyl amino purine (BAP) improved the berry set (Mullins, 1967), pistil size, compactness of bunch, and proportion of seedless grapes (Jacko and Szegedi, 1972; Takagi and Furukawa, 1977). Enhancement of fruit set and reduction in fruit size was observed in orange with the application of 5-10 ppm kinetin (Agusti *et al.*, 1990) while in lemon, Cuello *et al.* (1991) reported that kinetin had no effect on the number of flowers or fruits produced on shoots. In Satsuma mandarin, application of benzyl adenine (BA) 20 ppm at anthesis was found to enhance the fruit dry weight (Guardiola *et al.*, 1992). Kang *et al.* (1996) reported that spraying of 75-150 ppm BA reduced the length of flowering, fruit size, leaf fruit ratio and increased the number of flowers per branch by 2.8 to 3.4 times. It accelerated the colouring of fruit, advanced harvesting date by 10 days and increased the number of fruits by 26 to 29 per cent.

Cytokinins were also reported to improve the vegetative growth parameters in crop plants. The application of BA at 100 and 200 ppm accelerated auxillary bud sprouting in Satsuma trees (Zhu *et al.*, 1989). Increased number of flower buds and vegetative shoots per tree and percentage of sprouting nodes were observed in BA treated mandarin trees compared to control plants (Inoue and Ikoma, 1991). Thukral *et al.* (1994) reported enhanced tree height, tree spread, trunk diameter, shoot length and leaf area in lemon with 25 ppm BA.

Several reports are available on the effect of cytokinins on various biochemical and physiological processes. The application of kinetin had found to increase the chlorophyll content in *Phaseolus radiatus* seedlings (Balasimha *et al.*,

1977; Bai and Kastori, 1990). The enhanced leaf chlorophyll content was also noticed with the application of BA in sunflower (Goswami and Srivastava, 1988). Cytokinins were found to promote the peroxidase activity in sugar cane (Gaylor and Glasziou, 1969), lentil roots and barley coleoptiles (Darimont *et al.*, 1971) and maize seedlings (Sharma *et al.*, 1977). In tobacco pith, enhanced activity of peroxidase was noticed with kinetin application (Galston *et al.*, 1968). It inhibited the activity of shoots but enhanced the activity in the roots of *Lens culinaris* seedlings (Fries, 1972). The activity of nitrate reductase was also found to increase in response to the application of kinetin (Gunther, 1974). The BA also enhanced the NRA in excised embryos of *Agrostemma githago* (Borris and Schmerder, 1978). Rao *et al.* (1984) and Goswami and Srivastava (1988) have observed a two fold increase in NRA in maize when etiolated leaves were treated with exogenous BA.

Cytokinins were found to enhance the rate of photosynthesis in many crop plants by mainly affecting the activity of photosynthetic enzymes and maintaining the chloroplast. The kinetin is reported to enhance the activity of photosynthetic enzymes in rye (Feierabend, 1969), *Phaseolus* (Treharne *et al.*, 1970), cucumber (Harvey *et al.*, 1974) and *Arabidopsis* (Babadzhanova and Bakajeva, 1978). Up to 25 per cent increase in photosynthesis was reported with cytokinins (Catsky *et al.*, 1993). Sivakumar and Virendranath (2000) also reported enhanced photosynthesis in wheat with the application of BA.

2.3.3 PRUNING

Pruning is an important horticultural tool by which a crop can be regulated for desired level of productivity with higher quality. But adoption of such a technique depends up on several factors like fruiting habit of the crop, physiology of growth and development of the species, climatic and soil conditions. The nature and quality of vegetative portion to be removed by way of pruning can be decided only with the understanding of the site and time of flower bud differentiation and on the basis of an estimate of the expected crop. Since the literature on pepper is less, the relevant information on other crops have also been reviewed.

Pepper produces spikes on leaf axils of the current season growth of the laterals. Chandy and Pillai (1979b) suggested that the production of fruiting branches can be regulated by proper pruning technique. Pruning of hanging shoots and unwanted terminal shoots increased the extension growth of the laterals, production of bearing shoots, number of spikes and yield in the succeeding season (Kurien, 1982; Kurien and Nair, 1998). The spike characters, berry characters except berry weight and oleoresin content were unaffected by pruning.

Pruning in many crops promoted profused vegetative growth. Pruned trees had higher trunk girth than unpruned trees in apple (Gregov, 1975) and ber (Gupta and Singh, 1977). It was reported to have beneficial or detrimental effect on crops depending up on the time, extend and site of pruning. Pruning enhanced yield in grapes (Dujaili, 1989; Sims *et al.*, 1990; Hugelschaffer *et al.*, 1994), cashew (KAU, 1991; Mohan, 1991; Chattopadhyay and Ghosh, 1994), mandarins (Kim *et al.*, 1996) and mango (Gil *et al.*, 1998). While, pruning reduced yield in apple (Elfving, 1990; Marini *et al.*, 1991), sweet cherry (Rudolph *et al.*, 1991) and mango (Fivaz and stassen, 1996). The vines pruned to five buds produced the highest number of vegetative shoots, fruitful shoots, bunches and yield in grapes (Tomer, 1990). Fivaz and Stassen (1996) and Gil *et al.* (1998) reported that pruning produced quality fruits in mango. Pruning resulted in more number of shoots, delayed but uniform flowering in mango (Oosthuyse, 1994). In seedless lemon, light pruning resulted in higher yield while severe pruning reduced the yield (Firoz *et al.*, 1998). Medium pruned acid lime trees recorded the highest percentage of hermaphrodite flowers, fruit set and fruit retension (Ingle *et al.*, 2001).

Pruning can result in various physiological and biochemical changes in crop plants. Rao and Sathyanarayana (1978) reported improved C:N ratio between 40 and 90 days after pruning, which coincided with period of flower bud differentiation in grapes. In mango, Schaffer and Gaye (1989) reported higher leaf chlorophyll content in pruned trees. Severe pruning resulted in increased gibberellin and cytokinin concentration and reduced IAA in the florets of grape vines (Komatsu and Nakagawa, 1991).

2.4 CORRELATION STUDIES AND PATH ANALYSIS

Yield is a complex quantitative character, which is influenced by a number of other plant characters. These component characters of yield are correlated with yield and they are intercorrelated among them selves. Therefore, estimation of correlation between yield and its component characters are essential for effective selection programme. The partitioning of the cause and effect relationship among these component characters is done by path coefficient analysis.

Mathai (1983) observed that many of the yield attributes such as number of productive laterals per vine, total spike length per vine, total number of berries per vine, total number developed and undeveloped berries per vine were correlated with leaf area per vine at different positions in the canopy in light and shade grown plants. This emphasizes the importance of leaf area exposed to light in the upper, middle and lower part of the canopy in the productivity of black pepper.

The character such as spike yield, spike number, spike length, number of berries per spike and berry weight were found to be significantly and positively correlated with the yield (Ibrahim *et al.*, 1985). Sujatha (1991) and Sujatha and Namboodiri (1995) reported that characters such as green berry yield per vine, number of spikes per vine, length of spike, number of developed berries per spike and thickness of node and internode of orthotrope registered a high positive correlation with yield. These interrelationships among the characters too were high and positive.

Path analysis in pepper revealed that the number of spikes per vine, length of spike and number of developed berries per spike were the most important characters influencing net yield. The yield components like spike length, spike number etc. were found to have a direct effect on yield followed by number of developed berries per spike. Spike length was negatively correlated with yield. Hence, it showed that yield was not dependent on spike length and depends more on the number of developed berries per spike (Ibrahim *et al.*, 1985). These findings point to the possible advantages of selection based on these characters for higher productivity in black pepper.

From the available literatures, it can be concluded that yield in pepper is influenced by a wide range of physiological and biochemical factors within the plant and the environmental condition in which the plant grows. The modification of these, by the practices like irrigation during dry period, pruning of laterals and exogenous application of growth regulators may influence the crop phenology and thus the productivity in black pepper.

Materials and Methods

3. MATERIALS AND METHODS

The present investigations were carried out at the College of Horticulture, Vellanikkara, during the period from 2000 to 2003. The materials used, methods adopted and observations recorded during the course of the study are as follows:

3.1 GEOGRAPHICAL LOCATION, CLIMATE AND SOIL

The experimental field was situated at 10^{o} 32' N latitude and 76^{o} 13' E longitude with an altitude of 22.25 m above mean sea level with a tropical warm humid climate. The meteorological data for the period of investigations recorded at meteorological observatory, Vellanikkara are presented in Appendices I and II. The soil of the experimental plots was deep laterite with sandy clay loam texture.

3.2 SELECTION OF PLANTS

The existing eight year old pepper vines of Panniyur 1 and Panniyur 2 varieties available in pepper garden of the Department of Plantation Crops and Spices were selected for the experiments. The general view of the experimental plot is shown in Plate 1. The uniform yielding, healthy plants were selected based on the previous years' yield data. The vines were maintained under uniform cultural and manurial practices as per the recommended Package of Practices (KAU, 1996).

3.3 EXPERIMENTAL DETAILS

3.3.1 Experiment I: Effect of Irrigation on Yield of Black Pepper

The experiment on the effect of irrigation on yield of black pepper was carried out from December 2000 to April 2001 till the onset of pre monsoon showers. The experiment was repeated in the next season from December 2001 to April 2002. The details of the experiment are given below:

Plate 1. General view of the experimental plot

3.3.1.1 Treatments

There were totally 11 treatments as listed below:

T_1 : Without irrigation (Control)

T_2 : Imposing five litres of irrigation using rocker sprayer once in a week up to March

T_3 : Imposing five litres of irrigation using rocker sprayer once in a week up to February

T_4 : Imposing five litres of irrigation using rocker sprayer once in a week up to January

T_5 : Imposing five litres of irrigation using foggers once in a week up to March

T_6 : Imposing five litres of irrigation using foggers once in a week up to February

T_7 : Imposing five litres of irrigation using foggers once in a week up to January

T_8 : Imposing 10 litres of basin irrigation once in a week up to March

T_9 : Imposing 10 litres of basin irrigation once in a week up to February

T_{10}: Imposing 10 litres of basin irrigation once in a week up to January

T_{11}: Irrigation throughout summer period

3.3.1.2 Installation of Foggers in the Experimental Field

Filtered water (using screen filter, $15m^3$) from an outlet source was directed to a PVC pipe with the help of a control valve. Poly tubes (16 mm) were fitted to the pipe and were taken to the top of the canopy level, which were extended to both ends of the field. From the poly tubes, connections were taken to the top of the treatment plants (T_5, T_6 and T_7) and were tied on the standards. Foggers (E jet 360', 56 litres per hour) were fitted on it with the help of micro tubes. The fogger and its accessories used for the experiment and its installation in field are shown in Plate 2.

3.3.1.3 Experimental Design

The experiment was laid out in Randomised Block Design with eight replications of uniform mulched vines of Panniyur 1.

3.3.1.4 Observations

3.3.1.4.1 Morphological Characters

3.3.1.4.1.1 Growth and Yield Characters of Lateral

From each replication, ten laterals were selected randomly from all sides representing different canopy levels and tagged. The following growth and yield characters were recorded from these laterals for two consecutive years.

A) Accessories of fogger system

1) Control valve 2) Filter
3) Poly tube connection

B) Poly tube connection to top canopy level

C) Poly tube connections to treatment plants

D) A treatment plant with fogger

Plate 2. Installation of fogger system in the experimental field

3.3.1.4.1.1.1 Number of Leaves per Lateral

The number of leaves in each tagged lateral was counted and the average was worked out.

3.3.1.4.1.1.2 Leaf Area per Lateral

The length and maximum breadth of ten leaves selected form all the four sides of the vine were measured and the area was calculated by using the formula, Area = 0.71 (length x breadth), as suggested by Kumar and Prabhakaran (1980). The mean number of leaves per lateral was multiplied with the individual mean leaf area to get the leaf area per lateral and expressed in square centimeter.

3.3.1.4.1.1.3 Length of Lateral

The length of the current season growth of laterals was measured with the help of a measuring scale, the average was worked out and expressed in centimeter.

3.3.1.4.1.1.4 Internodal Thickness of Lateral

The circumference at the internodal region was measured in centimeter with the help of a twine and measuring scale and the mean was arrived at.

3.3.1.4.1.1.5 Angle of Insertion of Lateral

The angle subtended by the lateral with the main stem was measured in degrees with the help of a protractor and the mean was calculated.

3.3.1.4.1.1.6 Time of Spike Initiation

The time of spike emergence on the tagged laterals was recorded when the spikes were emerged out from the stipules on 50 per cent of the tagged laterals on individual vines. The number of plants initiated spiking for each treatment was worked

out. The observation was recorded at an interval of three days during spike initiation period.

3.3.1.4.1.1.7 Number of Productive Laterals per 0.25 m^2

With the help of a square wooden frame having 0.25 m^2 area, the spike bearing laterals were counted from all four sides of the vine at chest height and the mean was worked out.

3.3.1.4.1.1.8 Number of Spikes per Lateral

The number of spikes in each tagged lateral was counted and the average was worked out.

3.3.1.4.1.1.9 Spike to Leaf Ratio per Lateral

The ratio was computed by dividing the mean number of spikes produced on a lateral with the mean number of leaves produced on the same lateral.

3.3.1.4.1.2 Spike Characters

Ten spikes were randomly selected from each vine at harvest and spike length, number of berries, and compactness of the spike (number of berries per centimeter length of spike) were recorded and the mean was worked out.

3.3.1.4.1.3 Berry Characters

Soon after the harvest of the crop, 1000 well developed berries were separated from the spikes and their weight and volume (by water displacement method) were recorded.

3.3.1.4.1.4 Yield Characters

Total yield of green berries per vine was recorded immediately after harvest. Percentage recovery of dry pepper per vine was computed by drying 500 g of green berries under sunlight until berries recorded a constant dry weight. Total yield of dry berries per vine was computed by multiplying the green berry weight with percentage recovery of dry pepper.

3.3.1.4.2 Biochemical Characters

The laterals from three plants under each treatment were tagged for collecting the leaf samples for each analysis. The various biochemical characters in the first fully matured leaf of the tagged lateral were analysed at three different stages viz; before flushing, at flushing and flowering and berry set (Plate 3).

3.3.1.4.2.1 Leaf Chlorophyll

The estimation of chlorophyll in the leaf sample was done by the improved method of extraction (Shoaf and Lium, 1976) using dimethyl sulfoxide (DMSO). Fresh leaf sample of 0.1g was taken in a test tube and 20 ml of DMSO was added to it and kept overnight at room temperature for chlorophyll extraction. The absorbance of the solution was read using Spectronic 20 Spectrophotometer at 645, 652 and 663 nm against the solvent blank. Chlorophyll content of the sample was estimated using the formula:

$$\text{mg. chlorophyll 'a' } g^{-1} \text{ of tissue} = 12.7\,(A_{663}) - 2.69\,(A_{645}) \times \frac{V}{1000 \times W}$$

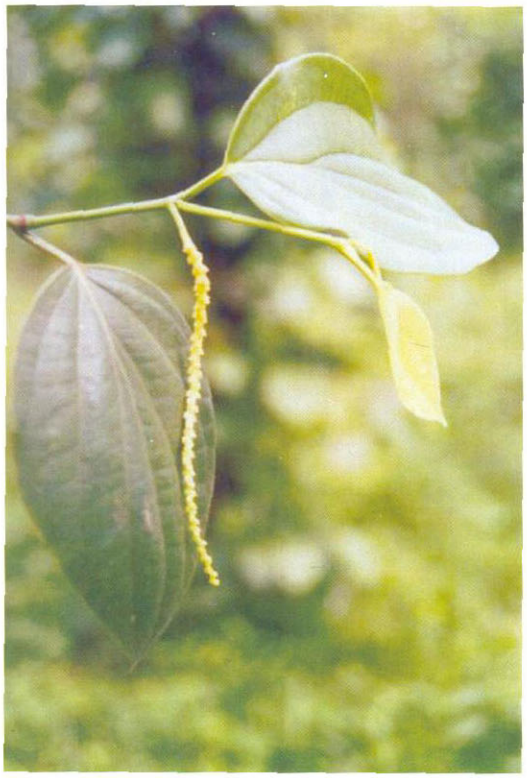
$$\text{mg. chlorophyll 'b' } g^{-1} \text{ of tissue} = 22.9\,(A_{645}) - 4.68\,(A_{663}) \times \frac{V}{1000 \times W}$$

$$\text{mg. total chlorophyll } g^{-1} \text{ of tissue} = 20.2\,(A_{645}) + 8.02\,(A_{663}) \times \frac{V}{1000 \times W}$$

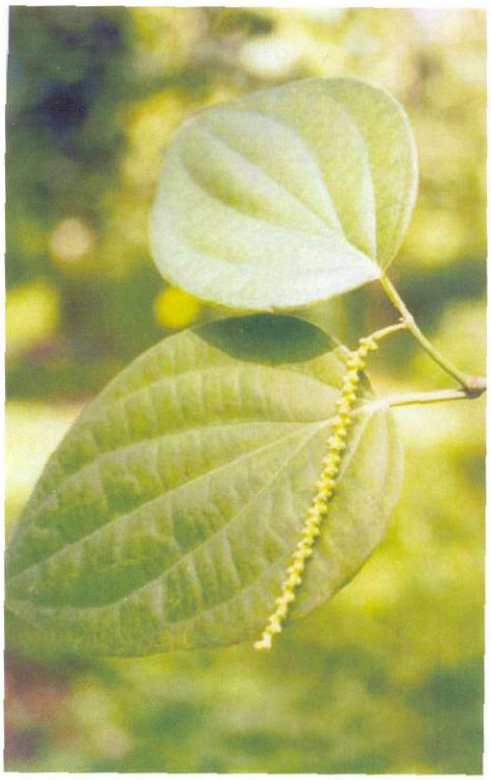
Where,

A = Absorbance at specific wave length (645, 652 and 663 nm)

A) Before flushing



B) Flushing and flowering



C) Fruit set

Plate 3. The stages of development in black pepper selected for biochemical and physiological studies

V = Volume of the chlorophyll extract (ml)

W = Fresh weight of the sample (g)

3.3.1.4.2.2 Total Phenol

The total phenol content was estimated using Folin ciocalteau method suggested by Sadasivam and Manickam (1996). A sample of 0.1 g fresh leaf was ground in a mortar and pestle and to the homogenized material, 50 ml distilled water was added and heated to facilitate phenol extraction. After cooling, it was made up to 100 ml and kept for half an hour to get a clear supernatant. One ml of it was taken in a test tube and made up to three ml with distilled water. Added 0.5 ml Folin ciocalteau reagent and after three minutes, two ml of 20 per cent sodium carbonate was added and mixed thoroughly. After 10 minutes, the intensity of the blue colour was measured at 650 nm against a reagent blank. The total phenol content in the test solution was determined with reference to a standard curve prepared from different concentrations of catechol and expressed as mg g^{-1} of fresh weight of the sample.

3.3.1.4.2.3 Polyphenol Oxidase Activity

Polyphenol oxidase activity was assayed by the method suggested by Malik and Singh (1980). The leaf sample collected in ice bucket was cleaned with distilled water and blotting paper. One gram leaf tissue was extracted in three ml of 0.1 *M* phosphate buffer (p^H 6.0) by grinding in mortar and pestle. The homogenate was centrifuged at 18,000 rpm for 15 minutes. The supernatant enzyme extract was used for the assay. Freshly prepared buffered catechol, 0.01 *M* (0.11 g of catechol dissolved in 100 ml of phosphate buffer, p^H 6.0) was used as the substrate. Three ml of phosphate buffer was taken in a cuvettee and spectrophotometer reading was adjusted to zero at 495 nm. Then 0.5 ml of enzyme extract was added to it and the absorbance was noted as the blank reading. To a cleaned cuvettee, three ml of buffered catechol and 0.5 ml of the enzyme extract was taken, mixed thoroughly and inserted immediately in to the spectrophotometer. The change in absorbance for every 30 seconds interval was recorded. The maximum value of absorbance (OD value) was taken as the total polyphenol oxidase activity of the enzyme extract.

3.3.1.4.2.4 Peroxidase Activity

The activity of peroxidase was assayed using guaiacol as the substrate (Sadasivam and Manickam, 1996) by measuring the rate of formation of guaiacol dehydrogenation product. The leaf sample was collected in an ice bucket and cleaned with distilled water and blotting paper. One gram leaf tissue was extracted in three ml of phosphate buffer, p^H 7.0 (buffer was brought to 25° C before assay) by grinding in chilled mortar and pestle. The homogenate was centrifuged at 18,000 rpm for 15 minutes in refrigerated centrifuge at 5° C. The supernatant was used for the enzyme assay. Pipetted out three ml buffer solution, 50 µl of 20 m*M* guaiacol (214 µl guaiacol dissolved in 100 ml of distilled water), 50 µl of enzyme extract and 30 µl of freshly prepared hydrogen peroxide (H_2O_2) solution (125 µl of 30 per cent H_2O_2 was diluted to 100 ml with distilled water such that the extinction of the solution was 0.485 at 240 nm) in a cuvettee. The content of the cuvettee was mixed well and the spectrophotometer was set to zero at 436 nm. When the absorbance of the sample had increased by 0.05, a stopwatch was started and the time required (Δt) in minutes to increase the absorbance by 0.1 was noted. Since the extinction coefficient of guaiacol dehydrogenation product at 436 nm under the conditions specified was 6.39 per micromole, enzyme activity per litre of the extract was calculated as follows:

$$\text{Peroxidase enzyme activity of the extract (Units litre}^{-1}) = \frac{3.18 \times 0.05 \times 1000}{6.39 \times 1 \times \Delta t \times 0.05} = \frac{498}{\Delta t}$$

3.3.1.4.2.5 Nitrate Reductase Activity

The *in vivo* assay of nitrate reductase was done by the method suggested by Malik and Singh (1980). The leaf samples collected in ice bucket were cleaned with distilled water and blotting paper. One gram of the leaf discs of approximately one cm diameter was suspended in a five ml reaction mixture (five per cent propanol and 0.02 *M* potassium nitrate in 0.1 *M* potassium phosphate buffer of p^H 7.5) in a capped test tube and was incubated in dark at 30° C for two hours. After incubation, 0.4 ml aliquot of the reaction mixture was taken in a test tube and added 0.2 ml of one per cent sulphanilamide (prepared in 3 *N* hydrochloric acid) and 0.2 ml of 0.2 per cent N-

naphthyl ethylene diamine dihydrochloride. After 20 minutes, four ml of distilled water was added to the test tube and the intensity of pink colour developed was recorded at 570 nm in a Spectronic 20 Spectrophotometer. The enzyme activity was estimated from the standard curve prepared by using different concentrations of potassium nitrite. The activity was expressed in terms of milli moles of nitrite formed per gram fresh weight of leaf per hour.

3.3.1.4.2.6 C:N Ratio

3.3.1.4.2.6.1 Total Carbon

The total C of leaf sample was estimated by wet digestion procedure suggested by Wakeel and Riley (1956). Ten mg of dried powdered leaf sample was taken in a test tube and 10 ml of chromic acid was added to it. The content of the test tube was heated for two and a half hour at 100° C in boiling water bath. After cooling, it was transferred to a conical flask and 200 ml distilled water was added to it. Three drops of 0.025 *M* ferrous phenanthroline indicator (prepared by dissolving 0.674 g o-phenanthroline monohydrate in 50 ml of 0.695 per cent ferrous sulphate solution) was added and mixed well. It was then titrated against 0.2 *N* ferrous ammonium sulphate solution (39.3 g ferrous ammonium sulphate dissolved in 400 ml distilled water containing 10 ml concentrated sulfuric acid (H_2SO_4) and diluted to 500 ml) taken in a burette. The volume required to change the colour to reddish brown was taken as the end point. A blank reading without leaf sample was also recorded. From the volume of ferrous ammonium sulphate required to react with the utilized chromic acid (for the oxidation of C to CO_2), the total C content of the sample was calculated and expressed in percentage.

3.3.1.4.2.6.2 Total Nitrogen

Total N content was estimated by Nesslers method as suggested by Snell and Snell (1967). Dried, powdered leaf sample of 0.5 g was taken in a digestion tube and 10 ml of concentrated H_2SO_4 was added to it and kept for overnight pre digestion. It was then digested in a digestion chamber to get a clear colourless solution. After

cooling, the sample was made up to 50 ml. To a 25 ml standard flask, 0.25 ml of the sample was taken and added one ml of 10 per cent sodium hydroxide and 0.5 ml of 10 per cent sodium silicate in a sequential manner and made up the volume. Finally 0.8 ml Nesslers reagent was added to develop an unstable orange red colour, which was read in a Spectronic 20 Spectrophotometer at 410 nm. The content of the total N in the sample was estimated with the help of a standard curve prepared from different concentrations of ammonium chloride.

3.3.1.4.2.6.3 C:N Ratio

From the total C and total N content obtained, C:N ratio was worked out.

3.3.1.4.2.7 Quality Parameters

The major quality parameters like essential oil, oleoresin and piperine were extracted from three replications of each treatment for two seasons viz; 2001 and 2002.

3.3.1.4.2.7.1 Essential Oil

The clevenger apparatus was used for the distillation of essential oil. Twenty gram of ground pepper powder was taken in a round bottomed flask and water distilled with 200 ml of distilled water for two hours. The volatile oil being lighter than water get condensed and collected on the top of the clevenger trap. The percentage of essential oil in the sample was worked out.

3.3.1.4.2.7.2 Oleoresin

Soxhlet extraction method (Horwitz, 1980) was used for estimating oleoresin by using the instrument Socs Plus (Plate 4). After grinding the pepper berries, five gram of sample was taken in a cellulose thimble kept in a pre-weighed beaker with 75 ml of 100 per cent acetone and placed in the extraction chamber of the apparatus. The instrument was adjusted to 90^0 C for first half an hour and then the temperature was

increased to 200^0 C. The oleoresin collected in the beaker after complete evaporation of the solvent was weighed and the percentage was calculated as,

$$\text{Percentage of oleoresin in the sample} = \frac{\text{Weight of oleoresin}}{\text{Weight of pepper powder}} \times 100$$

3.3.1.4.2.7.3 Piperine

The piperine content in dried berries was determined by spectrophotometric method described by Soubhagya *et al.* (1990). Freshly powdered pepper (100 mg) was transferred to a 100 ml volumetric flask. The volume was made up to 100 ml with acetone. The flask was shaken well and allowed to settle for two hours in the dark. Then, 0.5 ml of the solution was pipetted out and diluted to five ml with acetone. The absorbance of the solution was read at 337 nm. The piperine content in the sample was estimated with the help of standard curve prepared from different concentrations of pure piperine.

3.3.1.4.3 Physiological Characters

3.3.1.4.3.1 Photosynthetic Parameters

Physiological characters of yielding pepper vines related to photosynthesis were recorded for each treatment at three different stages viz; before flushing, at flushing and flowering and berry set (Plate 3). All the photosynthetic parameters were measured using a portable photosynthetic system (IRGA model- LCA 4, Analytical Development Co., England) with Parkinson Leaf Chamber (PLC) (Plate 5).

The top youngest fully expanded leaf of a lateral at different canopy levels was clamped to PLC and was exposed to direct sunlight. The position of the leaf after inserting in to the chamber was identical to its natural position. All the gas exchange traits were recorded under ambient conditions. Recording of data was done at saturated light intensities. All observations were made at 9.00 am as suggested by Satheeshan (2000). The relative humidity (RH) in the leaf chamber was maintained at a steady state level around the existing ambient RH by manipulating the rate of flow of dry air through air supply unit of portable IRGA. The following gas exchange parameters were

Plate 4. Socs Plus for extraction of oleoresin

Plate 5. Portable photosynthetic system (IRGA-Model LCA 4) with Parkinson Leaf Chambe

Plate 6. Plant Water Status Console for measurement of leaf water potential

Plate 7. Lux Meter for measurement of light interception

recorded after photosynthetic rate and stomatal conductance were stabilized to a steady state condition.

a. Photosynthetic rate (μ mol m^{-2} s^{-1})
b. Photosynthetically active radiation on leaf surface (μ mol m^{-2} s^{-1})
c. Stomatal conductance (mol m^{-2} s^{-1})
d. Stomatal resistance (m^2 s mol^{-1})
e. Leaf surface temperature (^{o} C)
f. Transpiration rate (mol m^{-2} s^{-1})

The measurements were recorded in the data logger attached to the instrument using built in software.

3.3.1.4.3.2 Leaf Water Potential

The pre dawn water potential of the youngest fully matured leaf was measured during December to April at weekly interval at early morning hours using the instrument, Plant Water Status Console (Model 3005, Soil Moisture Equipment Corporation, USA) (Plate 6). The leaf water potential was measured before and after irrigation from three plants per treatment, the mean was worked out for each month and expressed in M Pa.

3.3.2 Experiment II: Effect of Hormone Application on Flowering and Yield in Black Pepper

3.3.2.1 Treatments

There were totally 12 treatments as listed below:

T_1 : Gibberellic acid 25 ppm
T_2 : Gibberellic acid 50 ppm
T_3 : Gibberellic acid 100 ppm
T_4 : Kinetin 100 ppm

T_5 : Kinctin 150 ppm

T_6 : Kinetin 200 ppm

T_7 : Benzyl amino purine 200 ppm

T_8 : Benzyl amino purine 250 ppm

T_9 : Benzyl amino purine 300 ppm

T_{10} : Naphthalene acetic acid 50 ppm

T_{11} : Water spray

T_{12} : No spray

3.3.2.2 Application of Treatments

Stock solutions of 10,000 ppm of gibberellic acid, kinetin, benzyl amino purine and naphthalene acetic acid were prepared by dissolving the growth regulators in minimum quantity of solvent (1 *N* NaOH) and making up the volume with distilled water. It was then diluted to get the required concentrations. The growth regulators were applied on the vines as foliar spray with the help of a rocker sprayer in the morning hours on a bright sunny day at the spike initiation period during 2002. Water spray and no spray were kept as control treatments.

3.3.2.3 Experimental Design

The experiment was laid out in Randomised Block Design with eight replications of vines of Panniyur 2.

3.3.2.4 Observations

3.3.2.4.1 Morphological Characters

For taking observations, laterals were selected and various growth and yield characters except time of spike initiation, were recorded by the methods described in experiment I. The area of Panniyur 2 leaves was computed by using the formula, Area = 0.69 (length x breadth). The constant was arrived by using user defined non-linear regression analysis by comparing areas of 100 leaves obtained by leaf area meter

(Model LI 3000 A) and product of length and breadth. Various characters related to spike viz; length of spike, number of well developed berries, compactness of spike were recorded as in experiment I. Spikes were also collected a fortnight after anthesis, and the number of small berries formed on the spike was counted and recorded. The berry and yield characters were also recorded as in experiment I.

3.3.2.4.2 Biochemical Characters

Biochemical characters were analysed after spraying of growth regulators at flushing and flowering and at fruit set stages by following the procedures mentioned in experiment I.

3.3.2.4.3 Physiological Characters

The physiological parameters related to photosynthesis were recorded after spraying of growth regulators at flushing and flowering and at fruit set stages by using LCA 4 as described in experiment I.

3.3.3. Experiment III: Effect of Pruning of Laterals on Yield of Black Pepper

The uniform yielding healthy vines of Panniyur 2 were selected for the study and pruning of laterals were carried out in February immediately after harvest during 2001 and 2002.

3.3.3.1 Treatments

There were totally three treatments as follows:

T_1 : Pruning the laterals of pepper vine to one node below the point of harvest

T_2 : Pruning the laterals of pepper vine to two nodes below the point of harvest

T_3 : No pruning

3.3.3.2 Experimental Design

The experiment was laid out in Completely Randomized Design with 15 single plant replications.

3.3.3.3 Observations

3.3.3.3.1 Morphological Characters

The various morphological characters viz; growth and yield characters of laterals, spike and berry characters were observed by adopting the methods described under experiment I. The yield characters like green yield per lateral, green yield per vine and dry yield per vine were also recorded. For recording the green yield per lateral, the spikes from each tagged lateral were collected separately and weighed. The dry yield per vine was computed by multiplying the green yield per vine with the dry recovery percentage (recorded by the method described in 3.3.1.4.1.4) of representative samples of each treatment.

3.3.3.3.2 Biochemical Characters

The various biochemical characters mentioned in experiment I were analysed at before flushing, flushing and flowering and fruit set stages by following the procedures mentioned in experiment I.

3.3.3.3.3 Physiological Characters

The physiological parameters related to photosynthesis were recorded at before flushing, at flushing and flowering and fruit set stages by using LCA 4 as described in experiment I.

3.3.4 Interception of Light

The quantity of light intercepted by the experimental plants of Panniyur 1 and Panniyur 2 was measured by using a Digital Lux Meter (Plate 7). The light availability at eight different locations of the experimental field was recorded at one hour interval from 7 am to 6 pm at different physiological stages of pepper vine viz; before flushing (March), flushing and flowering and berry set (June), berry development (September) and at berry maturity (December). The percentage of light intercepted by

the experimental plants was calculated by dividing the quantity of light (expressed in Lux) intercepted in the experimental field with the amount of light intercepted in the open condition at each hour and the mean was worked out.

3.3.5 The Incidence of Pests and Diseases

Plants were observed for incidence of various pests and diseases of pepper and appropriate control measures were adopted in case of incidence of attack or infestation.

3.4 ECONOMICS OF TREATMENTS

Based on the cost of inputs for each treatment and yield obtained, total cost and total returns were worked out for the three experiments and from that benefit cost ratio (BCR) was calculated for obtaining the economics of the treatments. For experiments I and III, economics of treatments were computed separately for 2001 and 2002 and mean BCR was arrived at.

3.5 STATISTICAL ANALYSIS

For the statistical analysis, M STAT C package was followed. Data relating to different characters were analysed by applying the technique of analysis of variance (Panse and Sukhatme, 1989) and the significance was tested by using Duncan's Multiple Range Test at five per cent CD level. Necessary transformations were carried out wherever required and analysed statistically (Snedecor and Chochran, 1961). For obtaining the relationship between yield and its component characters and interrelations among the characters, correlation studies were conducted. The characters showing maximum correlation with dry berry yield per vine were subjected to path coefficient analysis as suggested by Wright (1921) and elaborated by Dewey and Lu (1959) to partition the cause and effect relationship among the characters.

Results

4. RESULTS

Three separate experiments were conducted on the existing vines of pepper garden, College of Horticulture, Kerala Agricultural University, Vellanikkara during 2000 to 2003 to investigate on " Physiomorphological and biochemical responses of black pepper to irrigation, pruning and hormone application for flushing, flowering and berry set." The various morphological, biochemical and physiological characters were studied during the experimental period and subjected to statistical analysis. The results obtained are described under different heads.

4.1 EXPERIMENT I: EFFECT OF IRRIGATION ON YIELD OF BLACK PEPPER

The results obtained on the effect of irrigation during summer months at systematic intervals on subsequent flushing and yield in pepper vines are furnished below:

4.1.1 Morphological Characters

4.1.1.1 Growth and Yield Characters of Lateral

The data on the effect of irrigation on various growth and yield characters of lateral in black pepper are presented in Tables 1(a) and (b).

4.1.1.1.1 Number of leaves per lateral

Analysis of the data indicated that treatment effect did not differ significantly both during 2001 and 2002. The leaf production per lateral was higher during 2002 (1.88) compared to 2001 (1.74). During both years, maximum number of leaves was recorded in the plants treated with fogger irrigation up to March (1.83 and 1.99 respectively for 2001 and 2002).

Table 1a. Effect of irrigation on growth and yield characters of lateral in black pepper var. Panniyur 1

Treatments	Number of leaves per lateral		Leaf area / lateral (cm^2)		Length of lateral (cm)		Internodal thickness of lateral (cm)		Angle of insertion of lateral (Degree)	
	2001	2002	2001	2002	2001	2002	2001	2002	2001	2002
T_1	1.78^a	1.83^a	200.30^a	263.22^a	11.30^a	12.17^a	1.37^a	1.31^a	90.75^a	90.44^a
T_2	1.78^a	1.88^a	195.05^a	269.61^a	11.50^a	12.37^a	1.41^a	1.37^a	82.50^a	87.50^a
T_3	1.73^a	1.93^a	205.23^a	281.36^a	10.50^a	10.84^a	1.42^a	1.24^a	84.75^a	88.96^a
T_4	1.75^a	1.80^a	201.47^a	272.64^a	10.70^a	10.95^a	1.40^a	1.31^a	89.00^a	92.09^a
T_5	1.83^a	1.99^a	206.34^a	280.65^a	12.10^a	13.55^a	1.41^a	1.35^a	89.75^a	88.33^a
T_6	1.65^a	1.88^a	185.47^a	249.83^a	9.87^a	12.88^a	1.36^a	1.39^a	82.00^a	90.00^a
T_7	1.70^a	1.58^a	177.37^a	226.00^a	10.30^a	10.78^a	1.37^a	1.31^a	88.63^a	94.79^a
T_8	1.76^a	1.95^a	213.15^a	303.48^a	11.90^a	12.01^a	1.30^a	1.36^a	88.13^a	93.33^a
T_9	1.73^a	198^a	196.87^a	279.73^a	12.00^a	11.82^a	1.39^a	1.34^a	83.63^a	86.58^a
T_{10}	1.68^a	1.88^a	205.65^a	263.33^a	10.50^a	12.02^a	1.35^a	1.34^a	89.63^a	90.83^a
T_{11}	1.75^a	1.98^a	212.35^a	283.42^a	11.50^a	13.08^a	1.41^a	1.46^a	86.88^a	90.88^a
Mean	1.74	1.88	199.93	270.30	11.11	12.04	1.38	1.34	86.88	90.34

The values with a common letter in the superscript did not differ significantly at 5 per cent level

T_1: No irrigation (Control)
T_2: Five litres of rocker sprayer irrigation up to March
T_3: Five litres of rocker sprayer irrigation up to February
T_4: Five litres of rocker sprayer irrigation up to January
T_5: Five litres of fogger irrigation up to March
T_6: Five litres of fogger irrigation up to February
T_7: Five litres of fogger irrigation up to January
T_8: Ten litres of basin irrigation up to March
T_9: Ten litres of basin irrigation up to February
T_{10}: Ten litres of basin irrigation up to January
T_{11}: Irrigation throughout summer period

4.1.1.1.2 Leaf Area per Lateral

During both the years 2001 and 2002, irrigation failed to exert a significant effect on the leaf area per lateral. However, basin irrigation up to March resulted in maximum leaf area during both years (213.15 cm^2 and 303.48 cm^2 during 2001 and 2002 respectively.)

4.1.1.1.3 Length of Lateral

From the data presented, it is understood that irrigation did not bring about significant increase in the lateral length both during 2001 and 2002. The mean length of the lateral recorded was slightly higher during 2002 (12.04 cm) compared to 2001 (11.11 cm). Though not significant, application of the treatment fogger irrigation up to March resulted in longer lateral irrespective of the years.

4.1.1.1.4 Internodal Thickness of Lateral

Internodal thickness also did not register significant variation as a result of irrigation. The application of the treatment rocker sprayer irrigation up to February resulted in maximum thickness (1.42 cm) during 2001. While in the succeeding year, continuously irrigated plants registered a maximum thickness of 1.46 cm.

4.1.1.1.5 Angle of Insertion of Lateral

The treatment plants did not differ considerably with regard to the angle of insertion of lateral made to the main stem. However, the angle of insertion ranged from 82.00 to 90.75 degrees during 2001 and 86.58 to 94.79 degrees during 2002.

4.1.1.1.6 Time of Spike Initiation of Lateral

The summer irrigation was not found to affect the time of spike initiation of lateral during both 2001 and 2002 (Tables 2a and 2b). Initiation of spike was noticed on the leaf axil along with flushing. No definite trend among the treatments was observed

Table 2a. Effect of irrigation on time of spike initiation of lateral during 2001 in black pepper var. Panniyur 1

Treatments	Number of plants initiated spiking								
	21/5/01	24/5/01	27/5/01	30/5/01	2/6/01	5/6/01	8/6/01	11/6/01	14/6/01
T_1	1	0	0	1	3	2	0	1	0
T_2	1	0	0	1	0	1	1	3	1
T_3	0	0	2	0	2	0	2	0	2
T_4	0	0	0	2	1	1	2	1	1
T_5	0	1	0	0	1	0	4	0	2
T_6	0	0	0	1	0	2	2	3	0
T_7	0	1	0	1	0	1	1	3	1
T_8	0	0	0	0	1	0	4	3	0
T_9	0	0	0	0	0	2	1	1	4
T_{10}	2	0	0	2	0	0	3	0	1
T_{11}	0	0	2	1	0	3	2	0	0
Total number	4	2	4	9	8	12	22	15	12

Table 2b. Effect of irrigation on time of spike initiation of lateral during 2002 in black pepper var. Panniyur 1

Treatments	Number of plants initiated spiking								
	12/5/02	15/5/02	18/5/02	21/5/02	24/5/02	27/5/02	30/5/02	2/6/02	5/6/02
T_1	0	0	0	0	0	2	0	6	0
T_2	0	0	0	1	1	2	1	2	1
T_3	0	0	0	0	2	0	5	1	0
T_4	1	0	0	1	1	2	2	1	0
T_5	0	0	0	0	0	4	2	1	1
T_6	0	0	0	0	2	2	3	0	1
T_7	0	0	0	0	0	3	2	1	2
T_8	0	0	1	0	2	2	1	2	0
T_9	1	0	0	2	0	3	2	0	0
T_{10}	0	0	0	0	3	0	1	4	0
T_{11}	0	0	0	1	1	2	0	3	1
Total number	2	0	1	5	12	22	19	21	6

T_1: No irrigation (Control)
T_2: Five litres of rocker sprayer irrigation up to March
T_3: Five litres of rocker sprayer irrigation up to February
T_4: Five litres of rocker sprayer irrigation up to January
T_5: Five litres of fogger irrigation up to March
T_6: Five litres of fogger irrigation up to February
T_7: Five litres of fogger irrigation up toJanuary
T_8: Ten litres of basin irrigation up to March
T_9: Ten litres of basin irrigation up to February
T_{10}: Ten litres of basin irrigation up to January
T_{11}: Irrigation throughout summer period

with regard to the number of plants initiated spiking on a particular day of observation. During 2001, the first spike initiation was observed on 21st May on the experimental plants of rocker sprayer irrigation up to March, basin irrigation up to January and control treatment. The spike initiation of 50 per cent of the tagged laterals of all the experimental plants got completed within 24 days. During 2002, initiation of first spike was observed on 12th of May in the treatment plants of rocker sprayer irrigation up to January and basin irrigation up to February and spike initiation was completed on 5th June in all experimental plants.

4.1.1.1.7 Number of Spike Bearing Laterals per 0.25 m^2

Irrigation significantly influenced the production of spike bearing laterals in a unit area. The year 2002 recorded more spike bearing laterals (11.99) compared to 2001 (8.88). During 2001, the maximum number of spike bearing laterals was produced in plants treated with fogger irrigation up to March (11.50), which was statistically on par with that of fogger irrigation up to February and basin irrigation up to March. Though not significant, the number of spike bearing laterals produced in the continuously irrigated plants was higher than unirrigated plants. The treatments irrigation up to February and March were superior to irrigation up to January both in fogger and in basin methods of application, while in rocker sprayer method, all the three treatments were equal in effect in improving the number of spike bearing laterals.

The treatments both rocker sprayer and fogger irrigation up to March registered highest number of spike bearing laterals during 2002 (14.13). The plants treated with irrigation throughout the summer period also recorded significantly higher number of spike bearing laterals (13.75) over unirrigated plants (11.25). Irrigation up to March recorded higher values within rocker sprayer and fogger treatments while in basin method, no significant variation among the three durations was observed.

4.1.1.1.8 Number of Spikes per Lateral

The spike production per lateral did not register any significant difference among irrigation treatments during 2001 and 2002. The mean number of spikes

Table 1b. Effect of irrigation on growth and yield characters of lateral in black pepper var. Panniyur 1

Treatments	Number of spike bearing laterals per 0.25 m^2		Number of spikes per lateral		Spike to leaf ratio per lateral	
	2001	2002	2001	2002	2001	2002
T_1	7.50^{de}	11.25^{c}	1.31^{a}	1.53^{a}	0.74^{a}	0.84^{a}
T_2	7.75^{de}	14.13^{a}	1.35^{a}	1.45^{a}	0.75^{a}	0.78^{a}
T_3	8.75^{cd}	12.13^{abc}	1.28^{a}	1.63^{a}	0.74^{a}	0.84^{a}
T_4	8.63^{cd}	11.75^{bc}	1.32^{a}	1.53^{a}	0.75^{a}	0.86^{a}
T_5	11.50^{a}	14.13^{a}	1.43^{a}	1.86^{a}	0.79^{a}	0.94^{a}
T_6	10.88^{ab}	10.88^{c}	1.23^{a}	1.55^{a}	0.75^{a}	0.83^{a}
T_7	8.00^{d}	10.13^{c}	1.25^{a}	1.33^{a}	0.74^{a}	0.84^{a}
T_8	10.38^{abc}	11.75^{bc}	1.31^{a}	1.63^{a}	0.75^{a}	0.83^{a}
T_9	8.88^{cd}	11.38^{c}	1.26^{a}	1.55^{a}	0.73^{a}	0.79^{a}
T_{10}	6.00^{e}	10.63^{c}	1.22^{a}	1.52^{a}	0.73^{a}	0.82^{a}
T_{11}	9.38^{bcd}	13.75^{ab}	1.29^{a}	1.78^{a}	0.74^{a}	0.90^{a}
Mean	8.88	11.99	1.30	1.58	0.75	0.84

The values with a common letter in the superscript did not differ significantly at 5 per cent level

T_1: No irrigation (Control)
T_2: Five litres of rocker sprayer irrigation up to March
T_3: Five litres of rocker sprayer irrigation up to February
T_4: Five litres of rocker sprayer irrigation up to January
T_5: Five litres of fogger irrigation up to March
T_6: Five litres of fogger irrigation up to February
T_7: Five litres of fogger irrigation up to January
T_8: Ten litres of basin irrigation up to March
T_9: Ten litres of basin irrigation up to February
T_{10}: Ten litres of basin irrigation up to January
T_{11}: Irrigation throughout summer period

produced during 2002 was slightly higher (1.58) compared to 2001 (1.30). Although not significant, plants treated with fogger irrigation up to March registered maximum number of spikes per lateral irrespective of the years.

4.1.1.1.9 Spike to Leaf Ratio per Lateral

The spike to leaf ratio per lateral also presented a nonsignificant result with different irrigation treatments given. However, the fogger irrigation up to March recorded highest value for spike to leaf ratio for both 2001 and 2002 (0.79 and 0.94 respectively). The mean spike to leaf ratio was slightly higher during 2002 (0.84) than 2001 (0.75).

4.1.1.2 Spike Characters

The data on the various characters related to spike are presented in Table 3.

4.1.1.2.1 Number of Well Developed Berries per Spike

The summer irrigation significantly enhanced the number of well developed berries during 2002. The highest berry number was noticed in plants treated with rocker sprayer irrigation up to March (79.15), followed by basin irrigation up to February, irrigation throughout the summer period, fogger irrigation up to March and basin irrigation up to March. In both rocker sprayer and fogger methods, irrigation up to March was the superior treatment whereas in basin method, irrigation up to February and March resulted in more or less equal number of berries in a spike.

4.1.1.2.2 Length of Spike

Irrigation treatments failed to bring about significant increase in spike length over unirrigated control plants irrespective of years. However, continuously irrigated plants registered maximum spike length during 2001 (15.74 cm) and basin irrigation up to March during 2002 (16.15 cm).

Table 3. Effect of irrigation on spike and berry characters of black pepper var. Panniyur 1

Treatments	Number of berries per spike		Length of spike (cm)		Spike compactness (No. cm^{-1})		Weight of 1000 green berries (g)		Volume of 1000 green berries (cc)	
	2001	2002	2001	2002	2001	2002	2001	2002	2001	2002
T_1	64.43^{abcde}	63.98^{d}	14.76^{abc}	15.57^{abc}	4.39^{a}	4.14^{de}	147.04^{c}	149.40^{cde}	129.38^{c}	138.75^{abc}
T_2	62.68^{bcde}	79.15^{a}	13.94^{bcd}	15.42^{abc}	4.50^{a}	5.16^{a}	170.88^{a}	153.66^{bcd}	154.38^{a}	142.50^{ab}
T_3	67.85^{abc}	65.08^{cd}	14.92^{abc}	14.37^{cd}	4.57^{a}	4.54^{bcd}	161.51^{ab}	151.35^{bcde}	148.75^{ab}	142.50^{ab}
T_4	59.43^{de}	62.65^{d}	13.03^{d}	14.74^{cd}	4.63^{a}	4.27^{cde}	165.08^{ab}	148.89^{cde}	148.75^{ab}	133.75^{bc}
T_5	63.03^{bcde}	71.71^{b}	13.69^{cd}	15.56^{abc}	4.64^{a}	4.61^{bc}	164.49^{ab}	160.81^{ab}	150.00^{ab}	146.25^{a}
T_6	59.94^{cde}	68.78^{cd}	14.14^{bcd}	14.90^{bcd}	4.24^{a}	4.37^{cde}	165.58^{ab}	154.00^{bcd}	150.00^{ab}	141.25^{ab}
T_7	62.65^{bcde}	59.20^{d}	14.15^{bcd}	14.09^{d}	4.46^{a}	4.25^{cde}	159.26^{b}	149.89^{cde}	144.38^{ab}	138.63^{abc}
T_8	69.40^{ab}	71.38^{bc}	15.32^{ab}	16.25^{a}	4.51^{a}	4.42^{bcde}	161.11^{b}	163.96^{a}	148.75^{ab}	141.38^{ab}
T_9	65.33^{abcd}	75.05^{ab}	14.19^{bcd}	15.53^{abc}	4.63^{a}	4.84^{ab}	158.34^{b}	143.50^{e}	143.75^{ab}	128.75^{c}
T_{10}	56.88^{e}	61.00^{d}	13.17^{d}	15.12^{abcd}	4.30^{a}	4.04^{e}	159.35^{b}	145.81^{de}	142.50^{b}	128.75^{c}
T_{11}	72.50^{a}	73.71^{ab}	15.74^{a}	16.15^{ab}	4.63^{a}	4.57^{bcd}	164.79^{ab}	157.85^{abc}	147.50^{ab}	143.75^{ab}
Mean	64.01	67.97	14.28	15.25	4.50	4.47	161.58	152.65	146.19	138.75

The values with a common letter in the superscript did not differ significantly at 5 per cent level

T_1: No irrigation (Control)
T_2: Five litres of rocker sprayer irrigation up to March
T_3: Five litres of rocker sprayer irrigation up to February
T_4: Five litres of rocker sprayer irrigation up to January
T_5: Five litres of fogger irrigation up to March
T_6: Five litres of fogger irrigation up to February
T_7: Five litres of fogger irrigation up to January
T_8: Ten litres of basin irrigation up to March
T_9: Ten litres of basin irrigation up to February
T_{10}: Ten litres of basin irrigation up to January
T_{11}: Irrigation throughout summer period

4.1.1.2.3 Spike Compactness

The analysis of the data indicated that the influence of irrigation on the spike compactness was significant only during 2002. However, the plants treated with fogger irrigation up to March registered a spike compactness of 4.64 No. cm^{-1} compared to 4.39 No. cm^{-1} recorded in unirrigated plants during 2001. During 2002, significantly highest spike compactness was recorded in the treatment rocker sprayer irrigation up to March (5.16 No. cm^{-1}), which was statistically on par with the treatment basin irrigation up to February (4.84 No. cm^{-1}). But continuous irrigation failed to enhance the spike compactness significantly over unirrigated control. With respect to different durations of irrigation, irrigation up to March was found superior in the rocker sprayer method whereas in fogger and basin methods, treatments did not show any significant variation in spike compactness.

4.1.1.3 Berry Characters

The data on the effect of irrigation on the berry characters like weight and volume of 1000 green berries are presented in Table 3.

4.1.1.3.1 Weight of 1000 Green Berries

It is evident from the data that irrigation significantly influenced the weight of 1000 green berries during both years. The mean weight of berries was slightly higher during 2001 (161.58 g) compared to 2002 (152.65 g). During 2001, the maximum weight of green berries was recorded in plants treated with rocker sprayer irrigation up to March (170.88 g). The berry weight was statistically on par with all other treatments except fogger irrigation up to January, basin irrigation up to January, February and March, and unirrigated control. The control plants recorded least berry weight (147.04 g). The different durations of irrigation did not result in any significant variation in berry weight in all the three methods of irrigation. During 2002, among the different irrigation treatments given, only basin and fogger methods of irrigation up to March registered significantly higher berry weight compared to unirrigated control plants (163.96 g and 160.81 g respectively). Compared to fogger and basin methods, rocker

sprayer method did not record any significant variation in 1000 berry weight with respect to durations of irrigation.

4.1.1.3.2 Volume of 1000 Green Berries

All the irrigation treatments given significantly enhanced the volume of green berries during 2001 over unirrigated control. The maximum berry volume was observed in plants treated with rocker sprayer irrigation up to March (154.38 cc) and least in control plants (129.38 cc). Within each method of application, there was no significant difference in berry volume with respect to durations of irrigation. During 2002, irrigation could not bring about significant increase in the berry volume over control. However, maximum berry volume was registered in the plants treated with fogger irrigation up to March (146.25 cc).

4.1.1.4 Yield Characters

The data on the effect of irrigation on the green yield, dry recovery percentage and dry yield of pepper during 2001 and 2002 are presented in Table 4.

4.1.1.4.1 Green Yield per Vine

The average green yield per vine recorded was higher during 2002 (4.97 kg) compared to 2001 (2.35 kg). The irrigation during summer months failed to bring about any significant effect on the green yield produced per pepper vine during 2001. However, the yield was highest in the treatment, basin irrigation up to March (3.24 kg). During 2002, the treatment basin irrigation up to March recorded significantly highest green yield (6.49 kg) that was on par with basin irrigation up to February, rocker sprayer irrigation up to February and continuous irrigation. The green yield recorded was least in unirrigated plants. Compared to rocker and basin methods, fogger method did not register any significant variation in green yield with respect to different durations of irrigation.

Table 4. Effect of irrigation on yield of black pepper var. Panniyur 1

Treatments	Green yield per vine (kg)		Dry recovery percentage		Dry yield per vine (kg)	
	2001	2002	2001	2002	2001	2002
T_1	1.96^{a}	3.97^{d}	32.63^{a}	31.53^{a}	0.64^{a}	1.27^{d}
T_2	2.85^{a}	4.32^{cd}	31.13^{a}	30.32^{a}	0.86^{a}	1.31^{d}
T_3	2.66^{a}	5.97^{ab}	31.00^{a}	30.27^{a}	0.82^{a}	1.81^{abc}
T_4	2.63^{a}	4.75^{cd}	31.75^{a}	30.67^{a}	0.84^{a}	1.46^{cd}
T_5	2.06^{a}	4.39^{cd}	30.13^{a}	29.76^{a}	0.62^{a}	1.31^{d}
T_6	2.23^{a}	4.93^{bcd}	30.00^{a}	30.63^{a}	0.67^{a}	1.52^{bcd}
T_7	2.08^{a}	4.17^{cd}	31.13^{a}	30.40^{a}	0.65^{a}	1.26^{d}
T_8	3.24^{a}	6.49^{a}	30.13^{a}	29.30^{a}	0.97^{a}	1.88^{a}
T_9	2.07^{a}	6.21^{a}	31.50^{a}	29.82^{a}	0.66^{a}	1.85^{ab}
T_{10}	1.95^{a}	4.15^{d}	32.75^{a}	30.86^{a}	0.63^{a}	1.27^{d}
T_{11}	2.11^{a}	5.34^{abc}	31.00^{a}	29.33^{a}	0.65^{a}	1.56^{abcd}
Mean	2.35	4.97	31.19	30.26	0.73	1.50

The values with a common letter in the superscript did not differ significantly at 5 per cent level

T_1: No irrigation (Control)
T_2: Five litres of rocker sprayer irrigation up to March
T_3: Five litres of rocker sprayer irrigation up to February
T_4: Five litres of rocker sprayer irrigation up to January
T_5: Five litres of fogger irrigation up to March
T_6: Five litres of fogger irrigation up to February
T_7: Five litres of fogger irrigation up to January
T_8: Ten litres of basin irrigation up to March
T_9: Ten litres of basin irrigation up to February
T_{10}: Ten litres of basin irrigation up to January
T_{11}: Irrigation throughout summer period

4.1.1.4.2 Dry Recovery Percentage

The effect of irrigation on the dry recovery percentage was nonsignificant during both 2001 and 2002. During 2001, the dry recovery percentage ranged from 30.00 (fogger irrigation up to February) to 32.75 (basin irrigation up to January). While during 2002, the maximum dry recovery percentage was noticed in unirrigated control plants (31.53).

4.1.1.4.3 Dry Yield per Vine

The summer irrigation exerted a significant effect on the dry yield per vine of black pepper only during 2002. The plants irrigated by basin method up to March registered maximum dry yield (1.88 kg) which was more or less equal to the dry yield recorded in the treatments, basin irrigation up to February (1.85 kg), rocker sprayer irrigation up to February (1.81 kg) and continuous irrigation (1.56 kg). The least dry yield was recorded in plants irrigated with fogger up to January. During 2001 also, maximum dry yield was noticed in plants treated with basin irrigation up to March (0.97 kg). Dry yield was observed to be higher during 2002 (1.50 kg) than that of 2001 (0.73 kg).

4.1.2 Biochemical Characters

The influence of summer irrigation on various biochemical parameters was studied during the important physiological stages like prior to flushing, at flushing and flowering and fruit set and the results obtained are presented under the following heads:

4.1.2.1 Leaf Chlorophyll

It is clear from the Table (5) that application of irrigation significantly enhanced the chlorophyll 'a' and total chlorophyll content over unirrigated control plants. The mean chlorophyll 'a' and total chlorophyll recorded were highest in plants treated with basin irrigation up to March (1.91 mg g^{-1} and 2.27 mg g^{-1} respectively). Rest of the treatments were statistically on par or inferior to control treatment.

Table 5. Effect of irrigation on chlorophyll content of leaves at different physiological stages in black pepper var. Panniyur 1

Treatments	Chlorophyll 'a' (mg g^{-1})				Chlorophyll 'b' (mg g^{-1})				Total chlorophyll (mg g^{-1})			
	Before flushing	Flushing and flowering	Fruit set	Treatment mean	Before flushing	Flushing and flowering	Fruit set	Treatment mean	Before flushing	Flushing and flowering	Fruit set	Treatment mean
T_1	2.02^{bcd}	1.31^{jk}	1.89^{de}	1.74^{B}	0.37^{abcdef}	$0.30^{efghijk}$	0.41^{abcd}	0.36^{A}	2.39^{bcd}	1.60^{h}	2.30^{cdef}	2.10^{B}
T_2	1.93^{cde}	1.19^{kl}	1.48^{hi}	1.53^{DE}	$0.26^{ghijklm}$	$0.28^{efghijkl}$	0.12^{n}	0.22^{D}	2.19^{ef}	1.47^{hi}	1.60^{h}	1.75^{F}
T_3	2.14^{b}	1.05^{lm}	1.44^{ij}	1.54^{CDE}	0.38^{abcde}	$0.28^{efghijkl}$	$0.30^{efghijk}$	0.32^{AB}	2.51^{b}	1.32^{ij}	1.78^{g}	1.87^{DE}
T_4	1.81^{e}	0.99^{mn}	1.27^{k}	1.36^{G}	$0.33^{cdefghi}$	0.25^{hijklm}	0.16^{mn}	0.25^{CD}	2.14^{ef}	1.24^{jk}	1.43^{hi}	1.60^{G}
T_5	1.86^{e}	0.91^{mn}	1.61^{gh}	1.46^{EF}	0.37^{abcdef}	0.23^{ijklm}	0.22^{jklm}	0.27^{BC}	2.23^{def}	1.13^{k}	1.83^{g}	1.73^{F}
T_6	1.85^{e}	0.88^{n}	1.59^{ghi}	1.44^{FG}	$0.28^{efghijkl}$	0.19^{lmn}	$0.35^{bcdefgh}$	0.27^{BC}	2.12^{f}	1.07^{k}	1.94^{g}	1.71^{F}
T_7	2.04^{bcd}	1.04^{lmn}	1.78^{ef}	1.62^{C}	0.44^{ab}	$0.28^{efghijkl}$	0.37^{abcdef}	0.36^{A}	2.48^{bc}	1.32^{ij}	2.14^{ef}	1.98^{C}
T_8	2.15^{b}	1.53^{ghi}	2.06^{bc}	1.91^{A}	$0.36^{abcdefg}$	$0.32^{defghij}$	$0.34^{bcdefgh}$	0.34^{A}	2.55^{b}	1.85^{g}	2.41^{bcd}	2.27^{A}
T_9	2.39^{a}	1.21^{k}	1.65^{fg}	1.75^{B}	0.46^{ab}	$0.27^{fghijkl}$	$0.29^{efghijkl}$	0.34^{A}	2.84^{a}	1.48^{hi}	1.94^{g}	2.09^{B}
T_{10}	2.13^{b}	1.02^{mn}	1.52^{ghi}	1.56^{CD}	$0.31^{defghijk}$	0.23^{ijklm}	$0.30^{efghijk}$	0.28^{BC}	2.31^{cde}	1.25^{jk}	1.80^{g}	1.79^{EF}
T_{11}	2.40^{a}	0.92^{mn}	1.44^{ij}	1.59^{CD}	0.43^{abc}	0.21^{klmn}	$0.30^{efghijk}$	0.31^{AB}	2.82^{a}	1.13^{k}	1.93^{g}	1.96^{CD}
Mean	2.06^{A}	1.10^{C}	1.61^{B}	1.59	0.36^{A}	0.26^{B}	0.29^{B}	0.30	2.42^{A}	1.35^{C}	1.92^{B}	1.90

The values with a common letter in the superscript did not differ significantly at 5 per cent level

T_1: No irrigation (Control)
T_2: Five litres of rocker sprayer irrigation up to March
T_3: Five litres of rocker sprayer irrigation up to February
T_4: Five litres of rocker sprayer irrigation up to January
T_5: Five litres of fogger irrigation up to March
T_6: Five litres of fogger irrigation up to February
T_7: Five litres of fogger irrigation up to January
T_8: Ten litres of basin irrigation up to March
T_9: Ten litres of basin irrigation up to February
T_{10}: Ten litres of basin irrigation up to January
T_{11}: Irrigation throughout summer period

Irrigation could not bring about significant increase in chlorophyll 'b' content of pepper leaves.

In general, chlorophyll 'a', chlorophyll 'b' and total chlorophyll showed a sharp decline after flushing and then rose to peak at fruit set. Prior to flushing, continuously irrigated plants and plants treated with basin irrigation up to February recorded significantly higher chlorophyll 'a' and total chlorophyll content over unirrigated plants whereas at flushing and flowering, only the treatment basin irrigation up to March resulted in significantly highest chlorophyll 'a' and total chlorophyll content (1.53 mg g^{-1} and 1.85 mg g^{-1} respectively). At fruit set stage also, basin irrigation up to March resulted in highest chlorophyll 'a' and total chlorophyll content (2.06 mg g^{-1} and 2.41 mg g^{-1} respectively for chlorophyll 'a' and total chlorophyll). None of the irrigation treatments could enhance the chlorophyll 'b' content of leaves at all the three stages analysed.

4.1.2.2 Total Phenol

The data presented in Table 6 revealed that summer irrigation had no significant effect over control on the mean total phenol content of leaves. However, maximum content of phenol was noticed in plants treated with basin irrigation up to February (7.06 mg g^{-1}). Total phenol in the leaves prior to flushing recorded highest value (7.55 mg g^{-1}) and it reduced in the new flushes (6.54 mg g^{-1}) and recorded least at fruit set stage (5.26 mg g^{-1}). Prior to flushing the plants treated with rocker sprayer irrigation up to March recorded significantly highest total phenol content (8.50 mg g^{-1}) followed by the phenol content of the plants treated with irrigation throughout the summer period and basin irrigation up to February, all of which were statistically on par. Both at flushing and flowering and fruit set stages, the treatments could not result in any significant change in the total phenol content of leaves over control.

4.1.2.3 Polyphenol Oxidase Activity

The data presented in Table 7 indicated a significant effect of irrigation on the polyphenol oxidase (PPO) activity of pepper leaves at different stages analysed.

Table 6. Effect of irrigation on total phenol content (mg g^{-1}) of leaves at different physiological stages in black pepper var. Panniyur 1

Treatments	Before flushing	Flushing and flowering	Fruit set	Treatment mean
T_1	6.83^{defg}	7.17^{cdef}	6.25^{ghi}	6.75^{ABC}
T_2	8.50^{a}	6.64^{efg}	5.68^{hijk}	6.94^{AB}
T_3	7.07^{cdef}	5.29^{kl}	4.07^{m}	5.47^{G}
T_4	7.42^{bcd}	6.14^{ghij}	4.07^{m}	5.88^{F}
T_5	7.51^{bcd}	7.11^{cdef}	5.57^{ijk}	6.73^{ABC}
T_6	7.68^{bc}	6.34^{gh}	5.23^{kl}	6.42^{CDE}
T_7	7.62^{bc}	6.48^{fg}	4.79^{l}	6.30^{E}
T_8	7.73^{bc}	6.55^{efg}	5.74^{hijk}	6.67^{BCD}
T_9	8.00^{ab}	7.49^{bcd}	5.68^{hijk}	7.06^{A}
T_{10}	6.53^{efg}	7.23^{cde}	5.33^{kl}	6.36^{DE}
T_{11}	8.11^{ab}	5.47^{jkl}	5.43^{jkl}	6.34^{DE}
Mean	7.55^{A}	6.54^{B}	5.26^{C}	6.45

Table 7. Effect of irrigation on total polyphenol oxidase activity (OD value) of leaves at different physiological stages in black pepper var. Panniyur 1

Treatments	Before flushing	Flushing and flowering	Fruit set	Treatment mean
T_1	0.489^{g}	0.558^{c}	0.375^{k}	0.474^{C}
T_2	0.534^{def}	0.516^{f}	0.350^{l}	0.467^{C}
T_3	0.538^{de}	0.530^{ef}	0.395^{j}	0.488^{B}
T_4	0.486^{gh}	0.577^{b}	0.349^{l}	0.471^{C}
T_5	0.483^{gh}	0.311^{m}	0.470^{hi}	0.421^{D}
T_6	0.405^{j}	0.525^{ef}	0.352^{l}	0.427^{D}
T_7	0.469^{hi}	0.347^{l}	0.348^{l}	0.388^{F}
T_8	0.499^{g}	0.549^{cd}	0.357^{l}	0.468^{C}
T_9	0.698^{a}	0.520^{ef}	0.294^{n}	0.504^{A}
T_{10}	0.398^{j}	0.464^{i}	0.345^{l}	0.402^{E}
T_{11}	0.565^{bc}	0.246^{o}	0.388^{jk}	0.400^{E}
Mean	0.506^{A}	0.468^{B}	0.366^{C}	0.446

The values with a common letter in the superscript did not differ significantly at 5 per cent level

T_1: No irrigation (Control)
T_2: Five litres of rocker sprayer irrigation up to March
T_3: Five litres of rocker sprayer irrigation up to February
T_4: Five litres of rocker sprayer irrigation up to January
T_5: Five litres of fogger irrigation up to March
T_6: Five litres of fogger irrigation up to February
T_7: Five litres of fogger irrigation up to January
T_8: Ten litres of basin irrigation up to March
T_9: Ten litres of basin irrigation up to February
T_{10}: Ten litres of basin irrigation up to January
T_{11}: Irrigation throughout summer period

The mean activity of PPO was highest in plants treated with basin irrigation up to February (0.503) followed by rocker sprayer irrigation up to February (0.488) both of which expressed statistical superiority over the PPO activity of unirrigated plants (0.474). The PPO activity was highest prior to flushing and it reduced in the new flushes at flowering and further reduced to fruit set. No definite trend among the treatments was observed at different stages with respect to the activity of PPO. Prior to flushing, the treatments, basin irrigation up to February, continuous irrigation and rocker sprayer irrigation up to February and March recorded significantly higher PPO activity with maximum in basin irrigation up to February (0.698). But at flushing and flowering, only rocker sprayer irrigation up to January recorded higher PPO activity over control. At fruit set stage, the plants treated with rocker sprayer irrigation up to February and fogger irrigation up to March exhibited significantly higher activity of PPO.

4.1.2.4 Peroxidase Activity

Though the treatment effects recorded significant difference in peroxidase activity at different stages analysed (Table 8), the mean activity of peroxidase did not show superiority over unirrigated control. At pre flushing and flushing and flowering stages, the plants treated with basin irrigation up to March (245.20 units litre $^{-1}$) and rocker sprayer irrigation up to March (61.58 units litre $^{-1}$) respectively registered significantly higher peroxidase activity over unirrigated plants. In the case of fruit set stage, all the irrigation treatments except, fogger irrigation up to January, basin irrigation up to January and March showed superiority over unirrigated plants. Generally, the peroxidase activity was observed to be maximum prior to flushing (144.38 units litre $^{-1}$), and then it reduced drastically in the new flushes at flowering (30.15 units litre $^{-1}$) and then showed an increasing trend at fruit set stage (66.56 units litre $^{-1}$).

4.1.2.5 Nitrate Reductase Activity

The irrigation during summer months was found to enhance the nitrate reductase activity (NRA) of the experimental plants at different physiological stages

Table 8. Effect of irrigation on peroxidase activity (Units litre^{-1}) of leaves at different physiological stages in black pepper var. Panniyur 1

Treatments	Before flushing	Flushing and flowering	Fruit set	Treatment mean
T_1	228.51^{b}	31.94^{lmno}	36.86^{lmn}	99.10^{AB}
T_2	114.04^{t}	61.58^{ghi}	98.57^{f}	91.40^{BC}
T_3	103.03^{ef}	42.64^{jkl}	109.86^{ef}	85.18^{CD}
T_4	149.44^{d}	29.57^{lmnopq}	64.21^{gh}	81.07^{D}
T_5	150.22^{d}	26.43^{nopq}	103.03^{ef}	93.23^{B}
T_6	105.56^{ef}	16.59^{q}	51.46^{hij}	58.20^{E}
T_7	182.88^{c}	17.67^{pq}	34.13^{lmno}	78.23^{D}
T_8	245.20^{a}	27.46^{mnopq}	37.79^{klmn}	103.48^{A}
T_9	54.36^{hij}	26.30^{nopq}	50.63^{ijk}	43.76^{F}
T_{10}	73.03^{g}	20.74^{opq}	40.89^{jklm}	44.89^{F}
T_{11}	180.96^{c}	30.70^{lmnop}	104.77^{ef}	105.48^{A}
Mean	144.38^{A}	30.15^{C}	66.56^{B}	80.37

Table 9. Effect of irrigation on nitrate reductase activity (m mol g fresh weight $^{-1}$ hour $^{-1}$) of leaves at different physiological stages in black pepper var. Panniyur 1

Treatments	Before flushing	Flushing and flowering	Fruit set	Treatment mean
T_1	0.32^{no}	1.21^{b}	0.69^{gh}	0.74^{B}
T_2	0.34^{mno}	1.57^{a}	0.69^{gh}	0.87^{A}
T_3	0.34^{mno}	0.91^{de}	0.41^{lmno}	0.55^{CD}
T_4	0.28^{o}	0.45^{klmn}	0.43^{lmno}	0.39^{E}
T_5	0.49^{jklm}	1.10^{bc}	1.03^{cd}	0.87^{A}
T_6	0.28^{o}	1.23^{b}	0.66^{ghi}	0.72^{B}
T_7	0.61^{hijk}	0.78^{efg}	0.43^{lmno}	0.61^{C}
T_8	0.49^{jklm}	0.88^{def}	0.86^{ef}	0.74^{B}
T_9	0.37^{lmno}	0.73^{fgh}	0.72^{fgh}	0.61^{C}
T_{10}	0.52^{ijkl}	0.61^{hijk}	0.31^{no}	0.48^{D}
T_{11}	0.62^{hij}	0.70^{gh}	0.48^{jklm}	0.60^{C}
Mean	0.42^{C}	0.93^{A}	0.61^{B}	0.65

The values with a common letter in the superscript did not differ significantly at 5 per cent level

T_1: No irrigation (Control)
T_2: Five litres of rocker sprayer irrigation up to March
T_3: Five litres of rocker sprayer irrigation up to February
T_4: Five litres of rocker sprayer irrigation up to January
T_5: Five litres of fogger irrigation up to March
T_6: Five litres of fogger irrigation up to February
T_7: Five litres of fogger irrigation up to January
T_8: Ten litres of basin irrigation up to March
T_9: Ten litres of basin irrigation up to February
T_{10}: Ten litres of basin irrigation up to January
T_{11}: Irrigation throughout summer period

analysed (Table 9). Among the various irrigation treatments given, rocker sprayer and fogger irrigation up to March enhanced the NRA of leaves (0.87 m mol nitrite g fresh weight $^{-1}$ hour $^{-1}$). The activity of nitrate reductase was very low in leaves prior to flushing (0.42 m mol nitrite g fresh weight $^{-1}$ hour $^{-1}$) and increased to a maximum at flowering (0.93 m mol nitrite g fresh weight $^{-1}$ hour $^{-1}$) and then reduced at fruit set (0.61 m mol nitrite g fresh weight $^{-1}$ hour $^{-1}$). Prior to flushing, maximum activity was observed in leaves of continuously irrigated plants whereas at flushing and flowering stage, the plants treated with rocker sprayer irrigation up to March recorded highest activity. At fruit set significantly higher NRA was observed in plants treated with fogger irrigation and basin irrigation up to March (1.03 and 0.86 m mol nitrite g fresh weight $^{-1}$ hour $^{-1}$ respectively).

4.1.2.6 C:N Ratio

The data on the total C, total N, and C:N ratio recorded significant variation between treatments, stages and treatments x stages (Table 10).

4.1.2.6.1 Total Carbon

Among the various irrigation treatments applied, only basin irrigation up to March could significantly enhance the mean total C content of pepper leaves (52.38 per cent). The total C content in the leaves increased to a maximum at flushing and flowering stage (50.60 per cent) and then reduced at fruit set (44.50 per cent). Prior to flushing and at flushing and flowering stages, the plants treated with basin irrigation up to March recorded highest total C content (51.66 and 58.88 per cent respectively). At flushing and flowering stage, the plants irrigated up to February by basin method also registered significantly higher total C over unirrigated control plants. However, at fruit set, control plants recorded maximum C content (50.22 per cent).

4.1.2.6.2 Total Nitrogen

The mean foliar level of N recorded significantly higher only in the treatment, fogger irrigation up to February (2.22 per cent). The N content was higher in

Table 10. Effect of irrigation on C:N ratio of leaves at different physiological stages in black pepper var. Panniyur 1

Treatments	Total carbon (%)				Total nitrogen (%)				C:N ratio			
	Before flushing	Flushing and flowering	Fruit set	Treatment mean	Before flushing	Flushing and flowering	Fruit set	Treatment mean	Before flushing	Flushing and flowering	Fruit set	Treatment mean
T_1	47.19^{def}	51.89^{bc}	50.22^{bcd}	49.77^{B}	2.02^{jkl}	2.13^{fghij}	2.28^{bcde}	2.14^{BC}	23.40^{efghij}	24.40^{cdef}	$22.06^{ghijklmn}$	23.29^{AB}
T_2	38.12^{nop}	48.97^{cde}	41.75^{ijklm}	42.95^{FG}	1.86^{mn}	2.30^{bcd}	2.11^{ghij}	2.09^{CD}	20.53^{mnopqr}	$21.34^{jklmnop}$	19.82^{opqr}	20.57^{E}
T_3	42.26^{hijkl}	47.14^{def}	44.77^{fghi}	44.72^{DEF}	1.92^{lm}	2.95^{ijk}	1.96^{klm}	1.98^{E}	$22.01^{ghijklmn}$	$23.23^{efghijk}$	$22.87^{fghijkl}$	22.70^{BC}
T_4	37.51^{op}	45.31^{fgh}	44.77^{fghi}	42.53^{G}	1.79^{no}	2.07^{ijk}	2.11^{ghij}	1.99^{E}	20.99^{lmnopq}	$21.92^{hijklmno}$	21.22^{klmnop}	21.38^{DE}
T_5	42.96^{hijkl}	44.98^{fgh}	44.77^{fghi}	44.24^{EFG}	1.70^{o}	2.08^{hijk}	2.55^{a}	2.11^{C}	25.24^{cde}	$21.63^{ijklmnop}$	17.57^{st}	21.48^{DE}
T_6	49.22^{cde}	49.56^{bcde}	40.54^{klmno}	46.44^{CD}	1.92^{lm}	2.53^{a}	2.20^{defgh}	2.22^{A}	25.73^{bcd}	19.64^{pqrs}	18.43^{rst}	21.27^{DE}
T_7	46.59^{efg}	52.47^{b}	43.56^{ghijk}	47.54^{C}	1.79^{no}	2.38^{b}	2.05^{ijk}	2.07^{CD}	26.03^{bc}	$22.05^{ghijklmn}$	21.28^{klmnop}	23.12^{AB}
T_8	51.66^{bc}	58.88^{a}	46.59^{efg}	52.38^{A}	1.79^{no}	2.51^{a}	2.33^{bc}	2.21^{AB}	28.88^{a}	23.58^{efghi}	20.02^{nopqr}	24.16^{A}
T_9	41.14^{jklmn}	56.55^{a}	38.72^{mnop}	45.47^{DE}	1.79^{no}	2.04^{ijkl}	2.22^{cdefg}	2.01^{DE}	$23.03^{fghijkl}$	27.70^{ab}	17.51^{t}	22.74^{BC}
T_{10}	39.93^{lmnop}	49.56^{bcde}	44.17^{fghij}	44.55^{EF}	1.88^{mn}	2.06^{ijk}	2.33^{bc}	2.09^{C}	$21.29^{jklmnop}$	24.06^{cdefg}	18.98^{qrst}	21.44^{DE}
T_{11}	36.91^{p}	51.30^{bc}	49.61^{bcde}	45.94^{CDE}	1.88^{mn}	2.16^{efghi}	2.24^{cdef}	2.09^{C}	19.56^{pqrs}	23.79^{defgh}	$22.15^{ghijklm}$	21.86^{CD}
Mean	43.05^{C}	50.60^{A}	44.50^{B}	46.05	1.85^{B}	2.21^{A}	2.22^{A}	2.09	23.34^{A}	23.03^{A}	20.17^{B}	22.18

The values with a common letter in the superscript did not differ significantly at 5 per cent level

T_1: No irrigation (Control)
T_2: Five litres of rocker sprayer irrigation up to March
T_3: Five litres of rocker sprayer irrigation up to February
T_4: Five litres of rocker sprayer irrigation up to January
T_5: Five litres of fogger irrigation up to March
T_6: Five litres of fogger irrigation up to February
T_7: Five litres of fogger irrigation up to January
T_8: Ten litres of basin irrigation up to March
T_9: Ten litres of basin irrigation up to February
T_{10}: Ten litres of basin irrigation up to January
T_{11}: Irrigation throughout summer period

the new flushes and recorded equal content at flowering and fruit set stages (2.21 and 2.22 per cent respectively). No definite trend among the treatments was observed at different stages analysed. Prior to flushing, none of the irrigation treatments could increase the foliar N while at flushing and flowering, the treatments basin irrigation and rocker sprayer irrigation up to March and fogger irrigation up to January and February significantly enhanced the total N content over unirrigated control. At fruit set stage, only plants treated with fogger irrigation up to March (2.55 per cent) registered significantly higher level of N in leaves.

4.1.2.6.3 C:N Ratio

Irrigation failed to enhance the mean C:N ratio of pepper leaves. However, it recorded significantly higher values at stages like, before flushing and flushing and flowering. Prior to flushing, the treatments, fogger irrigation up to January and February and basin irrigation up to March enhanced the C:N ratio. Whereas at flushing and flowering, plants treated with basin irrigation up to February alone recorded higher C:N ratio (27.70). None of the treatments enhanced the C:N ratio at fruit set. There was no considerable variation in the C:N ratio of past season leaves just before flushing (23.34) and in the new flushes at flowering (23.03). The C:N ratio recorded least at fruit set (20.17).

4.1.2.7 Quality Parameters

The effect of irrigation during drought months on the quality parameters like essential oil, oleoresin and piperine during 2001 and 2002 are presented in Table 11.

4.1.2.7.1 Essential Oil

Irrigation failed to enhance the essential oil content of berries during both 2001 and 2002. However, maximum oil content was recorded in plants treated with fogger irrigation up to February (3.25 per cent) and rocker sprayer irrigation up to February (3.50 per cent) respectively for 2001 and 2002.

Table 11. Effect of irrigation on quality parameters of berries in black pepper var. Panniyur 1

Treatments	Essential oil (%)		Oleoresin (%)		Piperine (%)	
	2001	2002	2001	2002	2001	2002
T_1	2.75^{a}	2.88^{abcde}	11.20^{a}	10.58^{cd}	4.20^{a}	4.67^{a}
T_2	2.63^{a}	2.38^{de}	10.80^{a}	10.82^{cd}	4.80^{a}	5.22^{a}
T_3	2.50^{a}	3.50^{a}	10.30^{a}	12.45^{ab}	4.70^{a}	4.77^{a}
T_4	2.63^{a}	3.13^{abc}	11.31^{a}	10.43^{cd}	4.75^{a}	4.85^{a}
T_5	3.00^{a}	2.63^{bcde}	12.10^{a}	10.01^{cd}	5.02^{a}	5.19^{a}
T_6	3.25^{a}	3.00^{abcd}	11.50^{a}	13.32^{a}	4.81^{a}	4.70^{a}
T_7	3.13^{a}	2.50^{cde}	12.50^{a}	11.20^{bc}	5.10^{a}	5.18^{a}
T_8	2.50^{a}	2.62^{bcde}	11.44^{a}	9.51^{d}	4.62^{a}	4.61^{a}
T_9	2.25^{a}	2.75^{bcde}	10.80^{a}	10.48^{cd}	4.20^{a}	5.06^{a}
T_{10}	2.25^{a}	2.25^{c}	10.50^{a}	11.39^{bc}	4.20^{a}	4.93^{a}
T_{11}	2.25^{a}	3.25^{ab}	10.18^{a}	9.58^{d}	4.75^{a}	4.91^{a}
Mean	2.26	2.81	11.15	10.89	4.65	4.92

The values with a common letter in the superscript did not differ significantly at 5 per cent level

T_1: No irrigation (Control)
T_2: Five litres of rocker sprayer irrigation up to March
T_3: Five litres of rocker sprayer irrigation up to February
T_4: Five litres of rocker sprayer irrigation up to January
T_5: Five litres of fogger irrigation up to March
T_6: Five litres of fogger irrigation up to February
T_7: Five litres of fogger irrigation up to January
T_8: Ten litres of basin irrigation up to March
T_9: Ten litres of basin irrigation up to February
T_{10}: Ten litres of basin irrigation up to January
T_{11}: Irrigation throughout summer period

4.1.2.7.2 Oleoresin

The oleoresin content was not significantly influenced by irrigation during 2001. The maximum oleoresin content was recorded in plants treated with fogger irrigation up to January (12.50 per cent) and least in the continuously irrigated plants (10.18 per cent). During 2002, significantly higher oleoresin content was registered in the treatments, fogger irrigation up to February (13.32 per cent) and rocker sprayer irrigation up to February (12.45 per cent). Rest of the treatments were statistically on par with that of the control.

4.1.2.7.3 Piperine

Summer irrigation failed to bring about any significant effect on the piperine content of pepper berries during both 2001 and 2002. The content of piperine ranged from 4.20 per cent (basin irrigation up to January, basin irrigation up to February and unirrigated control) to 5.1 per cent (fogger irrigation up to January) during 2001 while, it ranged from 4.61 per cent (basin irrigation up to March) to 5.22 per cent (rocker sprayer irrigation up to March).

4.1.3 Physiological Characters

The various physiological parameters were studied during different stages viz., before flushing, at flushing and flowering and fruit set and the results obtained are presented below:

4.1.3.1 Photosynthetic Rate

The leaf photosynthetic rate was measured under ambient condition by using a portable photosynthetic system and data are presented in Table 12. The mean photosynthetic rate recorded significantly higher only in the treatment, basin irrigation up to March (2.94 μ mol m^{-2} s^{-1}). Basin irrigation up to February also exhibited higher photosynthetic rate of 2.55 μ mol m^{-2} s^{-1} but was statistically on par with the photosynthetic rate recorded by the control plants.

Table 12. Effect of irrigation on photosynthetic rate (μ mol $m^{-2}s^{-1}$) at different physiological stages in black pepper var. Panniyur 1

Treatments	Before flushing	Flushing and flowering	Fruit set	Treatment mean
T_1	0.76^{klm}	3.66^{b}	2.07^{fgh}	2.16^{BCD}
T_2	0.58^{lm}	1.07^{ijklm}	3.74^{b}	1.80^{DE}
T_3	1.21^{ijkl}	2.36^{def}	3.09^{bcd}	2.22^{BC}
T_4	0.97^{klm}	1.82^{fghij}	2.17^{fg}	1.65^{E}
T_5	1.90^{fghi}	2.16^{fg}	1.49^{ghijk}	1.85^{CDE}
T_6	1.01^{jklm}	2.63^{cdef}	1.04^{jklm}	1.56^{E}
T_7	0.36^{m}	0.76^{klm}	2.08^{fgh}	1.07^{F}
T_8	1.51^{ghijk}	2.14^{fg}	5.18^{a}	2.94^{A}
T_9	1.30^{hijkl}	3.27^{bc}	3.09^{bcd}	2.55^{AB}
T_{10}	0.78^{klm}	1.19^{ijklm}	2.97^{bcde}	1.65^{E}
T_{11}	1.18^{ijklm}	1.51^{ghijk}	2.21^{efg}	1.63^{E}
Mean	1.05^{C}	2.05^{B}	2.65^{A}	1.92

Table 13. Effect of irrigation on photosynthetically active radiation (μ mol m^{-2} s^{-1}) at different physiological stages in black pepper var. Panniyur 1

Treatments	Before flushing	Flushing and flowering	Fruit set	Treatment mean
T_1	278.67^{b}	217.33^{c}	56.33^{nop}	184.11^{AB}
T_2	175.33^{defgh}	145.33^{efghi}	215.00^{cd}	178.56^{AB}
T_3	183.33^{cde}	112.00^{ijkl}	66.33^{mnop}	120.56^{D}
T_4	137.00^{hijk}	103.67^{jklm}	115.33^{ijkl}	118.67^{D}
T_5	164.00^{efgh}	141.33^{fghij}	61.00^{nop}	122.11^{D}
T_6	272.00^{b}	181.00^{cdef}	48.33^{p}	167.11^{BC}
T_7	157.00^{efgh}	96.67^{klmn}	50.00^{op}	101.22^{D}
T_8	305.00^{ab}	107.67^{ijkl}	110.67^{ijkl}	174.44^{ABC}
T_9	172.67^{efgh}	139.67^{ghij}	55.33^{op}	122.56^{D}
T_{10}	272.00^{b}	178.67^{cdefg}	144.00^{efghij}	198.22^{A}
T_{11}	327.33^{a}	89.67^{lmno}	44.67^{p}	153.89^{C}
Mean	222.21^{A}	137.55^{B}	87.91^{C}	149.22

The values with a common letter in the superscript did not differ significantly at 5 per cent level

T_1: No irrigation (Control)
T_2: Five litres of rocker sprayer irrigation up to March
T_3: Five litres of rocker sprayer irrigation up to February
T_4: Five litres of rocker sprayer irrigation up to January
T_5: Five litres of fogger irrigation up to March
T_6: Five litres of fogger irrigation up to February
T_7: Five litres of fogger irrigation up to January
T_8: Ten litres of basin irrigation up to March
T_9: Ten litres of basin irrigation up to February
T_{10}: Ten litres of basin irrigation up to January
T_{11}: Irrigation throughout summer period

Prior to flushing, the leaves had a low photosynthetic rate (1.05 μ mol m^{-2} s^{-1}), then it increased considerably in the new flushes at flowering stage (2.05 μ mol m^{-2} s^{-1}) and recorded maximum at fruit set (2.65 μ mol m^{-2} s^{-1}). Treatments did not show a definite trend in the rate of photosynthesis at different stages observed. Prior to flushing, only the plants treated with fogger irrigation up to March recorded significantly higher photosynthetic rate while at fruit set stage, the plants treated with rocker sprayer irrigation up to February and March, basin irrigation up to January, February and March registered significantly higher photosynthetic rate compared to unirrigated control plants. The maximum rate of photosynthesis at fruit set stage was observed in plants treated with basin irrigation up to March (5.18 μ mol m^{-2} s^{-1}), whereas at flushing and flowering, unirrigated control plants recorded maximum photosynthetic rate of leaves.

4.1.3.2 Photosynthetically Active Radiation

The mean photosynthetically active radiation (PAR) intercepted by the leaves of the treatment plants ranged from 101.22 μ mol m^{-2} s^{-1} (fogger irrigation up to January) to 198.22 μ mol m^{-2} s^{-1} (basin irrigation up to January)(Table 13). The PAR recorded maximum at pre flushing stage (222.21 μ mol m^{-2} s^{-1}) and then reduced at flushing and flowering stage (137.55 μ mol m^{-2} s^{-1}) and was least at fruit set (87.91 μ mol m^{-2} s^{-1}). Prior to flushing, maximum PAR was recorded in plants treated with continuous irrigation while at flushing and flowering stage, it recorded highest in the unirrigated control plants. At fruit set stage, PAR intercepted ranged from 44.67 (continuous irrigation) to 215.00 μ mol m^{-2} s^{-1} (rocker sprayer irrigation up to March).

4.1.3.3 Stomatal Conductance

The data (Table 14) revealed that irrigation during summer period had no significant effect on the stomatal conductance of black pepper at different physiological stages. However, the stomatal conductance recorded significant variation between stages. The mean stomatal conductance of the treatment plants ranged from 0.03 to 0.07 mol m^{-2} s^{-1} with the maximum value recorded in the plants treated with basin irrigation up to March. The stomatal conductance was found significantly higher at flushing and

Table 14. Effect of irrigation on stomatal conductance (mol $m^{-2}s^{-1}$) at different physiological stages in black pepper var. Panniyur 1

Treatments	Before flushing	Flushing and flowering	Fruit set	Treatment mean
T_1	0.02 ^{a} (0.72)	0.08 ^{a} (0.76)	0.05 ^{a} (0.74)	0.05 ^{A} (0.74)
T_2	0.02 ^{a} (0.72)	0.02 ^{a} (0.72)	0.09 ^{a} (0.77)	0.04 ^{A} (0.74)
T_3	0.02 ^{a} (0.72)	0.04 ^{a} (0.74)	0.08 ^{a} (0.76)	0.05 ^{A} (0.74)
T_4	0.03 ^{a} (0.73)	0.05 ^{a} (0.74)	0.03 ^{a} (0.73)	0.04 ^{A} (0.73)
T_5	0.02 ^{a} (0.72)	0.06 ^{a} (0.75)	0.04 ^{a} (0.73)	0.04 ^{A} (0.73)
T_6	0.01 ^{a} (0.71)	0.05 ^{a} (0.74)	0.03 ^{a} (0.73)	0.03 ^{A} (0.73)
T_7	0.01 ^{a} (0.71)	0.02 ^{a} (0.72)	0.05 ^{a} (0.74)	0.03 ^{A} (0.73)
T_8	0.04 ^{a} (0.74)	0.09 ^{a} (0.77)	0.07 ^{a} (0.76)	0.07 ^{A} (0.75)
T_9	0.02 ^{a} (0.72)	0.04 ^{a} (0.73)	0.05 ^{a} (0.74)	0.04 ^{A} (0.73)
T_{10}	0.01 ^{a} (0.71)	0.03 ^{a} (0.73)	0.07 ^{a} (0.76)	0.04 ^{A} (0.73)
T_{11}	0.03 ^{a} (0.73)	0.06 ^{a} (0.75)	0.01 ^{a} (0.71)	0.04 ^{A} (0.74)
Mean	0.02 ^{B} (0.72)	0.05 ^{A} (0.74)	0.05 ^{A} (0.74)	0.04 (0.74)

Table 15. Effect of irrigation on stomatal resistance (m^2 s mol^{-1}) at different physiological stages in black pepper var. Panniyur 1

Treatments	Before flushing	Flushing and flowering	Fruit set	Treatment mean
T_1	107.41 ^{c}	12.03^{p}	27.85^{klm}	49.09^{DE}
T_2	86.87 ^{d}	46.29^{gh}	19.33^{nop}	50.83^{CD}
T_3	47.50^{gh}	24.90^{lmn}	13.09^{p}	28.50^{G}
T_4	45.92^{gh}	37.13 ^{ij}	22.97^{lmn}	35.34^{F}
T_5	50.90^{g}	22.84^{lmn}	30.33^{jkl}	34.69^{F}
T_6	62.29^{f}	21.79^{mno}	61.48^{f}	48.52^{DE}
T_7	137.38^{b}	41.15^{hi}	18.96^{nop}	65.83^{B}
T_8	25.83^{lmn}	33.60^{jk}	14.89^{op}	24.77^{G}
T_9	87.20^{d}	27.71^{klm}	21.65^{mno}	45.52^{E}
T_{10}	149.98^{a}	74.80^{e}	14.62^{op}	79.80^{A}
T_{11}	34.88^{ijk}	42.12^{hi}	84.10^{d}	53.70^{C}
Mean	76.02^{A}	34.94^{B}	29.93^{C}	46.96

The figures in parentheses are transformed values

The values with a common letter in the superscript did not differ significantly at 5 per cent level

T_1: No irrigation (Control)
T_2: Five litres of rocker sprayer irrigation up to March
T_3: Five litres of rocker sprayer irrigation up to February
T_4: Five litres of rocker sprayer irrigation up to January
T_5: Five litres of fogger irrigation up to March
T_6: Five litres of fogger irrigation up to February
T_7: Five litres of fogger irrigation up to January
T_8: Ten litres of basin irrigation up to March
T_9: Ten litres of basin irrigation up to February
T_{10}: Ten litres of basin irrigation up to January
T_{11}: Irrigation throughout summer period

flowering and fruit set stages (0.05 mol m^{-2} s^{-1}) compared to pre flushing stage (0.02 mol m^{-2} s^{-1}). Prior to flushing, the stomatal conductance ranged from 0.01 to 0.04 mol m^{-2} s^{-1} whereas at flushing and flowering stage, it varied from 0.02 to 0.09 mol m^{-2} s^{-1}. At fruit set, the stomatal conductance recorded maximum (0.09 mol m^{-2} s^{-1}) in the plants treated with rocker sprayer irrigation up to March and minimum in continuous irrigation (0.01 mol m^{-2} s^{-1}).

4.1.3.4 Stomatal Resistance

Significantly higher stomatal resistance compared to unirrigated control was observed in the plants treated with fogger irrigation up to January, basin irrigation up to January and continuous irrigation (Table 15) among which maximum stomatal resistance was recorded in basin irrigation up to January (79.80 m^2 s mol $^{-1}$). The stomatal resistance was highest prior to flushing (76.02 m^2 s mol^{-1}) and it declined after flushing and recorded least at fruit set stage (29.93 m^2 s mol $^{-1}$). No definite trend among the treatments was observed in the different physiological stages analysed. Prior to flushing, significantly higher stomatal resistance was shown by two treatments, fogger irrigation and basin irrigation up to January while at flushing and flowering stage, all the treatments registered higher stomatal resistance. The maximum stomatal resistance of leaves was noticed in plants irrigated up to January by basin method (74.80 m^2 s mol $^{-1}$). At fruit set stage, continuously irrigated plants recorded highest stomatal resistance (84.10 m^2 s mol $^{-1}$), which was followed by the plants treated with fogger irrigation up to February (61.48 m^2 s mol^{-1}).

4.1.3.5 Leaf Surface Temperature

Among the various treatments applied, only basin irrigation up to January recorded significantly higher mean leaf surface temperature (34.11 $^{\circ}$ C) over control (32.87 $^{\circ}$ C) (Table 16). The surface temperature of leaves recorded maximum prior to flushing and showed a declining trend at flushing and flowering and fruit set stages. At pre flushing stage, maximum leaf temperature was noticed in plants irrigated up to January with basin method (37.90 $^{\circ}$ C). But at flushing and flowering and fruit set stages, treatments failed to show statistical superiority over unirrigated control.

Table 16. Effect of irrigation on leaf surface temperature (Degree celsius) at different physiological stages in black pepper var. Panniyur 1

Treatments	Before flushing	Flushing and flowering	Fruit set	Treatment mean
T_1	34.37^{bcd}	33.04^{def}	31.21^{fghij}	32.87^{B}
T_2	34.82^{bc}	33.38^{cde}	31.92^{efghij}	33.37^{AB}
T_3	34.93^{bc}	32.91^{defg}	31.26^{fghij}	33.03^{B}
T_4	34.87^{bc}	32.86^{defg}	31.30^{fghij}	33.01^{B}
T_5	32.76^{defgh}	31.16^{ghij}	31.01^{hij}	31.64^{C}
T_6	35.00^{bc}	32.88^{defg}	31.43^{fghij}	33.10^{B}
T_7	34.84^{bc}	33.42^{cde}	31.84^{efghij}	33.37^{AB}
T_8	31.78^{efghij}	30.50^{ij}	30.16^{j}	30.81^{C}
T_9	35.53^{b}	34.22^{bcd}	31.46^{fghij}	33.74^{AB}
T_{10}	37.90^{a}	32.66^{defgh}	31.78^{efghij}	34.11^{A}
T_{11}	35.35^{b}	32.88^{defg}	32.33^{efghi}	33.52^{AB}
Mean	34.74^{A}	32.72^{B}	31.43^{C}	32.96

Table 17. Effect of irrigation on transpiration rate (mol m^{-2} s^{-1}) at different physiological stages in black pepper var. Panniyur 1

Treatments	Before flushing	Flushing and flowering	Fruit set	Treatment mean
T_1	0.25^{klm}	1.08^{a}	0.60^{defg}	0.64^{B}
T_2	0.34^{ijklm}	0.36^{hijklm}	1.03^{ab}	0.57^{BCD}
T_3	0.44^{ghijk}	0.54^{efgh}	0.79^{cd}	0.59^{BC}
T_4	0.32^{ijklm}	0.62^{defg}	0.54^{efgh}	0.49^{DEF}
T_5	0.40^{hijkl}	0.65^{def}	0.49^{fghi}	0.52^{CDE}
T_6	0.24^{lm}	0.67^{def}	0.35^{hijklm}	0.42^{FG}
T_7	0.18^{m}	0.26^{jklm}	0.69^{de}	0.38^{G}
T_8	0.68^{def}	0.88^{bc}	0.76^{cd}	0.77^{A}
T_9	0.40^{hijkl}	0.67^{def}	0.69^{de}	0.59^{BC}
T_{10}	0.31^{ijklm}	0.40^{hijkl}	0.79^{cd}	0.50^{CDEF}
T_{11}	0.70^{cde}	0.45^{ghij}	0.26^{jklm}	0.47^{EFG}
Mean	0.39^{B}	0.60^{A}	0.64^{A}	0.54

The values with a common letter in the superscript did not differ significantly at 5 per cent level

T_1: No irrigation (Control)
T_2: Five litres of rocker sprayer irrigation up to March
T_3: Five litres of rocker sprayer irrigation up to February
T_4: Five litres of rocker sprayer irrigation up to January
T_5: Five litres of fogger irrigation up to March
T_6: Five litres of fogger irrigation up to February
T_7: Five litres of fogger irrigation up to January
T_8: Ten litres of basin irrigation up to March
T_9: Ten litres of basin irrigation up to February
T_{10}: Ten litres of basin irrigation up to January
T_{11}: Irrigation throughout summer period

4.1.3.6 Transpiration Rate

The mean transpiration rate was significantly higher only in the treatment plants irrigated up to March by basin method (0.77 mol m^{-2} s^{-1}) compared to unirrigated control plants (Table 17). The transpiration rate recorded higher at flushing and flowering and fruit set stages compared to pre flushing stage. Prior to flushing, the transpiration rate recorded maximum in the continuously irrigated plants (0.70 mol m^{-2} s^{-1}) followed by the plants treated with basin irrigation up to March (0.68 mol m^{-2} s^{-1}). But at flushing and flowering stage, the control plants recorded maximum transpiration rate (1.08 mol m^{-2} s^{-1}). At fruit set stage, the treatment rocker sprayer irrigation up to March (1.03 mol m^{-2} s^{-1}) was superior compared to other treatments.

4.1.3.7 Leaf Water Potential

The data on the effect of irrigation on leaf water potential of the treatment plants during the experimental period are furnished in Table 18. It indicated that leaf water potential measured before and after irrigation did not differ significantly among the treatments in all the months observed. However, it is clear from the data that, the water potential of pepper leaves decreased as the moisture stress and temperature increased with the advancement of summer season.

4.2 EXPERIMENT II: EFFECT OF HORMONE APPLICATION ON FLOWERING AND YIELD IN BLACK PEPPER

The results on the effect of different growth regulators on morphological, biochemical and physiological parameters are presented below under different heads:

4.2.1 Morphological Characters

4.2.1.1 Growth and Yield Characters of Lateral

The effect of growth regulators on various characters associated with the laterals of pepper vine is presented in Table 19.

Table 18. Effect of irrigation on leaf water potential (- M Pa) of black pepper var. Panniyur 1

Treatments	December		January		February		March		April	
	BI	AI	BI	AI	BI	AI	BI	AI	BI	AI
T_1	0.440[a]	0.367[a]	0.627[a]	0.593[a]	0.600[a]	0.610[a]	0.833[a]	0.830[a]	0.843[a]	0.847[a]
T_2	0.527[a]	0.373[a]	0.653[a]	0.480[a]	0.667[a]	0.620[a]	0.750[a]	0.800[a]	0.760[a]	0.767[a]
T_3	0.460[a]	0.280[a]	0.523[a]	0.433[a]	0.620[a]	0.590[a]	0.700[a]	0.680[a]	0.753[a]	0.747[a]
T_4	0.420[a]	0.340[a]	0.660[a]	0.663[a]	0.647[a]	0.653[a]	0.833[a]	0.810[a]	0.800[a]	0.770[a]
T_5	0.487[a]	0.420[a]	0.607[a]	0.547[a]	0.580[a]	0.540[a]	0.650[a]	0.670[a]	0.747[a]	0.750[a]
T_6	0.540[a]	0.480[a]	0.580[a]	0.500[a]	0.680[a]	0.690[a]	0.700[a]	0.690[a]	0.720[a]	0.727[a]
T_7	0.500[a]	0.453[a]	0.607[a]	0.640[a]	0.700[a]	0.707[a]	0.620[a]	0.640[a]	0.770[a]	0.760[a]
T_8	0.360[a]	0.307[a]	0.527[a]	0.440[a]	0.567[a]	0.487[a]	0.777[a]	0.800[a]	0.760[a]	0.760[a]
T_9	0.320[a]	0.280[a]	0.570[a]	0.450[a]	0.633[a]	0.650[a]	0.700[a]	0.770[a]	0.760[a]	0.807[a]
T_{10}	0.380[a]	0.380[a]	0.673[a]	0.680[a]	0.727[a]	0.733[a]	0.880[a]	0.860[a]	0.830[a]	0.813[a]
T_{11}	0.447[a]	0.333[a]	0.620[a]	0.420[a]	0.550[a]	0.460[a]	0.660[a]	0.540[a]	0.680[a]	0.553[a]
Mean	0.444	0.065	0.604	0.532	0.634	0.613	0.737	0.736	0.769	0.757

The values with a common letter in the superscript did not differ significantly at 5 per cent level

BI: Before irrigation AI: After irrigation

T_1: No irrigation (Control)
T_2: Five litres of rocker sprayer irrigation up to March
T_3: Five litres of rocker sprayer irrigation up to February
T_4: Five litres of rocker sprayer irrigation up to January
T_5: Five litres of fogger irrigation up to March
T_6: Five litres of fogger irrigation up to February
T_7: Five litres of fogger irrigation up to January
T_8: Ten litres of basin irrigation up to March
T_9: Ten litres of basin irrigation up to February
T_{10}: Ten litres of basin irrigation up to January
T_{11}: Irrigation throughout summer period

4.2.1.1.2 Number of Leaves per Lateral

The various growth regulator treatments tried, did not have significant influence on the number of leaves produced on the lateral. However, the plants treated with 100 ppm gibberellic acid (GA_3) produced the highest number of leaves (2.33). Least number of leaves was noticed in plants sprayed with water (1.65).

4.2.1.1.3 Leaf Area per Lateral

The treatments differed significantly with respect to leaf area produced per lateral. The growth regulator treatments viz., kinetin 200 ppm (293.83 cm^2), kinetin 150 ppm (293.48 cm^2), GA_3 100 ppm (288.15 cm^2) and benzyl amino purine (BAP) 250 ppm (281.22 cm^2) were on par with respect to the leaf area produced per lateral, but differed significantly from that of absolute control (201.41 cm^2) and water spray (194.95 cm^2).

4.2.1.1.4 Length of Lateral

It is evident from the data that there was significant increase in lateral length by the application of growth regulators. Maximum length of lateral was recorded in BAP 250 ppm (15.43 cm) that was on par with 50 and 100 ppm of GA_3 and 150 and 200 ppm of kinetin. Rest of the growth regulator treatments registered an equal effect with water spray and absolute control.

4.2.1.1.5 Internodal Thickness of Lateral

It is clear from the data presented that none of the growth regulator treatments could exert a significant effect on the internodal thickness of laterals. The maximum thickness was recorded by the plants sprayed with water (1.36 cm).

Table 19. Effect of growth regulators on growth and yield characters of black pepper var. Panniyur 2

Treatments	Number of leaves per lateral	Leaf area per lateral (cm^2)	Length of lateral (cm)	Internodal thickness of lateral (cm)	Angle of insertion of lateral (Degree)	Number of spike bearing laterals per $0.25m^2$	Number of spikes per lateral	Spike to leaf ratio per lateral
T_1	1.98^{a}	238.36^{ab}	11.49^{c}	1.20^{a}	80.13^{a}	10.00^{bcde}	1.00^{b}	0.54^{a}
T_2	1.95^{a}	257.76^{ab}	12.73^{abc}	1.28^{a}	83.00^{a}	13.75^{ab}	1.43^{b}	0.76^{a}
T_3	2.33^{a}	288.15^{a}	15.18^{ab}	1.26^{a}	75.75^{a}	12.25^{abcd}	1.23^{b}	0.57^{a}
T_4	1.83^{a}	237.73^{ab}	10.73^{c}	1.30^{a}	88.50^{a}	8.63^{de}	1.35^{b}	0.80^{a}
T_5	2.19^{a}	293.48^{a}	13.18^{abc}	1.30^{a}	84.75^{a}	12.50^{abc}	1.34^{b}	0.67^{a}
T_6	2.18^{a}	293.83^{a}	13.60^{abc}	1.27^{a}	83.75^{a}	11.00^{bcde}	1.23^{b}	0.58^{a}
T_7	1.98^{a}	260.88^{ab}	11.41^{c}	1.28^{a}	84.00^{a}	9.88^{cde}	1.18^{b}	0.61^{a}
T_8	2.18^{a}	281.22^{a}	15.43^{a}	1.34^{a}	80.00^{a}	14.75^{a}	1.83^{a}	0.84^{a}
T_9	1.88^{a}	233.14^{ab}	11.74^{bc}	1.21^{a}	74.50^{a}	15.25^{a}	1.35^{b}	0.73^{a}
T_{10}	1.95^{a}	241.16^{ab}	10.52^{c}	1.21^{a}	82.63^{a}	11.00^{bcde}	1.25^{b}	0.65^{a}
T_{11}	1.65^{a}	194.95^{b}	11.41^{c}	1.36^{a}	75.50^{a}	7.50^{e}	1.00^{b}	0.63^{a}
T_{12}	1.68^{a}	201.41^{b}	10.25^{c}	1.27^{a}	75.75^{a}	10.00^{bcde}	1.10^{b}	0.69^{a}
Mean	1.98	251.84	12.30	1.27	80.69	11.38	1.27	0.67

The values with a common letter in the superscript did not differ significantly at 5 per cent level

T_1: GA_3 25 ppm T_4: Kinetin 100 ppm T_7: BAP 200 ppm T_{10}: NAA 50 ppm
T_2: GA_3 50 ppm T_5: Kinetin 150 ppm T_8: BAP 250 ppm T_{11}: Water spray
T_3: GA_3 100 ppm T_6: Kinetin 200 ppm T_9: BAP 300 ppm T_{12}: No spray

4.2.1.1.6 Angle of Insertion of Lateral

None of the growth regulator treatments significantly influenced the angle of insertion of the laterals to the main stem. The angle of insertion ranged from 74.5 (300 ppm BAP) to 88.5 degrees (100 ppm kinetin).

4.2.1.1.7 Number of Spike Bearing Laterals per 0.25 m^2

The effect of growth regulators on the production of spike bearing laterals was found significant. The highest number of spike bearing lateral was noticed in plants sprayed with 300 ppm BAP (15.25), which was on par with the growth regulator treatments, 250 ppm BAP (14.75), 50 ppm GA_3 (13.75), 150 ppm kinetin (12.5) and 100 ppm GA_3 (12.25). The least number of spike bearing laterals was observed in the plants sprayed with water (7.5). The different levels of GA_3 were found on par with respect to the production of spike bearing laterals whereas, higher levels of kinetin and BAP produced more spike bearing laterals compared to the lowest level of concentration.

4.2.1.1.8 Number of Spikes per Lateral

Among the different growth regulators tried, BAP 250 ppm (1.83) alone increased the number of spikes produced on a lateral. Others were on par with control. The number of spikes produced per lateral was least in plants sprayed with water and 25 ppm GA_3.

4.2.1.1.9 Spike to Leaf Ratio per Lateral

The treatments did not differ significantly with respect to spike to leaf ratio per lateral. However, the plants treated with BAP 250 ppm recorded the highest spike to leaf ratio (0.84).

4.2.1.2 Spike Characters

The data on the effect of growth regulators on various characters related to spike are presented in Table 20.

4.2.1.2.1 Number of Berries per Spike at Fortnight After Anthesis

The data on the number of berries per spike a fortnight after anthesis did not vary significantly with respect to the growth regulator application. However, maximum number of berries per spike was noticed in the plants treated with 25 ppm GA_3 (61.18).

4.2.1.2.2 Number of Berries per Spike at Harvest

The application of growth regulators had no significant effect on the total number of berries per spike over control. However, among the growth regulators, 250 ppm BAP (62.58), 25 ppm GA_3 (61.68), 100 ppm kinetin (59.26) and 300 ppm BAP (59.23) resulted in higher number of berries.

4.2.1.2.3 Length of Spike

Significant increase in spike length over absolute control was obtained only with the application of 100 ppm GA_3. The control plants sprayed with water recorded minimum spike length (9.59 cm).

4.2.1.2.4 Spike Compactness

Growth regulators failed to exhibit superiority over control on compactness of spike. However, the spike compactness recorded was higher in plants sprayed with 250 ppm BAP (5.73 No. cm^{-1}) and 100 ppm kinetin (5.57 No. cm^{-1}).

4.2.1.3 Berry Characters

The data on the effect of growth regulators on weight and volume of 1000 green berries are presented in Table 20.

Table 20. Effect of growth regulators on spike and berry characters of black pepper var. Panniyur 2

Treatments	Number of berries per spike at fortnight after anthesis	Number of berries per spike at harvest	Length of spike (cm)	Spike compactness (No. cm $^{-1}$)	Weight of 1000 green berries (g)	Volume of 1000 green berries (cc)
T_1	61.18^{a}	61.68^{a}	11.66^{ab}	5.33 ^{abc}	143.50 ^{bc}	133.13^{a}
T_2	60.30^{a}	54.63^{bcd}	11.18 ^{abc}	4.90 ^{cd}	147.86 ^{bc}	135.00^{a}
T_3	56.98^{a}	56.15^{abcd}	12.53 ^{a}	4.55 ^{d}	160.83 ^{a}	148.75^{a}
T_4	58.83^{a}	59.26^{ab}	10.61 ^{bcd}	5.57 ^{a}	146.94 ^{bc}	130.75^{a}
T_5	58.23^{a}	56.83^{abc}	10.70 ^{bcd}	5.33 ^{abc}	151.00 ^{ab}	137.50^{a}
T_6	57.58^{a}	53.78^{bcd}	10.92 ^{bcd}	4.98 ^{bcd}	151.49 ^{ab}	138.13^{a}
T_7	54.10^{a}	49.45^{d}	9.96 ^{cd}	4.97 ^{bcd}	150.88 ^{ab}	133.75^{a}
T_8	53.85^{a}	62.58^{a}	11.01 ^{bc}	5.73 ^{a}	144.19 ^{bc}	131.25^{a}
T_9	51.93^{a}	59.23^{ab}	10.80 ^{bcd}	5.49 ^{ab}	149.03 ^{bc}	132.50^{a}
T_{10}	51.18^{a}	55.85^{abcd}	10.64 ^{bcd}	5.31 ^{abc}	144.39 ^{bc}	132.50^{a}
T_{11}	56.50^{a}	51.13^{cd}	9.59 ^{d}	5.31 ^{abc}	149.14 ^{bc}	135.00^{a}
T_{12}	57.73^{a}	58.53^{ab}	10.75 ^{bcd}	5.44 ^{ab}	139.55 ^{c}	127.50^{a}
Mean	56.53	56.59	10.86	5.24	148.23	134.65

The values with a common letter in the superscript did not differ significantly at 5 per cent level

T_1: GA_3 25 ppm T_4: Kinetin 100 ppm T_7: BAP 200 ppm T_{10}: NAA 50 ppm
T_2: GA_3 50 ppm T_5: Kinetin 150 ppm T_8: BAP 250 ppm T_{11}: Water spray
T_3: GA_3 100 ppmT_6: Kinetin 200 ppm T_9: BAP 300 ppm T_{12}: No spray

4.2.1.3.1 Weight of 1000 Green Berries

The weight of 1000 green berries was maximum in the treatment 100 ppm GA_3 (160.83 g), which was on par with 150 and 200 ppm of kinetin and 200 ppm BAP. The berry weight was minimum (139.55 g) in the absolute control. The highest level of GA_3 (100 ppm) was more effective in enhancing the weight of berries than other two levels applied. But in the case of kinetin and BAP, all concentrations were equal in effect with regard to 1000 green berry weight.

4.2.1.3.2 Volume of 1000 Green Berries

It was found that none of the levels of growth regulators could exert a significant effect on the volume of 1000 green berries. However, berry volume ranged from 127.50 cc (absolute control) to 148.75 cc (100 ppm GA_3) among the treatments.

4.2.1.4 Yield Characters

The data on the effect of growth regulators on yield of black pepper are furnished in Table 21.

4.2.1.4.1 Green Yield per Vine

The application of growth regulators significantly enhanced the green yield of pepper. Among the different growth regulator treatments tried, 100 ppm GA_3 recorded maximum green yield (5.69 kg) which was statistically on par with that of 50 ppm GA_3, all levels of kinetin and 250 ppm BAP. Rest of the treatments were on par with control. Among the different concentrations of kinetin, maximum yield was observed in plants treated with 150 ppm kinetin (5.40 kg).

4.2.1.4.2 Dry Recovery Percentage

The growth regulators could not increase dry recovery percentage of black pepper. The control treatment recorded maximum dry recovery percentage of berries

Table 21. Effect of growth regulators on yield of black pepper var. Panniyur 2

Treatments	Green yield per vine (kg)	Dry recovery percentage	Dry yield per vine (kg)
T_1	4.12^{bcde}	31.65^{cde}	1.31^{bcde}
T_2	5.11^{ab}	30.10^{f}	1.54^{abc}
T_3	5.69^{a}	30.67^{def}	1.74^{a}
T_4	5.17^{ab}	31.15^{def}	1.61^{ab}
T_5	5.40^{a}	30.08^{f}	1.62^{ab}
T_6	4.49^{abcd}	30.51^{ef}	1.36^{abcd}
T_7	3.25^{de}	32.88^{abc}	1.07^{de}
T_8	4.57^{abc}	31.97^{bcd}	1.46^{abc}
T_9	3.66^{cde}	32.64^{abc}	1.19^{cde}
T_{10}	3.15^{e}	30.97^{def}	0.98^{e}
T_{11}	3.65^{cde}	33.36^{a}	1.21^{cde}
T_{12}	3.58^{cde}	33.05^{ab}	1.16^{cde}
Mean	4.32	31.59	1.36

The values with a common letter in the superscript did not differ significantly at 5 per cent level

T_1: GA_3 25 ppm T_4: Kinetin 100 ppm T_7: BAP 200 ppm T_{10}: NAA 50 ppm
T_2: GA_3 50 ppm T_5: Kinetin 150 ppm T_8: BAP 250 ppm T_{11}: Water spray
T_3: GA_3 100 ppm T_6: Kinetin 200 ppm T_9: BAP 300 ppm T_{12}: No spray

(33.36 per cent). The dry weight percentage was on par with the growth regulator treatments, 200 ppm (32.88 per cent) and 300 ppm (32.64 per cent) of BAP. The 150 ppm kinetin recorded minimum dry recovery percentage (30.08 per cent).

4.2.1.4.3 Dry Yield per Vine

The application of growth regulators resulted in significant increase in the dry yield per vine. The plants treated with 100 ppm GA_3 registered maximum yield (1.74 kg), which was on par with the yield obtained with the treatments 100, 150 and 200 ppm of kinetin, 50 ppm GA_3 and 250 ppm BAP. Rest of the treatments were on par with the control treatments. The least dry weight was noticed in plants sprayed with NAA 50 ppm (0.98 kg).

4.2.2 Biochemical Characters

The various biochemical parameters were analyzed after the application of growth regulators at flushing and flowering and fruit set stages. The results obtained are presented below:

4.2.2.1 Leaf Chlorophyll

The application of growth regulators enhanced the leaf chlorophyll content (Table 22). The plants treated with 100 ppm GA_3, 250 and 300 ppm of BAP significantly increased the chlorophyll 'a' content compared to control plants whereas, chlorophyll 'b' and total chlorophyll content of the leaves were enhanced only by the application of 100 ppm GA_3. All the chlorophyll parameters recorded maximum in plants treated with 100 ppm GA_3 (1.77 mg g^{-1}, 0.43 mg g^{-1}, and 2.2 mg g^{-1} respectively for chlorophyll 'a', 'b' and total chlorophyll content).

The chlorophyll 'a', 'b' and total chlorophyll of leaves increased at fruit set stage compared to that of flushing and flowering stage. All levels of GA_3, 100 and 150 ppm of kinetin, 200 and 250 ppm of BAP recorded significantly higher chlorophyll 'a' content while chlorophyll 'b' was high with the treatments 100 ppm GA_3, all levels of

Table 22. Effect of growth regulators on chlorophyll content of leaves at different physiological stages in black pepper var. Panniyur 2

Treatments	Chlorophyll 'a' (mg g^{-1})			Chlorophyll 'b' (mg g^{-1})			Total chlorophyll (mg g^{-1})		
	Flushing and flowering	Fruit set	Treatment mean	Flushing and flowering	Fruit set	Treatment mean	Flushing and flowering	Fruit set	Treatment mean
T_1	1.36^{J}	1.56^{fg}	1.46^{GH}	0.33^{ijkl}	0.37^{defghi}	0.35^{DE}	1.69^{ij}	1.93^{f}	1.81^{E}
T_2	1.45^{i}	1.77^{e}	1.61^{EF}	0.34^{hijk}	0.41^{bcdef}	0.37^{BCD}	1.79^{ghi}	2.17^{e}	1.98^{D}
T_3	1.45^{i}	2.09^{b}	1.77^{A}	0.36^{fghij}	0.50^{a}	0.43^{A}	1.81^{gh}	2.59^{a}	2.20^{A}
T_4	1.35^{J}	1.97^{c}	1.66^{CDE}	0.35^{ghij}	0.43^{bc}	0.39^{BC}	1.69^{ij}	2.40^{cd}	2.04^{BCD}
T_5	1.47^{hi}	1.89^{d}	1.68^{BCD}	0.39^{cdefgh}	0.41^{bcde}	0.40^{AB}	1.86^{fg}	2.29^{d}	2.08^{BC}
T_6	1.16^{kl}	1.72^{e}	1.44^{H}	0.35^{ghij}	0.42^{bcd}	0.38^{BCD}	1.51^{k}	2.14^{e}	1.83^{E}
T_7	1.31^{J}	1.70^{e}	1.51^{G}	0.33^{ijkl}	0.38^{defghi}	0.35^{CDE}	1.64^{j}	2.08^{e}	1.86^{E}
T_8	1.53^{gh}	1.93^{cd}	1.73^{AB}	0.35^{ghij}	0.40^{cdefg}	0.37^{BCD}	1.88^{fg}	2.32^{d}	2.10^{B}
T_9	1.21^{k}	2.19^{a}	1.70^{BC}	0.31^{jklm}	0.36^{efghij}	0.34^{E}	1.52^{k}	2.55^{ab}	2.03^{BCD}
T_{10}	1.17^{kl}	1.61^{e}	1.39^{I}	0.26^{mn}	0.24^{n}	0.25^{F}	1.43^{k}	1.84^{fgh}	1.64^{F}
T_{11}	1.13^{l}	2.07^{b}	1.60^{F}	0.29^{klm}	0.41^{bcde}	0.35^{DE}	1.74^{hij}	2.47^{bc}	2.11^{B}
T_{12}	1.20^{kl}	2.06^{b}	1.63^{DEF}	0.28^{lmn}	0.46^{ab}	0.37^{BCDE}	1.48^{k}	2.51^{abc}	2.00^{CD}
Mean	1.32^{B}	1.88^{A}	1.60	0.33^{B}	0.40^{A}	0.36	1.67^{B}	2.27^{A}	1.97

The values with a common letter in the superscript did not differ significantly at 5 per cent level

T_1: GA_3 25 ppm T_4: Kinetin 100 ppm T_7: BAP 200 ppm T_{10}: NAA 50 ppm
T_2: GA_3 50 ppm T_5: Kinetin 150 ppm T_8: BAP 250 ppm T_{11}: Water spray
T_3: GA_3 100 ppm T_6: Kinetin 200 ppm T_9: BAP 300 ppm T_{12}: No spray

kinetin and 250 ppm BAP at flushing and flowering stage. In the case of total chlorophyll, only 150 ppm kinetin and 250 ppm BAP registered significantly higher values over control plants. At fruit set stage, application of only 300 ppm BAP significantly enhanced the chlorophyll 'a' over control plants, while none of the growth regulators could enhance the chlorophyll 'b' and total chlorophyll content of leaves.

4.2.2.2 Total Phenol

Among the growth regulators tried, only 200 ppm kinetin and 300 ppm BAP registered high total phenol content (7.33 mg g^{-1} and 6.58 mg g^{-1} respectively)(Table 23). Rest of the growth regulators reduced the total phenol content of leaves compared to control plants. The higher content of phenol was observed at flushing and flowering (6.22 mg g^{-1}) and it reduced after flowering at fruit set stage (5.74 mg g^{-1}). At flushing and flowering stage, 200 ppm kinetin alone increased the phenol content of pepper leaves. But at fruit set stage, the growth regulator treatments except 100 ppm GA_3, 100 ppm kinetin, 250 ppm BAP enhanced the total phenol content significantly.

4.2.2.2 Polyphenol Oxidase Activity

The PPO activity recorded significant increase only in plants treated with 100 ppm kinetin (0.387) (Table 24). Reduced activity of PPO was noticed in plants applied with rest of the growth regulator treatments. No remarkable variation in the activity of PPO was observed between flushing and flowering and fruit set stages. At flushing and flowering, 50 ppm NAA, lowest level of kinetin and BAP and highest level of GA_3 enhanced the PPO activity with maximum total activity in the plants treated with 100 ppm kinetin (0.435). At fruit set, all the growth regulator treatments applied, reduced PPO activity significantly compared to control plants.

4.2.2.4 Peroxidase Activity

It is clear from the data (Table 25) that application of growth regulators both BAP (200, 250, and 300 ppm) and GA_3 (100 ppm) significantly enhanced the peroxidase activity of leaves compared to untreated plants. Maximum activity was

Table 23. Effect of growth regulators on total phenol content (mg g^{-1}) of leaves at different physiological stages in black pepper var. Panniyur 2

Treatments	Flushing and flowering	Fruit set	Treatment mean
T_1	6.02^{fg}	5.85^{gh}	5.93^{CD}
T_2	5.51^{hi}	6.10^{fg}	5.81^{D}
T_3	5.03j	5.51^{hi}	5.27^{E}
T_4	5.85^{gh}	4.95^{J}	5.40^{E}
T_5	5.51^{hi}	6.75^{de}	6.13^{CD}
T_6	7.59^{a}	7.08^{bcd}	7.33^{A}
T_7	4.17^{k}	6.00^{fg}	5.09^{E}
T_8	7.42^{ab}	4.28^{k}	5.85^{D}
T_9	7.28^{abc}	5.88^{gh}	6.58^{B}
T_{10}	6.37^{ef}	5.86^{gh}	6.12^{CD}
T_{11}	6.88^{cd}	5.32^{ij}	6.10^{CD}
T_{12}	7.04^{bcd}	5.36^{ij}	6.20^{C}
Mean	6.22^{A}	5.74^{B}	5.98

Table 24. Effect of growth regulators on total polyphenol oxidase activity (OD value) of leaves at different physiological stages in black pepper var. Panniyur 2

Treatments	Flushing and flowering	Fruit set	Treatment mean
T_1	0.294^{ghi}	0.206^{m}	0.250^{FG}
T_2	0.265^{jk}	0.258^{k}	0.261^{F}
T_3	0.332^{e}	0.351^{cd}	0.341^{B}
T_4	0.435^{a}	0.338^{de}	0.387^{A}
T_5	0.309^{fg}	0.313^{f}	0.311^{C}
T_6	0.280^{ij}	0.289^{hi}	0.284^{E}
T_7	0.344^{cde}	0.359^{c}	0.351^{B}
T_8	0.258^{k}	0.233^{l}	0.245^{G}
T_9	0.283^{i}	0.315^{f}	0.299^{D}
T_{10}	0.402^{b}	0.301^{fgh}	0.351^{B}
T_{11}	0.304^{fgh}	0.402^{b}	0.353^{B}
T_{12}	0.305^{fgh}	0.387^{b}	0.346^{B}
Mean	0.318^{A}	0.313^{A}	0.315

The values with a common letter in the superscript did not differ significantly at 5 per cent level

T_1: GA_3 25 ppm T_4: Kinetin 100 ppm T_7: BAP 200 ppm T_{10}: NAA 50 ppm
T_2: GA_3 50 ppm T_5: Kinetin 150 ppm T_8: BAP 250 ppm T_{11}: Water spray
T_3: GA_3 100 ppm T_6: Kinetin 200 ppm T_9: BAP 300 ppm T_{12}: No spray

noticed in plants sprayed with 250 ppm BAP (116.35 units litre $^{-1}$). Compared to flowering stage, fruit set stage recorded higher activity of peroxidase. At flowering stage, 250 ppm BAP alone enhanced the peroxidase activity while at fruit set stage, all levels of BAP and 100 ppm GA_3 enhanced the activity of peroxidase.

4.2.2.5 Nitrate Reductase Activity

The growth regulators except BAP enhanced the nitrate reductase activity of pepper leaves (Table 26). The maximum activity was observed in the plants treated with 50 ppm NAA (1.10 m mol g fresh weight $^{-1}$ hour $^{-1}$), which was on par with 100 and 150 ppm of kinetin and 25 ppm GA_3. The activity was maximum in NAA treatment at flowering stage. At fruit set, the activity of NAA treated plants became statistically on par with that of untreated plants and 100 ppm kinetin exhibited highest NRA. The activity of nitrate reductase was found to be higher at flushing and flowering (0.99 m mol g fresh weight $^{-1}$ hour^{-1}) compared to that of fruit set stage (0.69 m mol g fresh weight $^{-1}$ hour^{-1}).

4.2.2.6 C:N Ratio

The data on the effect of growth regulators on total C, total N and C:N ratio of pepper leaves at flushing and flowering and fruit set stages are presented in Table 27.

4.2.2.6.1 Total Carbon

The data indicated that the two higher levels of GA_3 and BAP, two lower levels of kinetin and 50 ppm NAA enhanced the total C content of black pepper leaves. The maximum C content was noticed in plants treated with 100 ppm GA_3 (52.26 per cent). The total C content recorded higher value at flushing and flowering stage (51.74 per cent) and it considerably reduced after fruit set (44.89 per cent). At flowering, maximum content was exhibited by the plants sprayed with 100 ppm GA_3 (56.7 per cent). Total C content increased with increased concentration of GA_3, while it recorded highest in the medium concentration of kinetin (150 ppm) and BAP (250 ppm). The 50 ppm NAA also significantly enhanced the total C content. At fruit set stage, the

Table 25. Effect of growth regulators on peroxidase activity (Units litre $^{-1}$) of leaves at different physiological stages in black pepper var. Panniyur 2

Treatments	Flushing and flowering	Fruit set	Treatment mean
T_1	33.81^{ij}	37.56^{hi}	35.69^{H}
T_2	25.75^{k}	57.40^{f}	41.58^{G}
T_3	30.78^{jk}	117.09^{b}	73.94^{D}
T_4	24.88^{k}	62.84^{ef}	43.86^{G}
T_5	47.76^{g}	62.84^{ef}	55.30^{F}
T_6	43.92^{gh}	78.12^{d}	61.02^{E}
T_7	33.18^{ij}	129.94^{a}	81.56^{C}
T_8	102.76^{c}	129.94^{a}	116.35^{A}
T_9	45.95^{g}	129.94^{a}	87.95^{B}
T_{10}	39.03^{hi}	82.26^{d}	60.65^{E}
T_{11}	47.71^{g}	67.07^{e}	57.39^{EF}
T_{12}	41.47^{gh}	80.27^{d}	60.81^{E}
Mean	43.08^{B}	86.27^{A}	64.68

Table 26. Effect of growth regulators on nitrate reductase activity (m mol g fresh weight $^{-1}$ hour $^{-1}$) of leaves at different physiological stages in black pepper var. Panniyur 2

Treatments	Flushing and flowering	Fruit set	Treatment mean
T_1	1.12^{bcd}	0.97^{ef}	1.05^{AB}
T_2	1.20^{b}	0.64^{hi}	0.92^{D}
T_3	1.11^{bcd}	0.76^{gh}	0.93^{CD}
T_4	1.12^{bcd}	1.04^{de}	1.08^{A}
T_5	1.07^{cde}	0.96^{ef}	1.02^{ABC}
T_6	1.18^{bc}	0.76^{gh}	0.97^{BCD}
T_7	0.57^{ij}	0.50^{j}	0.54^{F}
T_8	0.58^{ij}	0.51^{ij}	0.55^{F}
T_9	0.54^{ij}	0.54^{ij}	0.54^{F}
T_{10}	1.66^{a}	0.54^{ij}	1.10^{A}
T_{11}	0.91^{f}	0.58^{ij}	0.75^{E}
T_{12}	0.89^{fg}	0.51^{j}	0.69^{E}
Mean	0.99^{A}	0.69^{B}	0.84

The values with a common letter in the superscript did not differ significantly at 5 per cent level

T_1: GA_3 25 ppm T_4: Kinetin 100 ppm T_7: BAP 200 ppm T_{10}: NAA 50 ppm
T_2: GA_3 50 ppm T_5: Kinetin 150 ppm T_8: BAP 250 ppm T_{11}: Water spray
T_3: GA_3 100 ppm T_6: Kinetin 200 ppm T_9: BAP 300 ppm T_{12}: No spray

depletion of C was more in GA_3, BAP (except 300 ppm) and NAA treated plants. The 100 and 150 ppm of kinetin and 300 ppm BAP registered significantly higher total C content over control plants.

4.2.2.6.2 Total Nitrogen

The application of growth regulators significantly enhanced the foliar N content of black pepper. All levels of GA_3, the two lower levels of kinetin and higher levels of BAP and 50 ppm NAA enhanced the overall N content. In all the growth regulators, the medium concentration registered highest N content. The level of foliar N was higher at fruit set stage (2.34 per cent) than at flushing and flowering (2.22. per cent). At flowering all the growth regulator treatments except 200 ppm of kinetin and BAP enhanced the N content of leaves. The maximum content was noticed in plants treated with 50 ppm GA_3 (2.80 per cent). But at fruit set stage, only 150 ppm kinetin and 250 ppm BAP maintained their superiority over untreated control plants.

4.2.2.6.3 C:N Ratio

Among the different growth regulator treatments, only 100 ppm of GA_3 and kinetin recorded significantly higher C:N ratio (22.84 and 22.86 respectively) over untreated plants. The C:N ratio was found higher at flushing and flowering stage (23.45 per cent) and it reduced at fruit set stage (19.23 per cent). At flowering stage, none of the growth regulator treatments could exert significant influence on the C:N ratio of pepper leaves. However, maximum ratio of C:N was noticed in plants treated with 100 ppm GA_3 (25.54). But at fruit set stage, 50 ppm GA_3, 100 ppm kinetin and 300 ppm BAP enhanced the ratio between total C and total N of pepper leaves.

4.2.2.7 Quality Parameters

The data on the effect of growth regulators on various quality parameters viz., essential oil, oleoresin and piperine content of berries are presented in Table 28.

Table 27. Effect of growth regulators on C:N ratio of leaves at different physiological stages in black pepper var. Panniyur 2

Treatments	Total carbon (%)			Total nitrogen (%)			C:N ratio		
	Flushing and flowering	Fruit set	Treatment mean	Flushing and flowering	Fruit set	Treatment mean	Flushing and flowering	Fruit set	Treatment mean
T_1	51.03^{def}	39.64^{kl}	45.34^{CD}	2.33^{fg}	2.24^{h}	2.28^{BC}	21.93^{efg}	17.69^{mn}	19.81^{F}
T_2	56.13^{ab}	47.22^{ghi}	51.68^{AB}	2.80^{a}	2.20^{h}	2.50^{A}	20.05^{hijk}	21.49^{efgh}	20.77^{CDEF}
T_3	56.70^{a}	47.81^{fghi}	52.26^{A}	2.22^{h}	2.38^{ef}	2.30^{B}	25.54^{a}	20.13^{hijk}	22.84^{A}
T_4	51.60^{de}	50.72^{def}	51.16^{AB}	2.11^{i}	2.39^{e}	2.25^{CD}	24.49^{ab}	21.22^{fghi}	22.86^{A}
T_5	53.30^{bcd}	48.88^{efgh}	51.09^{AB}	2.54^{c}	2.45^{d}	2.49^{A}	21.01^{ghij}	19.96^{ijk}	20.48^{EF}
T_6	49.33^{efgh}	36.91^{l}	43.12^{D}	2.03^{jk}	2.04^{j}	2.03^{G}	24.34^{ab}	18.09^{mn}	21.21^{CDE}
T_7	49.33^{efgh}	39.93^{kl}	44.63^{CD}	1.96^{l}	2.30^{g}	2.13^{F}	25.21^{ab}	17.39^{mn}	21.30^{CDE}
T_8	55.57^{abc}	44.75^{ij}	50.16^{AB}	2.32^{g}	2.62^{b}	2.47^{A}	23.96^{bcd}	17.10^{n}	20.53^{DEF}
T_9	50.46^{defg}	48.39^{efgh}	49.43^{B}	2.23^{h}	2.33^{fg}	2.28^{BC}	22.66^{def}	20.77^{ghij}	21.72^{BC}
T_{10}	52.73^{cd}	46.64^{hi}	49.69^{B}	2.10^{i}	2.38^{ef}	2.24^{D}	25.12^{ab}	19.63^{jkl}	22.38^{AB}
T_{11}	46.49^{hi}	42.88^{jk}	44.69^{CD}	2.04^{jk}	2.33^{fg}	2.18^{E}	22.83^{cde}	18.42^{lmn}	20.62^{DEF}
T_{12}	48.20^{fgh}	44.89^{ij}	46.55^{C}	1.99^{kl}	2.39^{e}	2.19^{E}	24.26^{abc}	18.84^{klm}	21.55^{BCD}
Mean	51.74^{A}	44.89^{B}	48.31	2.22^{B}	2.34^{A}	2.28	23.45^{A}	19.23^{B}	21.34

The values with a common letter in the superscript did not differ significantly at 5 per cent level

T_1: GA_3 25 ppm T_4: Kinetin 100 ppm T_7: BAP 200 ppm T_{10}: NAA 50 ppm
T_2: GA_3 50 ppm T_5: Kinetin 150 ppm T_8: BAP 250 ppm T_{11}: Water spray
T_3: GA_3 100 ppm T_6: Kinetin 200 ppm T_9: BAP 300 ppm T_{12}: No spray

4.2.2.7.1 Essential Oil

The analysis of data indicated that only 150 ppm kinetin significantly improved the essential oil content (3.5 per cent) compared to water spray and absolute control. The oil content was least in plants treated with 50 ppm NAA (1.5 per cent).

4.2.2.7.2 Oleoresin

None of the growth regulators could enhance the oleoresin content of pepper berries significantly over control plants. However, higher oleoresin content was noticed in growth regulator treatments, 200 ppm BAP (13.29 per cent) and 50 ppm GA_3 (13.19 per cent).

4.2.2.7.3 Piperine

The various growth regulator treatments tried, failed to have a significant influence on the piperine content of berries. However maximum percentage of piperine was noticed in plants treated with 100 ppm kinetin (6.43 per cent) and least in plants treated with water (4.99 per cent).

4.2.3 Physiological Characters

The physiological parameters were observed after the application of growth regulators, at flushing and flowering and fruit set stages and the results obtained are presented below:

4.2.3.1 Photosynthetic Rate

The foliar application of growth regulators significantly increased the leaf photosynthetic rate compared to untreated plants (Table 29). The maximum rate was observed in plants treated with 100 ppm GA_3 (3.49 μ mol m^{-2} s^{-1}). The photosynthetic rate showed an increasing trend with increased concentration of GA_3, while in the case of kinetin and BAP, medium concentration of the chemicals (150 ppm kinetin and 250

Table 28. Effect of growth regulators on quality of black pepper var. Panniyur 2

Treatments	Essential oil (%)	Oleoresin (%)	Piperine (%)
T_1	1.75^{cde}	11.55^{bc}	5.30^{a}
T_2	1.88^{cde}	13.19^{a}	6.03^{a}
T_3	2.00^{cde}	12.16^{ab}	5.81^{a}
T_4	1.63^{de}	13.01^{ab}	6.43^{a}
T_5	3.50^{a}	11.78^{ab}	5.70^{a}
T_6	2.25^{bc}	12.34^{ab}	5.22^{a}
T_7	1.88^{cdc}	13.29^{a}	5.37^{a}
T_8	2.00^{cde}	10.04^{c}	5.68^{a}
T_9	2.08^{cd}	12.21^{ab}	5.91^{a}
T_{10}	1.50^{e}	12.65^{ab}	5.90^{a}
T_{11}	2.63^{b}	13.01^{ab}	4.99^{a}
T_{12}	2.13^{bcd}	12.07^{ab}	5.79^{a}
Mean	2.10	12.28	5.68

The values with a common letter in the superscript did not differ significantly at 5 per cent level

T_1: GA_3 25 ppm T_4: Kinetin 100 ppm T_7: BAP 200 ppm T_{10}: NAA 50 ppm
T_2: GA_3 50 ppm T_5: Kinetin 150 ppm T_8: BAP 250 ppm T_{11}: Water spray
T_3: GA_3 100 ppm T_6: Kinetin 200 ppm T_9: BAP 300 ppm T_{12}: No spray

ppm BAP) recorded maximum photosynthetic rate. Considerable variation in photosynthetic rate was not observed between stages. Soon after the application (at flushing and flowering), the maximum photosynthetic rate was observed in plants treated with 100 ppm GA_3 (5.34 μ mol m^{-2} s^{-1}). But at fruit set stage, the rate of photosynthesis in plants treated with 100 ppm GA_3 became statistically on par with that of 50 ppm. In the case of kinetin and BAP, medium concentration resulted in highest photosynthetic rate both at flushing and flowering and fruit set stages. The 150 ppm kinetin was found as the superior treatment with regard the photosynthetic rate of leaves at fruit set.

4.2.3.2 Photosynthetically Active Radiation

The photosynthetically active radiation intercepted by leaves of the experimental plants registered significant difference between them (Table 30). The mean PAR received was highest in plants treated with 150 ppm kinetin (256.67 μ mol m^{-2} s^{-1}). The PAR intercepted during flushing and flowering and fruit set stages did not record any significant variation. At flushing and flowering stage, the PAR ranged from 101.33 (BAP 250 ppm) to 282.00 (100 ppm kinetin) while at fruit set, it ranged from 71.67 (250 ppm BAP) to 384.00 (150 ppm kinetin).

4.2.3.3 Stomatal Conductance

From the data (Table 31), it is clear that growth regulators recorded significant effect on the average stomatal conductance of the treatment plants. The plants treated with 100 ppm GA_3, 150 ppm kinetin and 250 ppm BAP recorded significantly high stomatal conductance compared to untreated plants. The stomatal conductance increased with increased concentration of GA_3, but BAP and kinetin recorded high stomatal conductance with medium level of concentration. The stomatal conductance did not record significant difference among the treatment plants both at flushing and flowering and fruit set stages. However, maximum stomatal conductance was noticed in plants treated with 250 ppm BAP at both stages (0.107 mol m^{-2} s^{-1} and 0.103 mol m^{-2} s^{-1} respectively).

Table 29. Effect of growth regulators on photosynthetic rate (μ mol $m^{-2} s^{-1}$) at different physiological stages in black pepper var. Panniyur 2

Treatments	Flushing and flowering	Fruit set	Treatment mean
T_1	1.36^{ijklm}	2.93^{cd}	2.15^{DE}
T_2	2.67^{cde}	2.11^{efgh}	2.39^{CD}
T_3	5.34^{a}	$1.64^{fghijkl}$	3.49^{A}
T_4	1.48^{hijklm}	3.81^{b}	2.65^{BC}
T_5	2.30^{def}	3.90^{b}	3.10^{AB}
T_6	1.48^{hijklm}	1.53^{ghijkl}	1.50^{FG}
T_7	1.93^{fghi}	1.74^{fghijk}	1.83^{EF}
T_8	2.20^{efg}	3.31^{bc}	2.76^{BC}
T_9	1.82^{fghij}	1.45^{hijklm}	1.63^{FG}
T_{10}	2.91^{cd}	2.24^{def}	2.57^{CD}
T_{11}	1.02^{lm}	0.82^{m}	0.92^{H}
T_{12}	1.12^{klm}	1.18^{jklm}	1.15^{GH}
Mean	2.14^{A}	2.22^{A}	2.18

Table 30. Effect of growth regulators on photosynthetically active radiation (μ mol $m^{-2} s^{-1}$) at different physiological stages in black pepper var. Panniyur 2

Treatments	Flushing and flowering	Fruit set	Treatment mean
T_1	189.33^{cdef}	130.67^{ghij}	160.00^{BCD}
T_2	271.00^{b}	207.33^{cde}	239.17^{A}
T_3	103.33^{ijk}	157.00^{fgh}	130.17^{DE}
T_4	282.00^{b}	211.33^{cd}	246.67^{A}
T_5	129.33^{hij}	384.00^{a}	256.67^{A}
T_6	160.00^{fgh}	128.33^{hij}	144.17^{DE}
T_7	217.67^{c}	149.00^{fgh}	183.33^{B}
T_8	101.33^{ijk}	71.67^{k}	86.50^{F}
T_9	280.33^{b}	185.00^{cdef}	232.67^{A}
T_{10}	179.33^{cdef}	173.33^{defg}	176.33^{BC}
T_{11}	135.33^{ghi}	158.00^{fgh}	146.67^{CDE}
T_{12}	166.00^{efgh}	87.33^{jk}	126.67^{E}
Mean	184.58^{A}	170.25^{A}	177.42

The values with a common letter in the superscript did not differ significantly at 5 per cent level

T_1: GA_3 25 ppm T_4: Kinetin 100 ppm T_7: BAP 200 ppm T_{10}: NAA 50 ppm
T_2: GA_3 50 ppm T_5: Kinetin 150 ppm T_8: BAP 250 ppm T_{11}: Water spray
T_3: GA_3 100 ppm T_6: Kinetin 200 ppm T_9: BAP 300 ppm T_{12}: No spray

4.2.3.4 Stomatal Resistance

The growth regulators except GA_3 treatments and 150 ppm kinetin significantly enhanced the stomatal resistance over untreated plants (Table 32). The maximum stomatal resistance was noticed in plants treated with 200 ppm kinetin (53.81 m^2 s mol $^{-1}$). The highest concentration of both kinetin and BAP resulted in higher stomatal resistance. Compared to lower levels, the stomatal resistance was found low in plants treated with 150 ppm kinetin. No considerable variation was observed in the stomatal resistance recorded for flowering and fruit set stages. At flowering, stomatal resistance was maximum in plants treated with 300 ppm BAP (61.58 m^2 s mol $^{-1}$) whereas at fruit set stage, application of 200 ppm kinetin resulted in the highest stomatal resistance (61.06 m^2 s mol $^{-1}$).

4.2.3.5 Leaf Surface Temperature

Growth regulator treatments could not increase the leaf surface temperature significantly over untreated plants (Table 33). However, maximum leaf temperature was noticed in plants treated with 25 ppm GA_3 (34.43 ^{0} C). The temperature of leaves did not show any remarkable variation between stages. At flowering (soon after spray) the plants treated with 25 ppm GA_3 and 300 ppm BAP exhibited significantly higher leaf temperature. But at fruit set stage, all the growth regulator treatments failed to enhance the leaf temperature over untreated plants.

4.2.3.6 Transpiration Rate

The data presented in Table 34 indicated that application of growth regulators enhanced the transpiration rate of pepper leaves significantly. The mean transpiration was highest in plants treated with 250 ppm BAP (1.11 mol m^{-2} s^{-1}). All levels of GA_3 significantly enhanced the transpiration rate with maximum in plants treated with 100 ppm GA_3 (0.81 mol m^{-2} s^{-1}), while in the case of kinetin and BAP, medium level recorded maximum transpiration. Same trend was observed at flushing and flowering and also at fruit set stages. The stages did not record any significant variation in the mean transpiration rate of treatment plants.

Table 31. Effect of growth regulators on stomatal conductance (mol m^{-2} s^{-1}) at different physiological stages in black pepper var. Panniyur 2

Treatments	Flushing and flowering	Fruit set	Treatment mean
T_1	0.033^{a} (0.730)	0.063^{a} (0.750)	0.0480^{CD} (0.740)
T_2	0.040^{a} (0.735)	0.063^{a} (0.750)	0.052^{BCD} (0.743)
T_3	0.090^{a} (0.767)	0.040^{a} (0.735)	0.065^{BC} (0.751)
T_4	0.023^{a} (0.723)	0.073^{a} (0.757)	0.048^{CD} (0.740)
T_5	0.067^{a} (0.753)	0.070^{a} (0.755)	0.068^{B} (0.754)
T_6	0.020^{a} (0.721)	0.040^{a} (0.735)	0.030^{EF} (0.728)
T_7	0.067^{a} (0.752)	0.037^{a} (0.732)	0.052^{BCD} (0.742)
T_8	0.107^{a} (0.779)	0.103^{a} (0.776)	0.105^{A} (0.777)
T_9	0.040^{a} (0.735)	0.073^{a} (0.757)	0.057^{BCD} (0.746)
T_{10}	0.020^{a} (0.721)	0.020^{a} (0.721)	0.020^{F} (0.721)
T_{11}	0.053^{a} (0.744)	0.040^{a} (0.735)	0.047^{DE} (0.739)
T_{12}	0.057^{a} (0.746)	0.027^{a} (0.726)	0.042^{DE} (0.736)
Mean	0.051^{A} (0.742)	0.054^{A} (0.744)	0.053 (0.743)

Table 32. Effect of growth regulators on stomatal resistance (m^2 s mol^{-1}) at different physiological stages in black pepper var. Panniyur 2

Treatments	Flushing and flowering	Fruit set	Treatment mean
T_1	31.72^{fg}	18.90^{ij}	25.31^{E}
T_2	16.51^{ij}	19.08^{ij}	17.79^{FG}
T_3	17.72^{ij}	36.16^{efg}	26.94^{DE}
T_4	51.55^{bc}	19.15^{ij}	35.35^{C}
T_5	16.82^{ij}	10.55^{j}	13.68^{G}
T_6	46.56^{cd}	61.06^{a}	53.81^{A}
T_7	30.82^{g}	34.65^{fg}	32.73^{CD}
T_8	59.09^{ab}	10.84^{j}	34.96^{C}
T_9	61.58^{a}	40.27^{def}	50.93^{AB}
T_{10}	44.06^{cde}	50.99^{bc}	47.52^{B}
T_{11}	21.72^{hi}	29.75^{gh}	25.73^{E}
T_{12}	18.39^{ij}	28.20^{gh}	23.29^{EF}
Mean	34.71^{A}	29.96^{A}	32.34

The values with a common letter in the superscript did not differ significantly at 5 per cent level

T_1: GA_3 25 ppm T_4: Kinetin 100 ppm T_7: BAP 200 ppm T_{10}: NAA 50 ppm
T_2: GA_3 50 ppm T_5: Kinetin 150 ppm T_8: BAP 250 ppm T_{11}: Water spray
T_3: GA_3 100 ppm T_6: Kinetin 200 ppm T_9: BAP 300 ppm T_{12}: No spray

Table 33. Effect of growth regulators on leaf surface temperature (Degree celsius) at different physiological stages in black pepper var. Panniyur 2

Treatments	Flushing and flowering	Fruit set	Treatment mean
T_1	35.44^{a}	33.42^{cde}	34.43^{A}
T_2	33.55^{bcde}	32.58^{cde}	33.07^{B}
T_3	33.19^{cde}	32.59^{cde}	32.89^{BC}
T_4	33.86^{abcde}	32.85^{cde}	33.35^{AB}
T_5	34.02^{abcde}	34.16^{abcd}	34.09^{AB}
T_6	33.30^{cde}	34.24^{abc}	33.77^{AB}
T_7	33.44^{bcde}	33.04^{cde}	33.24^{AB}
T_8	33.33^{cde}	32.48^{de}	32.90^{BC}
T_9	35.14^{ab}	32.40^{e}	33.77^{AB}
T_{10}	30.58^{f}	33.10^{cde}	31.84^{C}
T_{11}	33.39^{cde}	33.11^{cde}	33.25^{AB}
T_{12}	32.68^{cde}	33.80^{abcde}	33.24^{AB}
Mean	33.49^{A}	33.15^{A}	33.32

Table 34. Effect of growth regulators on transpiration rate (mol m^{-2} s^{-1}) at different physiological stages in black pepper var. Panniyur 2

Treatments	Flushing and flowering	Fruit set	Treatment mean
T_1	0.51^{h}	0.49^{hi}	0.50^{E}
T_2	0.49^{hi}	0.79^{de}	0.64^{D}
T_3	0.83^{de}	0.78^{e}	0.81^{C}
T_4	0.38^{kl}	0.89^{c}	0.64^{D}
T_5	0.84^{d}	1.06^{b}	0.95^{B}
T_6	0.23^{m}	0.45^{ij}	0.34^{G}
T_7	0.73^{f}	0.54^{h}	0.63^{D}
T_8	1.03^{b}	1.18^{a}	1.11^{A}
T_9	0.24^{m}	0.23^{m}	0.24^{H}
T_{10}	0.63^{g}	0.64^{g}	0.64^{D}
T_{11}	0.42^{jk}	0.41^{jkl}	0.42^{F}
T_{12}	0.45^{ij}	0.37^{l}	0.41^{F}
Mean	0.57^{A}	0.65^{A}	0,61

The values with a common letter in the superscript did not differ significantly at 5 per cent level

T_1: GA_3 25 ppm T_4: Kinetin 100 ppm T_7: BAP 200 ppm T_{10}: NAA 50 ppm
T_2: GA_3 50 ppm T_5: Kinetin 150 ppm T_8: BAP 250 ppm T_{11}: Water spray
T_3: GA_3 100 ppm T_6: Kinetin 200 ppm T_9: BAP 300 ppm T_{12}: No spray

4.3 EXPERIMENT III: EFFECT OF PRUNING OF LATERALS ON YIELD OF BLACK PEPPER

The laterals of pepper vines var. Panniyur 2 were pruned during 2001 and 2002 immediately after harvest, and its effects on succeeding years' flushing and berry yield were studied. The results obtained are furnished below under different heads:

4.3.1 Morphological Characters

4.3.1.1 Growth and Yield Characters of Lateral

The data on the effect of pruning on various characters associated with laterals are presented in Table 35.

4.3.1.1.1 Number of Leaves per Lateral

The average number of leaves produced on a lateral as a result of pruning was slightly higher during 2002 (1.99) than during 2001 (1.85). The one node pruned plants recorded significantly higher number of leaves (2.18) during 2001 as compared to control plants. The same trend was observed during 2002 also with out any significant effect.

4.3.1.1.2 Leaf Area per Lateral

The mean leaf area per lateral also recorded higher value during the year 2002 (210.73 cm^2) compared to 2001 (144.81 cm^2). During 2001, one node pruned plants showed significantly highest leaf area (166.95 cm^2) than rest of the treatment plants. Though nonsignificant, the same response was noticed during 2002 also.

4.3.1.1.3 Length of Lateral

The one node pruning treatment resulted in significantly longer laterals during 2001 (11.51cm) compared to control treatment (8.01cm). There was no

Table 35. Effect of pruning on growth and yield characters of black pepper var. Panniyur 2

Characters	Year	Treatments			Mean
		T_1	T_2	T_3	
Number of leaves per lateral	2001	2.18 [a]	1.84 [ab]	1.52 [b]	1.85
	2002	2.21 [a]	2.06 [a]	1.69 [a]	1.99
Leaf area per lateral (cm^2)	2001	166.95 [a]	133.66 [b]	133.81 [b]	144.81
	2002	232.00 [a]	199.62 [a]	200.57 [a]	210.73
Length of lateral (cm)	2001	11.51 [a]	10.41 [a]	8.01 [b]	9.98
	2002	10.47 [a]	9.02 [a]	9.93 [a]	9.80
Internodal thickness of lateral (cm)	2001	1.23 [a]	1.26 [a]	1.29 [a]	1.26
	2002	1.13 [b]	1.07 [b]	1.31 [a]	1.17
Angle of insertion of lateral (Degree)	2001	82.33 [a]	80.00 [a]	86.13 [a]	82.82
	2002	84.73 [a]	83.53 [a]	82.93 [a]	83.73
Number of spike bearing laterals per 0.25 m^2	2001	9.27 [a]	7.27 [a]	8.47 [a]	8.33
	2002	9.73 [a]	9.40 [a]	9.47 [a]	9.53
Number of spikes per lateral	2001	0.66 [a]	0.66 [a]	0.90 [a]	0.74
	2002	1.17 [a]	0.95 [a]	1.25 [a]	1.13
Spike to leaf ratio per lateral	2001	0.33 [a]	0.38 [a]	0.60 [a]	0.44
	2002	0.60 [a]	0.53 [a]	0.74 [a]	0.62

The values with a common letter in the superscript did not differ significantly at 5 per cent level

T_1: Pruning the laterals to one node below the point of harvest

T_2: Pruning the laterals to two nodes below the point of harvest

T_3: No pruning

remarkable variation in the lateral length between one node and two node pruned plants. Though not significant the same result was observed during 2002 also.

4.3.1.1.4 Internodal Thickness of Lateral

It was evident from the data that pruning did not influence the internodal thickness of laterals favourably. The internodal thickness recorded maximum in control plants both during 2001 and 2002 (1.29 cm and 1.31cm respectively).

4.3.1.1.5 Angle of Insertion of Lateral

There was no significant difference in the experimental plants with respect to the angle of insertion of laterals to the main stem during 2001 and 2002. However, the maximum value for angle of insertion of laterals was observed in control (86.13 degrees) and one node pruned (84.73 degrees) plants during 2001 and 2002 respectively.

4.3.1.1.6 Time of Spike Initiation of Lateral

The spike initiation was observed along with flushing in the experimental plants. The spikes emerged out just opposite to the leaf axil when newly produced leaves were completely unfurled. It was found that pruning did not influence the time of spike initiation in pepper vines during both 2001 and 2002. During 2001, the spike initiation started on 24th May in control plants and one node pruned plants (Table 36). Two node pruned plants initiated flushing and spike production three days later. During 2002, the spike initiation was first observed on 15th May and it took 18 days to commence spike initiation on 50 per cent of the tagged laterals of the treatment plants while it took 21 days during 2001. No definite trend was observed in the number of plants flushed in each interval among the treatments.

4.3.1.1.7 Number of Spike Bearing Laterals per 0.25 m^2

The mean number of spike bearing laterals produced during 2002 was higher (9.53) than the year 2001 (8.33). The data furnished indicated that pruning in black

Table 36. Effect of pruning on spike initiation of lateral in black pepper variety Panniyur 2

Year	No. of plants initiated spiking				Total
	Date	T_1	T_2	T_3	
2001	24/5	1	0	1	2
	27/5	0	1	1	2
	30/5	3	2	0	5
	2/6	2	4	3	9
	5/6	3	3	5	11
	8/6	3	2	3	8
	11/6	2	3	1	6
	14/6	1	0	1	2
2002	15/5	2	0	0	2
	18/5	0	1	1	2
	21/5	3	2	3	8
	24/5	2	3	3	8
	27/5	4	2	2	8
	30/5	4	4	4	12
	2/6	0	3	2	5

T_1: Pruning the laterals to one node below the point of harvest

T_2: Pruning the laterals to two nodes below the point of harvest

T_3: No pruning

pepper did not affect significantly the number of spike bearing laterals produced in a unit area. However, one node pruned plants produced highest number of laterals during both years (9.27 and 9.73 respectively).

4.3.1.1.8 Number of Spikes per Lateral

The pruning failed to exert a significant effect on the spike production of laterals both during 2001 and 2002.The number of spikes produced per lateral was highest in control plants during both years (0.90 and 1.25 respectively). The mean number of spikes on a lateral recorded higher during 2002 compared to 2001.

4.3.1.1.9 Spike to Leaf Ratio per Lateral

The experimental plants recorded higher spike to leaf ratio during the year 2002 (0.62) compared to 2001 (0.44). Among the treatments, the control recorded maximum spike to leaf ratio compared to pruning treatments during both years (0.60 and 0.74 respectively for 2001 and 2002).

4.3.1.2 Spike Characters

The data on various characters associated with spike are presented in Table 37.

4.3.1.2.1 Number of Berries per Spike

The mean number of berries produced per spike was higher during 2002 (46.39) compared to 2001 (42.76). Although not significant, the maximum number of berries was observed in two node pruned plants during 2001 (45.72). During 2002, the control plants were superior with respect to the number of berries per spike (53.12). Between pruning treatments, one node pruning resulted in higher berry number (45.42) than two node pruning (40.62).

4.3.1.2.2 Length of Spike

The treatments recorded significant variation on spike length during both the years 2001 and 2002. The mean length of spike was higher during 2002 (9.33 cm) than 2001 (8.79 cm). During 2001, the significantly higher spike length was observed in two node pruned plants (9.26 cm) compared to unpruned plants (8.31 cm). While during 2002, control treatment became superior (10.15 cm) to both pruning treatments and the spike length was found least in two node pruned plants (8.47 cm).

4.3.1.2.3 Spike Compactness

The mean spike compactness recorded higher value (4.97 No. cm $^{-1}$) during 2002 than 2001 (4.86 No. cm $^{-1}$). Even though there was no remarkable variation between treatments, spike compactness was maximum in two node pruned plants (4.92 No. cm $^{-1}$) during 2001 and control plants (5.25 No. cm $^{-1}$) during 2002.

4.3.1.3 Berry Characters

The data furnished in Table 37 indicated that berry characters like berry weight and berry volume did not show statistical significance during both 2001 and 2002.

4.3.1.3.1 Weight of 1000 Green Berries

Pruning did not influence weight of 1000 green berries during both 2001 and 2002. Control plants recorded maximum berry weight (140.83 g and 137.71 g respectively) during both years.

4.3.1.3.2 Volume of 1000 Green Berries

The mean berry volume was slightly higher during 2001 (128.11 cc) than 2002 (123.89 cc). Control plants registered maximum berry volume during both 2001 (130.33 cc) and 2002 (124.60 cc).

Table 37. Effect of pruning on spike and berry characters of black pepper var. Panniyur 2

Characters	Year	Treatments			Mean
		T_1	T_2	T_3	
Number of berries per spike	2001	42.17 [a]	45.72 [a]	40.39 [a]	42.76
	2002	45.42 [b]	40.62 [c]	53.12 [a]	46.39
Length of spike (cm)	2001	8.80 [ab]	9.26 [a]	8.31 [b]	8.79
	2002	9.39 [b]	8.47 [c]	10.15 [a]	9.33
Spike compactness (No. cm^{-1})	2001	4.81 [a]	4.92 [a]	4.86 [a]	4.86
	2002	4.84 [a]	4.83 [a]	5.25 [a]	4.97
Weight of 1000 green berries (g)	2001	138.64 [a]	136.53 [a]	140.83 [a]	138.67
	2002	137.58 [a]	136.78 [a]	137.71 [a]	137.36
Volume of 1000 green berries (cc)	2001	128.67 [a]	125.33 [a]	130.33 [a]	128.11
	2002	124.00 [a]	123.07 [a]	124.60 [a]	123.89

Table 38. Effect of pruning on yield of black pepper var. Panniyur 2

Treatments	Green yield per lateral (g)		Green yield per vine (kg)		Dry yield per vine (kg)	
	2001	2002	2001	2002	2001	2002
T_1	7.41 [a]	9.12 [a]	4.61 [a]	5.29 [a]	1.56 [a]	1.77 [a]
T_2	7.98 [a]	7.50 [b]	4.56 [a]	4.39 [a]	1.51 [a]	1.50 [a]
T_3	6.65 [a]	8.37 [ab]	4.35 [a]	4.57 [a]	1.45 [a]	1.52 [a]
Mean	7.35	8.33	4.51	4.75	1.51	1.59

The values with a common letter in the superscript did not differ significantly at 5 per cent level

T_1: Pruning the laterals to one node below the point of harvest

T_2: Pruning the laterals to two nodes below the point of harvest

T_3: No pruning

4.3.1.4 Yield Characters

The data on the effect of pruning on yield of black pepper are presented in the Table 38.

4.3.1.4.1 Green Yield per Lateral

The data indicated that pruning failed to improve green yield per lateral during both years. The mean yield per lateral was slightly higher during 2002 (8.33 g) than 2001 (7.35 g).

4.3.1.4.2 Green Yield per Vine

The mean yield per vine was slightly higher during 2002 (4.75 kg) compared to 2001 (4.51 kg). For both years, the highest yield was recorded by the treatment one node pruning (4.61 kg and 5.29 kg for 2001 and 2002 respectively) but it was statistically on par with rest of the treatments.

4.3.1.4.3 Dry Yield per Vine

The mean dry yield per vine was slightly higher during 2002 compared to 2001. Though not significant the maximum yield was noticed in one node pruned plants for both years (1.56 kg and 1.77 kg respectively for 2001 and 2002).

4.3.2 Biochemical Characters

The results obtained on the effect of pruning on biochemical characters during different physiological stages viz; before flushing, at flushing and flowering, and fruit set are furnished below:

4.3.2.1 Leaf Chlorophyll

Pruning failed to enhance chlorophyll content of black pepper leaves (Table 39). All the components of chlorophyll recorded maximum in control plants (1.63 mg

Table 39. Effect of pruning on chlorophyll and total phenol content of leaves at different physiological stages in black pepper var. Panniyur 2

Characters	Treatments	Before flushing	Flushing and flowering	Fruit set	Treatment mean
Chlorophyll 'a' (mg g^{-1})	T_1	1.63^{b}	1.26^{c}	1.89^{a}	1.59^{A}
	T_2	1.63^{b}	1.01^{c}	2.01^{a}	1.55^{A}
	T_3	1.88^{ab}	1.15^{c}	1.87^{ab}	1.63^{A}
	Mean	1.71^{B}	1.14^{C}	1.92^{A}	1.59
Chlorophyll 'b' (mg g^{-1})	T_1	0.23^{d}	0.21^{d}	0.39^{abc}	0.28^{B}
	T_2	0.23^{d}	0.21^{d}	0.36^{bc}	0.27^{B}
	T_3	0.47^{a}	0.30^{cd}	0.43^{ab}	0.40^{A}
	Mean	0.31^{B}	0.24^{C}	0.39^{A}	0.31
Total chlorophyll (mg g^{-1})	T_1	1.86^{b}	1.45^{c}	2.27^{a}	1.86^{B}
	T_2	1.85^{b}	1.21^{d}	2.35^{a}	1.81^{B}
	T_3	2.36^{a}	1.47^{c}	2.29^{a}	2.04^{A}
	Mean	2.02^{B}	1.38^{c}	2.31^{A}	1.90
Total phenol (mg g^{-1})	T_1	7.70^{b}	5.95^{e}	4.58^{g}	6.08^{B}
	T_2	9.57^{a}	6.91^{d}	5.94^{e}	7.47^{A}
	T_3	7.18^{c}	5.61^{f}	4.52^{g}	5.77^{C}
	Mean	8.15^{A}	6.16^{B}	5.01^{C}	6.44

The values with a common letter in the superscript did not differ significantly at 5 per cent level

T_1: Pruning the laterals to one node below the point of harvest

T_2: Pruning the laterals to two nodes below the point of harvest

T_3: No pruning

g^{-1}, 0.40 mg g^{-1} and 2.04 mg g^{-1} respectively for chlorophyll 'a', chlorophyll 'b' and total chlorophyll). In all the experimental plants, chlorophyll 'a', chlorophyll 'b' and total chlorophyll reduced at flushing and flowering and showed maximum content at fruit set.

4.3.2.2 Total Phenol

The total phenol content of pepper leaves differed significantly with respect to treatments, stages, and interaction between treatments and stages (Table 39). Significantly higher phenol content was observed in two node and one node pruned plants (7.47 mg g^{-1} and 6.08 mg g^{-1} respectively) compared to control plants (5.77 mg g^{-1}). In all the experimental plants, the total phenol content decreased significantly at flushing and flowering and reduced further at fruit set stage. In all stages two node pruning treatment was superior to one node pruning treatment.

4.3.2.3 Polyphenol Oxidase Activity

Among the treatments, the total activity of PPO was significantly higher in the treatment two node pruning (0.492) than one node pruning (0.374) and the activity of enzyme was least in control (Table 40). The PPO activity showed a declining trend after flushing and reduced further to fruit set stage. In all the three stages, PPO activity recorded highest in two node pruned plants and least in control plants.

4.3.2.4 Peroxidase Activity

One node pruned plants exhibited significantly highest enzymatic activity (91.00 units $litre^{-1}$) compared to other treatment plants (Table 40). The mean activity of the enzyme was maximum prior to flushing (85.51 units $litre^{-1}$) and it reduced in the new flushes at flowering stage and then showed an increasing trend at fruit set. In all the three stages, peroxidase activity recorded maximum in one node pruned plants.

4.3.2.5 Nitrate Reductase Activity

The pruning did not influence the activity of nitrate reductase in pepper leaves (Table 40). However, NRA recorded maximum in two node pruned plants (0.88

Table 40. Effect of pruning on enzymatic activities of leaves at different physiological stages in black pepper var. Panniyur 2

Characters	Treatments	Before flushing	Flushing and flowering	Fruit set	Treatment mean
Polyphenol oxidase (OD value)	T_1	0.440^{b}	0.353^{c}	0.330^{d}	0.374^{B}
	T_2	0.594^{a}	0.440^{b}	0.443^{b}	0.492^{A}
	T_3	0.365^{c}	0.321^{d}	0.258^{e}	0.315^{C}
	Mean	0.466^{A}	0.371^{B}	0.344^{C}	0.394
Peroxidase (Units litre^{-1})	T_1	100.46^{a}	80.72^{C}	91.82^{b}	91.00^{A}
	T_2	76.45^{c}	63.23^{d}	74.06^{c}	71.25^{B}
	T_3	79.62^{c}	62.59^{d}	65.65^{d}	69.29^{B}
	Mean	85.51^{A}	68.85^{C}	77.18^{B}	77.18
Nitrate reductase (m mol g fresh weight $^{-1}$ hour $^{-1}$)	T_1	0.35^{a}	0.79^{a}	0.69^{a}	0.61^{B}
	T_2	0.67^{a}	1.16^{a}	0.82^{a}	0.88^{A}
	T_3	0.65^{a}	0.96^{a}	0.97^{a}	0.86^{A}
	Mean	0.56^{C}	0.97^{A}	0.83^{B}	0.78

The values with a common letter in the superscript did not differ significantly at 5 per cent level

T_1: Pruning the laterals to one node below the point of harvest

T_2: Pruning the laterals to two nodes below the point of harvest

T_3: No pruning

m mol g fresh weight^{-1} hour^{-1}). The activity of nitrate reductase recorded highest at flushing and flowering (0.97 m mol g fresh weight^{-1} hour^{-1}) and least prior to flushing (0.56 m mol g freshweight^{-1} hour^{-1}).

4.3.2.6 C:N Ratio

The data presented in Table (41) indicated that the effect of pruning on total C, total N and C:N ratio was significant between treatments, stages and treatments x stages.

4.3.2.6.1 Total Carbon

Among the treatments, one node pruning resulted in significantly highest total C content (48.67 per cent). The C content recorded maximum at flushing and flowering stage (51.91 per cent) followed by fruit set (45.31 per cent) and was least prior to flushing (40.92 per cent). Among the three stages analysed, the C content was significantly higher in one node pruned plants at pre flushing and also at flushing and flowering stages (45.92 and 53.93 per cent respectively) compared to control plants. But at fruit set stage the C content of all treatment plants became statistically on par.

4.3.2.6.2 Total Nitrogen

The foliar N content was significantly higher in one node pruned and two node pruned (2.29 per cent and 2.26 per cent respectively) plants compared to control plants (1.98 per cent). The N content rose immediately after flushing and recorded maximum at fruit set in all the experimental plants. The N content at different physiological stages ranged from 1.89 per cent (before flushing) to 2.43 per cent (fruit set). Prior to flushing and at flushing and flowering, two node pruned plants recorded highest N content (2.02 and 2.35 per cent respectively) but at fruit set stage, one node pruned plants registered significantly highest foliar N. Control pants recorded least N content in all stages.

Table 41. Effect of pruning on C:N ratio of leaves at different physiological stages in black pepper var. Panniyur 2

Characters	Treatments	Before flushing	Flushing and flowering	Fruit set	Treatment mean
Total carbon (%)	T_1	45.92^{cd}	53.93^{a}	46.15^{cd}	48.67^{A}
	T_2	40.54^{e}	52.47^{ab}	43.14^{de}	45.38^{B}
	T_3	36.30^{f}	49.33^{bc}	46.64^{cd}	44.09^{B}
	Mean	40.92^{C}	51.91^{A}	45.31^{B}	46.05
Total nitrogen (%)	T_1	1.88^{f}	2.29^{c}	2.69^{a}	2.29^{A}
	T_2	2.02^{e}	2.35^{bc}	2.42^{b}	2.26^{A}
	T_3	1.76^{g}	1.99^{e}	2.18^{d}	1.98^{B}
	Mean	1.89^{C}	2.21^{B}	2.43^{A}	2.18
C:N ratio	T_1	24.44^{a}	23.58^{ab}	17.16^{e}	21.73^{B}
	T_2	20.10^{d}	22.39^{bc}	17.83^{e}	20.10^{B}
	T_3	20.65^{cd}	24.80^{a}	21.38^{cd}	22.28^{A}
	Mean	21.73^{B}	23.59^{A}	18.79^{C}	21.40

The values with a common letter in the superscript did not differ significantly at 5 per cent level

T_1: Pruning the laterals to one node below the point of harvest

T_2: Pruning the laterals to two nodes below the point of harvest

T_3: No pruning

4.3.2.6.3 C:N Ratio

Pruning failed to enhance C:N ratio of black pepper leaves. It recorded maximum at flushing and flowering stage (23.59) followed by before flushing (21.73) and least during fruit set stage (18.79). The one node pruned plants recorded highest C:N ratio at pre flushing stage. In other two stages control plants recorded maximum C:N ratio.

4.3.2.7 Quality Parameters

The effect of pruning on quality parameters viz., essential oil, oleoresin and piperine content of the berries during 2001 and 2002 are presented in Table 42.

4.3.2.7.1 Essential Oil

Irrespective of the years pruning failed to improve the essential oil content of berries. The control plants recorded highest oil percentage during both 2001 and 2002 (3.00 and 2.38 per cent respectively).

4.3.2.7.2 Oleoresin

During 2001, two node pruned plants registered highest oleoresin content (13.5 per cent) of the berries whereas, one node pruned plants recorded maximum oleoresin (12.90 per cent) during 2002 both with out a significant effect.

4.3.2.7.3 Piperine

Pruning could not exert a significant effect on piperine content of berries during both 2001 and 2002. However, maximum content was noticed in control plants (5.63 per cent) during 2001 and one node pruned plants (5.56 per cent) during 2002.

Table 42. Effect of pruning on quality parameters of berries in black pepper var. Panniyur 2

Treatments	Essential oil (%)		Oleoresin (%)		Piperine (%)	
	2001	2002	2001	2002	2001	2002
T_1	2.50[a]	2.25[a]	12.81[a]	12.90[a]	5.4[a]	5.56[a]
T_2	2.25[a]	2.00[a]	13.50[a]	11.04[a]	5.25[a]	5.06[a]
T_3	3.00[a]	2.38[a]	13.20[a]	12.54[a]	5.63[a]	5.39[a]
Mean	2.58	2.21	13.17	12.16	5.43	5.34

The values with a common letter in the superscript did not differ significantly at 5 per cent level

T_1: Pruning the laterals to one node below the point of harvest

T_2: Pruning the laterals to two nodes below the point of harvest

T_3: No pruning

4.3.3 Physiological Characters

The data on the effect of pruning on various physiological parameters at different physiological stages viz., prior to flushing, at flushing and flowering and fruit set are presented in Table 43.

4.3.3.1 Photosynthetic Rate

The photosynthetic rate was significantly maximum in leaves of one node pruned plants (2.93 μ mol m^{-2} s^{-1}) followed by two node pruned plants and least in control plants. Prior to flushing, photosynthetic rate was minimum (1.24 μ mol m^{-2} s^{-1}) and it increased drastically at flushing and spike initiation (2.11 μ mol m^{-2} s^{-1}) and reached maximum at fruit set stage (3.19 μ mol m^{-2} s^{-1}). In the first two stages, one node pruned plants exhibited significantly highest rate of photosynthesis (1.70 and 3.40 μ mol m^{-2} s^{-1} respectively) but at fruit set, the photosynthetic rate of two node pruned plants (3.73 μ mol m^{-2} s^{-1}) became more or less equal to that of one node pruned plants (3.69 μ mol m^{-2} s^{-1}).

4.3.3.2 Photosynthetically Active Radiation

The leaves of control plants intercepted maximum PAR (261.33 μ mol m^{-2} s^{-1}). Among different physiological stages, the PAR intercepted prior to flushing was highest (365.27 μ mol m^{-2} s^{-1}) followed by fruit set and least during flushing and spike initiation stage (163.87 μ mol m^{-2} s^{-1}). The PAR intercepted by the experimental plants differed significantly in all stages except prior to flushing. No definite trend among the treatments was observed in all the three stages.

4.3.3.3 Stomatal Conductance

Pruning did not influence the stomatal conductance of black pepper leaves. However, one node pruned plants recorded maximum stomatal conductance (0.05 mol m^{-2} s^{-1}). The stomatal conductance registered an increasing trend from before flushing

Table 43. Effect of pruning on physiological parameters at different physiological stages in black pepper var. Panniyur 2

Characters	Treatments	Before flushing	Flushing and flowering	Fruit set	Treatment mean
Photosynthetic rate (μ mol $m^{-2} s^{-1}$)	T_1	1.70^{c}	3.40^{a}	3.69^{a}	2.93^{A}
	T_2	0.84^{e}	1.40^{cd}	3.73^{a}	1.99^{B}
	T_3	1.18^{de}	1.53^{cd}	2.14^{b}	1.62^{C}
	Mean	1.24^{c}	2.11^{B}	3.19^{A}	2.18
Photosynthetically active radiation (μ mol $m^{-2} s^{-1}$)	T_1	346.20^{a}	230.00^{b}	150.40^{c}	242.00^{A}
	T_2	346.20^{a}	79.40^{d}	144.40^{c}	204.33^{B}
	T_3	360.40^{a}	182.20^{c}	241.40^{b}	261.33^{A}
	Mean	365.27^{A}	163.87^{B}	178.73^{B}	235.96
Stomatal conductance (mol m^{-2} s^{-1})	T_1	0.03^{bc} (0.73)	0.07^{a} (0.76)	0.04^{b} (0.74)	0.05^{A} (0.74)
	T_2	0.02^{c} (0.72)	0.01^{c} (0.72)	0.08^{a} (0.76)	0.04^{A} (0.73)
	T_3	0.04^{b} (0.74)	0.03^{bc} (0.73)	0.05^{b} (0.74)	0.04^{A} (0.74)
	Mean	0.03^{B} (0.73)	0.04^{B} (0.73)	0.06^{A} (0.75)	0.04 (0.74)
Stomatal resistance (m^2 s mol^{-1})	T_1	30.97^{c}	18.25^{d}	40.37^{b}	29.86^{C}
	T_2	44.02^{b}	67.77^{a}	12.32^{e}	41.37^{B}
	T_3	32.08^{c}	64.79^{a}	42.65^{b}	46.51^{A}
	Mean	35.69^{B}	50.27^{A}	31.78^{c}	39.25
Leaf surface temperature (Degree celsius)	T_1	38.06^{a}	33.49^{c}	33.80^{c}	35.11^{A}
	T_2	37.94^{a}	33.49^{c}	32.35^{c}	34.59^{A}
	T_3	36.42^{b}	33.70^{c}	33.53^{c}	34.55^{A}
	Mean	37.47^{A}	33.56^{B}	33.22^{B}	34.75
Transpiration rate (mol m^{-2} s^{-1})	T_1	0.81^{ab}	0.90^{a}	0.65^{abc}	0.79^{A}
	T_2	0.99^{a}	0.24^{c}	0.95^{a}	0.73^{A}
	T_3	1.11^{a}	0.35^{bc}	0.61^{abc}	0.69^{A}
	Mean	0.97^{A}	0.50^{C}	0.74^{B}	0.73

The values with a common letter in the superscript did not differ significantly at 5 per cent level

Figures in parentheses are transformed values

T_1: Pruning the laterals to one node below the point of harvest

T_2: Pruning the laterals to two nodes below the point of harvest

T_3: No pruning

(0.03 mol m^{-2} s^{-1}) to fruit set (0.06 mol m^{-2} s^{-1}) stage. Pruned plants recorded significantly higher stomatal conductance over control plants at flushing and flowering (one node pruned plants) and at fruit set stage (two node pruned plants).

4.3.3.4 Stomatal Resistance

The stomatal resistance was significantly highest in control plants (46.51 m^2 s mol^{-1}) and least in one node pruned plants (29.86 m^2 s mol^{-1}). The stomatal resistance increased sharply after flushing (50.27 m^2 s mol^{-1}) and then further reduced to a low value at fruit set stage (31.78 m^2 s mol^{-1}). It recorded highest in two node pruned plants except at fruit set stage. At fruit set stage, control plants showed maximum stomatal resistance (42.65 m^2 s mol^{-1}).

4.3.3.5 Leaf Surface Temperature

No significant difference between treatments was observed with regard to the leaf surface temperature. Prior to flushing, leaf temperature recorded significantly higher (37.47 ^{0} C) compared to other two stages. At flushing and flowering and at fruit set stages, treatments did not register any considerable variation in leaf temperature. But prior to flushing, one node pruned plants recorded significantly higher leaf temperature (38.06^o C) compared to control plants.

4.3.3.6 Transpiration Rate

The treatments did not record any remarkable variation in the transpiration rate of leaves. The transpiration rate recorded maximum prior to flushing (0.97 mol m^{-2} s^{-1}), then reduced at flowering (0.5 mol m^{-2} s^{-1}) and again increased at fruit set stage (0.74 mol m^{-2} s^{-1}). Only at flushing and flowering, treatments recorded significant variation with highest transpiration rate in one node pruned plants (0.90 mol m^{-2} s^{-1}).

4.4 CORRELATION AND PATH ANALYSIS

The various morphological, biochemical and physiological characters were correlated with dry pepper yield and interrelationships among them were worked out.

4.4.1 Correlation Between Morphological Characters and Yield

The various yield contributing characters were correlated with dry pepper yield and correlation coefficients obtained are presented in Table 44. Among the morphological characters studied, angle of insertion of lateral to the main stem, number of berries per spike, spike length, berry weight and green yield per vine recorded highly significant positive correlation with dry yield whereas the green berry volume registered significance only at five per cent level. The length of lateral, internodal thickness and spike compactness recorded significant negative correlation with dry yield.

The correlation matrix showing the interrelationships between morphological parameters is presented in Table 45. The internodal thickness of lateral registered significant positive association with lateral length, spike compactness and negative association with number of spike bearing laterals, weight and volume of berries, and green yield. Angle of insertion of lateral showed significant positive correlation with number of productive laterals, spike characters and green yield. However, negative association was observed with lateral length, spike compactness, berry volume and dry recovery percentage.

The length of lateral showed significant positive correlation with number of leaves, leaf area and number of spikes per lateral and negative correlation with green yield per vine. With regard to number of spikes per lateral, highly significant positive correlation was observed with number of leaves, leaf area per lateral, number of spike bearing laterals, spike to leaf ratio, number of berries per spike and spike length. Spike length registered highly significant positive correlation with berry number ($r = 0.8059$). Both characters exerted a highly significant positive effect on green yield ($r = 0.4996$ and $r = 0.4240$ respectively). Leaf area per lateral and number of spike bearing laterals also exhibited significant positive correlation with spike length and berry number. Berry characters like weight and volume were found associated negatively with internodal thickness of lateral, spike compactness and positively correlated with spike length and green yield.

Table 44. Correlation between morphological, biochemical and physiological characters and dry pepper yield in black pepper

Sl.No	Characters	Correlation coefficient with dry yield
A	Morphological characters	
1	Number of leaves per lateral	-0.1375
2	Leaf area per lateral	0.0011
3	Length of lateral	-0.2623**
4	Internodal thickness of lateral	-0.2059*
5	Angle of insertion of lateral	0.3042**
6	Number of spike bearing laterals per 0.25 m^2	0.0988
7	Number of spikes per lateral	0.0104
8	Spike to leaf ratio per lateral	0.1919
9	Number of berries per spike	0.3901**
10	Length of spike	0.4419**
11	Spike compactness	-0.2452*
12	Weight of 1000 green berries	0.5059**
13	Volume of 1000 green berries	0.2328*
14	Green yield per vine	0.9822**
15	Dry recovery percentage	0.1190
B	Biochemical characters	
1	Chlorophyll 'a'	0.2475*
2	Chlorophyll 'b'	0.1620
3	Total chlorophyll	0.1448
4	Total phenol	-0.0554
5	Polyphenol oxidase activity	0.2165
6	Nitrate reductase activity	0.0130
7	Peroxidase activity	-0.0199
8	Total carbon	0.2154
9	Total nitrogen	0.1427
10	C/N ratio	0.0147
11	Oleoresin	-0.1684
12	Piperine	0.0242
13	Essential oil	0.0979
C	Physiological characters	
1	Photosynthetic rate	0.3232**
2	Photosynthetically active radiation	0.1938
3	Stomatal conductance	0.1270
4	Stomatal resistance	-0.1643
5	Leaf surface temperature	-0.1494
6	Transpiration rate	0.2703*

* Significant at 5 per cent level
** Significant at 1per cent level

Table 45. Intercorrelation matrix of morphological characters and dry yield of black pepper

Characters	No. of leaves per lateral	Leaf area per lateral	No. of productive lateral / 0.25m^2	Internodal thickness of lateral	Angle of insertion of lateral	Lateral length	No. of spikes per lateral	Spike to leaf ratio per lateral	No. of berries per spike	Length of spike	Spike compactness	Weight of 1000 green berries	Volume of 1000 green berries	Dry recovery per-centage	Green yield per vine	Dry yield per vine
No. of leaves per lateral	1.000															
Leaf area per lateral	0.9252**	1.000														
No. of productive lateral / 0.25m^2	0.3868**	0.4432**	1.000													
Internodal thickness of lateral	0.0727	0.1053	-0.2301*	1.000												
Angle of insertion of lateral	-0.1335	0.0826	0.1988*	0.0919	1.000											
Lateral length	0.7429**	0.6131**	0.1359	0.2884**	-0.2657**	1.000										
No. of spikes per lateral	0.7787**	0.8402**	0.3327**	0.1566	0.2040*	0.6417**	1.000									
Spike to leaf ratio per lateral	-0.3032**	-0.1291	-0.1119	0.0732	0.4377**	-0.0996	0.3316**	1.000								
No. of berries per spike	0.1415	0.3288**	0.4090**	-0.0157	0.3507**	0.0551	0.2859**	0.1347	1.000							
Length of spike	0.1052	0.3554**	0.4156**	-0.1757	0.4105**	0.0121	0.4199**	0.3645**	0.8059**	1.000						
Spike compactness	0.0318	-0.1546	-0.1998*	0.2852**	-0.2243*	0.0819	-0.3180**	-0.4313**	-0.1398	-0.6906**	1.000					
Weight of 1000 green berries	-0.0369	-0.0122	0.0546	-0.4132**	-0.1737**	-0.0901	-0.0001	0.0917	0.1932	0.3471**	-0.3681**	1.000				
Volume of 1000 green berries	0.0410	0.0942	0.1268	-0.2720**	-0.2907**	0.0159	-0.0133	-0.0872	0.1074	0.3012**	-0.4065**	0.7343**	1.000			
Dry recovery percentage	-0.0032	-0.1510	-0.4091**	-0.0405	-0.3708**	0.0320	-0.2364*	-0.2826**	-0.2454*	-0.3914**	0.3704**	-0.0018	-0.1148	1.000		
Green yield per vine	-0.1403	0.0218	0.1654	-0.2225*	0.3542**	-0.2674**	0.0324	0.2155*	0.4240**	0.4996**	-0.3018**	0.4961**	0.2759**	-0.0569	1.000	
Dry yield per vine	-0.1375	0.0011	0.0988	-0.2059*	0.3042**	-0.2623**	0.0104	0.1919	0.3901**	0.4419**	-0.2452*	0.5059**	0.2328*	0.1190	0.9822**	1.000

* Significant at 5 per cent level ** Significant at 1 per cent level

4.4.2 Correlation Between Biochemical Characters and Yield

Among the biochemical characters, only chlorophyll 'a' showed significant positive correlation with yield (r = 0.2475)(Table 44). Rest of the parameters except total phenol, peroxidase activity and oleoresin content exhibited nonsignificant positive association with dry yield. Chlorophyll 'a', 'b' and total chlorophyll recorded significant positive correlation with total phenol content, peroxidase activity and piperine content (Table 46). Chlorophyll 'a' alone registered significant positive correlation with total C content of leaves. Leaf chlorophyll and total phenol content showed a significant positive correlation with piperine content and negative correlation with essential oil content of berries. The enzyme polyphenol oxidase, expressed highly significant negative correlation with peroxidase activity and piperine content of berries while the correlation with essential oil content was positively significant. Significant positive correlation between foliar N and total C was also observed.

4.4.3 Correlation Between Physiological Characters and Yield

Among the various physiological characters studied, photosynthetic rate (r = 0.2703) recorded highly significant positive correlation with dry yield (Table 44). Intercorrelation matrix presented in Table 47 revealed that PAR, stomatal conductance and transpiration rate exhibited highly significant positive correlation with photosynthetic rate whereas, stomatal resistance and leaf surface temperature recorded significantly negative correlation. The leaf surface temperature and transpiration rate exhibited highly significant positive correlation with PAR but stomatal conductance had significant positive correlation only at five per cent level. Stomatal resistance showed highly significant negative correlation with stomatal conductance and transpiration rate and positive correlation with leaf surface temperature. A highly significant positive correlation (r = 0.7279) between stomatal conductance and transpiration rate was also observed during the present study.

4.4.4 Path Coefficient Analysis

Since most of the morphological parameters exhibited significantly high correlation with yield, they were subjected to path coefficient analysis to determine the

Table 46. Intercorrelation matrix of biochemical characters and dry yield of black pepper

Characters	Chlorophyll 'a'	Chlorophyll 'b'	Total chlorophyll	Total phenol	Polyphenol oxidase activity	Nitrate reductase activity	Peroxidase activity	Total carbon	Total nitrogen	C:N ratio	oleoresin	Piperine	Essential oil	Dry yield
Chlorophyll 'a'	1.000													
Chlorophyll 'b'	0.7884 **	1.000												
Total chlorophyll	0.9321 **	0.8126 **	1.000											
Total phenol	0.2949 *	0.2497 *	0.2683 *	1.000										
Polyphenol oxidase activity	-0.2023	-0.3180 **	-0.2781 *	-0.4034 **	1.000									
Nitrate reductase activity	-0.0604	0.0015	-0.0570	-0.0877	0.1704	1.000								
Peroxidase activity	0.3443 **	0.3160 **	0.3746 **	0.4801 **	-0.3130 **	-0.3400 **	1.000							
Total carbon	0.2778 *	0.1585	0.2211	0.0346	-0.0930	-0.2474 *	-0.2059	1.000						
Total nitrogen	0.1642	0.1314	0.1723	-0.0661	-0.0878	0.0354	-0.0012	0.2994 *	1.000					
C:N ratio	0.0474	-0.0161	-0.0054	0.0902	0.0064	-0.2191	-0.1509	0.4769 **	-0.6880 **	1.000				
Oleoresin	0.0333	0.1730	0.1352	-0.0917	-0.1297	0.1944	-0.1258	0.1125	0.1163	0.0025	1.000			
Piperine	0.3250 **	0.3832 **	0.2707 *	0.2640 *	-0.4091 **	0.0608	0.2082	0.0283	0.0654	-0.0184	0.2935 *	1.000		
Essential oil	-0.3991 **	-0.3021 *	-0.3654 **	-0.3109 **	0.3131 **	-0.0121	-0.0964	-0.2365 *	0.0289	-0.1924	0.3338 **	0.5009 **	1.000	
Dry yield	0.2475 *	0.1620	0.1448	-0.0554	0.2165	0.0130	-0.0199	0.2154	0.1427	0.0147	-0.1684	0.0242	0.0979	1.000

* Significant at 5 per cent level. ** Significant at 1 per cent level.

Table 47. Intercorrelation matrix of physiological characters and dry yield of black pepper

Characters	Photo synthetic rate	Photo synthetically active radiation	Stomatal conductance	Stomatal resistance	Leaf surface temperature	Transpiration rate	Dry yield
Photosynthetic rate	1.000						
Photosynthetically active radiation	0.3108**	1.000					
Stomatal conductance	0.5550**	0.3066*	1.000				
Stomatal resistance	-0.5150**	-0.1504	-0.4984**	1.000			
Leaf surface temperature	-0.2886*	0.5861**	-0.1931	0.2781*	1.000		
Transpiration rate	0.7161**	0.5076**	0.7279**	-0.6230**	-0.0614	1.000	
Dry yield	0.3232**	0.1938	0.1270	-0.1643	-0.1494	0.2703*	1.000

* Significant at 5 per cent level ** Significant at 1 per cent level

relative contribution of different characters towards yield and to measure the co-ordinated relationships existing among these traits. Out of the 15 characters analyzed, nine characters showed positive direct effect on yield (Table 48). But all these positive and negative direct effects were found negligible except for leaf area per lateral, dry recovery percentage and green yield. The green yield per vine expressed highest positive direct effect on yield (0.9464) while dry recovery percentage recorded a low direct effect (0.1927). The leaf area per lateral expressed a low negative direct effect (-0.1884).

With respect to the indirect effects, all the morphological parameters influenced the dry yield mainly through green yield per vine. The yield contributing characters like angle of insertion of lateral to the main stem, number of berries per spike, spike length and 1000 berry weight recorded high positive indirect effect on yield through green yield. The number of leaves and spikes per lateral and lateral length expressed a negative low indirect effect on yield through leaf area per lateral. The indirect effects of spike compactness and internodal thickness on dry berry yield through green yield per vine was moderately negative whereas it was moderately positive for berry volume and spike to leaf ratio.

4.5 INTERCEPTION OF LIGHT

The data on the percentage of light available in the experimental fields of Panniyur 1 and Panniyur 2 at different physiological stages are given in Table 49. The light infiltrated in the field was found to vary with each hour in response to the cloudiness and position of the sun and did not show any definite trend. The mean percentage of light at different stages did not show much variation both in Panniyur 1 and Panniyur 2. However, from the data it is clear that light availability in the experimental field of Panniyur 2 was higher compared to Panniyur 1 in all the stages observed.

4.6 INCIDENCE OF DISEASES AND PESTS

The plants were observed for the incidence of major pests and diseases, during the experimental period. With the onset of South West monsoon, some of the

Table 48. Direct and indirect effects of morphological characters on dry yield of black pepper

	X1	X2	X3	X4	X5	X6	X7	X8	X9	X10	X11	X12	X13	X14	X15	Correlation with dry yield
X1	**0.0900**	-0.1743	0.0066	0.0023	0.0015	-0.0246	0.0776	0.0107	-0.0067	0.0095	0.0010	-0.0032	0.0032	-0.0006	-0.1328	-0.1375
X2	0.0833	**-0.1884**	0.0076	0.0034	-0.0009	-0.0203	0.0837	0.0046	-0.0155	0.0321	-0.0049	-0.0011	-0.0074	-0.0291	0.0206	0.0011
X3	0.0348	-0.0835	**0.0171**	-0.0073	-0.0022	-0.0045	0.0331	0.0040	-0.1930	0.0375	-0.0064	0.0048	-0.0100	-0.0789	0.1565	0.0988
X4	0.0065	-0.0198	-0.0039	**0.0318**	-0.0010	-0.0096	0.0156	-0.0026	0.0007	-0.0159	0.0091	-0.0361	0.0213	0.0078	-0..2106	-0.2059 *
X5	-0.0120	-0.0156	0.0034	0.0029	**-0.0110**	0.0088	0.0203	-0.0155	-0.0166	0.0371	0.0072	-0.0152	0.0228	-0.0715	0.3352	0.3042 **
X6	0.0669	-0.1155	0.0023	0.0092	0.0029	**-0.0332**	0.0639	0.0035	-0.0026	0.0011	0.0026	-0.0079	-0.0012	0.0062	-0.2530	-0.2623 **
X7	0.0701	-0.1583	0.0057	0.0050	-0.0022	-0.0213	**0.0996**	-0.0117	-0.0135	0.0379	-0.0101	0.0000	0.0010	-0.0456	0.0307	0.0104
X8	-0.0273	0.0243	-0.0019	0.0023	-0.0048	0.0033	0.0330	**-0.0354**	-0.0064	0.0329	-0.0138	0.0080	0.0068	-0.0545	0.2040	0.1919
X9	0.0127	-0.0620	0.0070	-0.0005	-0.0039	-0.0018	0.0285	-0.0048	**-0.0473**	0.0728	-0.0045	0.0169	-0.0084	-0.0473	0.4022	0.3901 **
X10	0.0095	-0.0670	0.0071	-0.0056	-0.0045	-0.0004	0.0418	-0.0129	-0.0381	**0.0903**	-0.0220	0.0303	-0.0236	-0.0754	0.4729	0.4419 **
X11	0.0029	0.0291	-0.0034	-0.0091	0.0025	-0.0028	-0.0317	0.0153	0.0066	-0.0624	**0.0319**	-0.0322	0.0319	0.0714	-0.2856	-0.2452 *
X12	-0.0033	0.0023	0.0009	-0.0132	0.0019	0.0030	0.0000	-0.0032	-0.0091	0.0313	-0.0170	**0.0874**	-0.0576	-0.0003	0.4696	0.5059 **
X13	0.0037	-0.0178	0.0922	-0.0087	0.0032	-0.0005	-0.0013	0.0031	-0.0051	0.0272	-0.0130	0.0642	**-0.0785**	-0.0221	0.2611	0.2328 *
X14	-0.0003	0.0285	-0.0070	0.0013	0.0041	-0.0011	-0.0236	0.0100	0.0116	-0.0353	0.0118	-0.0002	0.0090	**0.1927**	-0.0539	0.1190
X15	-0.0126	-0.0041	0.0028	-0.0071	-0.0039	0.0089	0.0032	-0.0076	-0.0201	0.0451	-0.0096	0.0434	-0.0217	-0.0110	**0.9464**	0.9822 **

residual = 0.0005

* Significant at 5 per cent level
** Significant at 1 per cent level
0.0 to 0.09: negligible
0.1 to 0.19: low
0.2 to 0.29: moderate
0.3 to 0.99: high

X1: No. of leaves per lateral
X2: Leaf area per lateral
X3: No. of productive lateral/0.25 m^2
X4: Internodal thickness of lateral
X5: Angle of insertion of lateral
X6: Length of lateral
X7: No. of spikes per lateral
X8: Spike to leaf ratio per lateral
X9: No. of berries per spike
X10: Length of spike
X11: Spike compactness
X12: Weight of 1000 green berries
X13: Volume of 1000 green berries
X14: Dry recovery percentage
X15: Green yield per vine

Table 49. Percentage of light interception at different physiological stages in the experimental fields of Panniyur 1 and Panniyur 2

Time	Before flushing		Flushing and flowering		Berry development		Berry maturity	
	P_1	P_2	P_1	P_2	P_1	P_2	P_1	P_2
7am	30.50	34.18	19.24	22.13	14.73	19.12	37.00	28.92
8am	32.37	37.93	28.50	30.24	21.00	34.46	33.52	19.16
9 am	41.31	42.81	36.14	41.25	43.97	64.92	35.05	25.72
10am	23.05	22.54	45.15	61.26	49.72	58.41	20.55	42.21
11am	56.00	32.26	60.13	62.30	60.54	36.01	38.43	29.35
12pm	50.86	40.80	55.15	61.15	56.55	70.69	15.99	27.65
1pm	10.42	60.51	50.30	49.20	46.20	58.06	22.11	17.25
2pm	54.39	57.82	42.25	44.50	41.40	48.30	40.00	47.15
3pm	21.09	35.01	32.15	35014	30.06	47.89	39.03	48.73
4pm	20.81	34.19	14.10	19.20	15.28	21.08	39.93	51.19
5pm	28.13	32.36	12.43	15.34	8.60	19.13	36.32	46.35
6pm	34.09	37.67	8.50	10.05	11.75	15.25	33.50	46.13
Mean	33.59	39.01	33.67	37.65	33.32	41.11	32.62	35.82

P_1 – Panniyur 1 P_2 – Panniyur 2

plants expressed the symptoms of mild foot rot disease. Further development and spread of the disease was prevented by soil drenching of 0.2 per cent Fytolan uniformly for all the plants. Mild incidence of leaf spot leading to shot hole symptom was also observed. The causal organism was identified as *Colletotrichum gloeosporioides* through the isolation of the pathogen. But the disease was not in a noticeable level.

Among the pests, marginal leaf gall thrips and mites were observed as minor pests on pepper leaves. On a few spikes, attack of mealy bug was noticed. Plants were almost free from the attack of pollu beetle.

In general, there was no serious incidence of pests and diseases during the experimental period and no marked differences in the severity of pests and diseases could be observed among the various treatments applied for the three experiments tried.

4.7 ECONOMICS OF TREATMENTS

4.7.1 Experiment I

The data on the economics of treatments as influenced by the irrigation during both 2001 and 2002 are furnished in Table 50. Generally the cost of cultivation, total returns and BCR recorded higher during 2002 compared to 2001. Total cost was highest in the treatment rocker sprayer irrigation up to March and least in control irrespective of years. Among the treatments, excluding control, the cost of cultivation recorded lowest in the treatment, basin irrigation up to January. The return was maximum in the treatment, basin irrigation up to March for both years. The second higher return was observed in rocker sprayer irrigation up to March during 2001 and basin irrigation up to February during 2002. The benefit cost ratio (BCR) registered highest in the treatment basin irrigation up to March (1.92) during 2001 and basin irrigation up to February (3.19) during 2002. However, the mean BCR recorded maximum in the treatment, basin irrigation up to March (2.50). The control treatment showed a BCR of 1.95.

Table 50. Economics of treatments for experiment I

Treatments	Total cost (Rs ha^{-1})			Total returns (Rs ha^{-1})			Benefit cost ratio		
	2001	2002	Mean	2001	2002	Mean	2001	2002	Mean
T_1	41,851	43,940	42,896	61,861	1,05,823	83,842	1.48	2.41	1.95
T_2	1,10,611	1,14,844	1,12,728	83,125	1,09,156	96,141	0.75	0.95	0.85
T_3	84,192	87,614	85,903	79,259	1,50,818	1,15,039	0.94	1.72	1.33
T_4	62,805	65,549	64,177	81,192	1,21,655	1,01,424	1.29	1.86	1.58
T_5	84,292	86,403	85,348	59,927	1,09,156	84,542	0.71	1.26	0.99
T_6	84,269	86,369	85,319	64,760	1,26,654	95,707	0.77	1.47	1.12
T_7	84,247	86,336	85,292	62,827	1,04,990	83,909	0.75	1.22	0.99
T_8	48,740	51,039	49,890	93,757	1,56,651	1,25,204	1.92	3.07	2.50
T_9	46,073	48,295	47,184	63,794	1,54,151	1,08,973	1.39	3.19	2.29
T_{10}	43,985	46,129	45,057	60,894	1,05,823	83,359	1.38	2.29	1.84
T_{11}	52,961	55,395	54,178	62,827	1,29,987	96,407	1.19	2.35	1.77

Price of pepper Rs. 87 kg^{-1} (2001), Rs. 75 kg^{-1} (2002)

T_1: No irrigation (Control)
T_2: Five litres of rocker sprayer irrigation up to March
T_3: Five litres of rocker sprayer irrigation up to February
T_4: Five litres of rocker sprayer irrigation up to January
T_5: Five litres of fogger irrigation up to March
T_6: Five litres of fogger irrigation up to February
T_7: Five litres of fogger irrigation up to January
T_8: Ten litres of basin irrigation up to March
T_9: Ten litres of basin irrigation up to February
T_{10}: Ten litres of basin irrigation up to January
T_{11}: Irrigation throughout summer period

4.7.2 Experiment II

Among the treatments tried, the highest cost of cultivation was shown by the treatment, 200 ppm kinetin (Table 51). All the cytokinin treatments showed higher cost of cultivation compared to GA_3 treatments and NAA. The total cost increased with the increase in the concentration of the chemical and it recorded least in absolute control. Total returns was maximum in the treatment, 100 ppm GA_3, followed by 150 ppm kinetin. The BCR registered higher in absolute control and water sprayed plants followed by GA_3 treatments. Among the growth regulator treatments, only GA_3 treatments and NAA recorded BCR higher than one.

4.7.3 Experiment III

The data on the economics of treatments as influenced by pruning are presented in Table 52. The total cost was found higher during 2002 compared to 2001. For both pruning treatments, the total cost was found same and was higher compared to control treatment. Total returns recorded highest in one node pruning treatment irrespective of the years. The total returns and BCR were low during 2002 compared to 2001. Benefit cost ratio recorded was highest in control treatment during 2001 (3.35) and one node pruning during 2002 (2.95). However, the average BCR recorded was highest in control treatment.

Table 51. Economics of treatments for experiment II

Treatments	Total cost (Rs ha^{-1})	Total returns (Rs ha^{-1})	Benefit cost ratio
T_1	56,383	1,09,156	1.94
T_2	64,660	1,28,321	1.99
T_3	81,214	1,44,986	1.79
T_4	2,68,973	1,34,153	0.50
T_5	3,79,407	1,34,987	0.36
T_6	4,89,840	1,13,322	0.23
T_7	1,25,876	89,158	0.71
T_8	1,45,319	1,21,655	0.84
T_9	1,64,761	99,157	0.60
T_{10}	48,769	81,659	1.67
T_{11}	48,106	1,00,823	2.10
T_{12}	43,940	96,657	2.20

Price of pepper Rs. 75 kg^{-1} (2002)

T_1: GA_3 25 ppm T_4: Kinetin 100 ppm T_7: BAP 200 ppm T_{10}: NAA 50 ppm
T_2: GA_3 50 ppm T_5: Kinetin 150 ppm T_8: BAP 250 ppm T_{11}: Water spray
T_3: GA_3 100 ppm T_6: Kinetin 200 ppm T_9: BAP 300 ppm T_{12}: No spray

Table 52. Economics of treatments for experiment III

Treatments	Total cost (Rs ha^{-1})			Total returns (Rs ha^{-1})			Benefit cost ratio		
	2001	2002	Mean	2001	2002	Mean	2001	2002	Mean
T_1	47,773	50,051	48,912	1,50,785	1,47,485	1,49,135	3.16	2.95	3.06
T_2	47,773	50,051	48,912	1,45,952	1,24,988	1,35,470	3.06	2.50	2.78
T_3	41,851	43,940	42,896	1,40,153	1,26,654	1,33,404	3.35	2.88	3.12

Price of pepper Rs. 87 kg^{-1} (2001), Rs. 75 kg^{-1} (2002)

T_1: Pruning the laterals to one node below the point of harvest

T_2: Pruning the laterals to two nodes below the point of harvest

T_3: No pruning

Discussion

5. DISCUSSION

Black pepper is a major spice crop of India, contributing a lion share of export earnings from spices. Even though India being a major producer of pepper, productivity of the crop is low compared to other pepper producing countries. In order to capture the world market and to meet the internal demand, we have to boost our pepper production by various crop management practices available. Hence the present investigations were carried out during 2000 to 2003 at pepper garden, Department of Plantation Crops and Spices, College of Horticulture, Vellanikkara. The results obtained from the investigations for enhancing the pepper production are discussed hereunder different heads:

5.1 EXPERIMENT I: EFFECT OF IRRIGATION ON YIELD OF BLACK PEPPER

Black pepper is subjected to moisture stress during December to April, because of the uneven distribution of rainfall prevailing in Kerala. The present study aimed to elucidate the effect of dry spell on subsequent season's yield by substituting irrigation at periodic intervals during the drought period. It can also help in the optimization of irrigation schedule for the drought period to obtain maximum yield in pepper.

5.1.1 Morphological Characters

A perusal of the data indicated that irrigation during summer months failed to manifest a significant effect on growth characters of the lateral viz., number of leaves per lateral, leaf area per lateral, length of lateral, internodal thickness of lateral, angle of insertion of lateral to the main stem, time of spike initiation of the lateral, number of spikes and spike to leaf ratio per lateral, both during 2001 and 2002. However, fogger irrigation up to March recorded higher values with respect to number of leaves, number of spikes and spike to leaf ratio per lateral. Pepper being a perennial crop, there is a possibility that irrigation may enhance these characters significantly in the coming years.

Summer irrigation was found to influence the production of spike bearing laterals in a unit area. The plants irrigated with fogger method up to February (T_6) and March (T_5) and basin method up to March (T_8) registered higher number of spike bearing laterals during 2001 whereas, plants irrigated up to March by rocker sprayer (T_2) and fogger (T_5) methods and continuous irrigation (T_{11}) produced higher number of spike bearing laterals during 2002 (Fig. 1).

Though summer irrigation failed to enhance the spike length, it could increase the number of well developed berries in a spike during 2002. The maximum number of berries was noticed in plants, treated with rocker sprayer irrigation up to March (T_2). The plants treated with fogger irrigation up to March (T_5), basin irrigation up to February (T_9) and March (T_8) and irrigation throughout summer period (T_{11}) also recorded significantly higher berry number compared to unirrigated plants (Fig. 2). The increase in number of well developed berries without significant increment in spike length may be due to the development of more number of well developed berries from undeveloped berries produced in the spike as a result of irrigation. The spike compactness was also influenced significantly by the irrigation only during 2002 and maximum compactness was registered in plants treated with rocker sprayer irrigation up to March (T_2)(Table 3). This can be attributed to the higher number of well developed berries produced on the spike during 2002.

Application of irrigation resulted in higher berry weight during both years of the experiment. During 2001, maximum weight of green berries was recorded in plants treated with rocker sprayer irrigation up to March (T_2) whereas during 2002, basin irrigation up to March (T_8) recorded highest berry weight (Fig. 3). Berry volume also registered significant enhancement in response to the irrigation treatments. All treatments influenced positively the volume of green berries during 2001 with maximum in rocker sprayer irrigation up to March (Fig. 4) while they failed to maintain their significant effect on the berry volume in the subsequent year. However, plants treated with fogger irrigation up to March (T_5) registered higher berry volume during 2002.

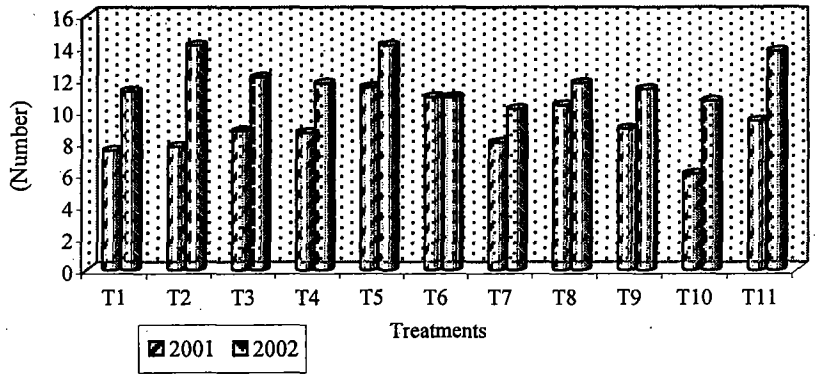


Fig. 1. Effect of irrigation on number of spike bearing laterals in black pepper var. Panniyur 1

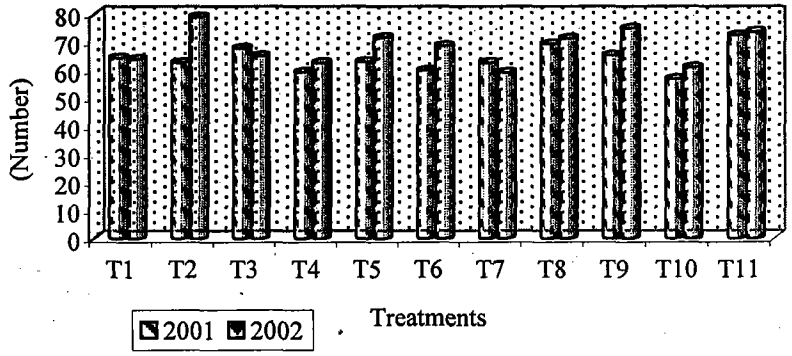


Fig. 2. Effect of irrigation on number of well developed berries per spike in black pepper var. Panniyur 1

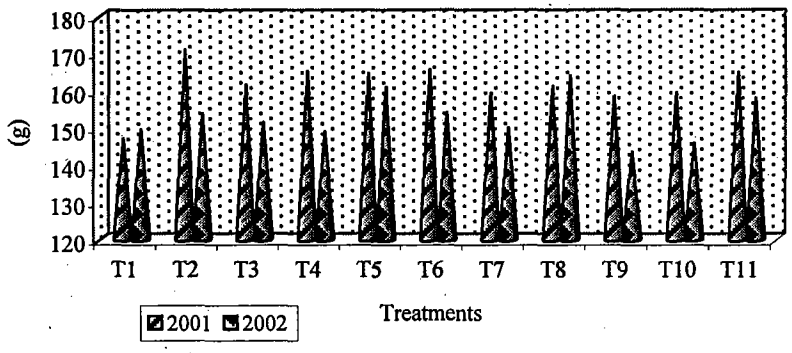


Fig. 3. Effect of irrigation on weight of 1000 green berries in black pepper var. Panniyur 1

T1: No irrigation (Control)

T2: Five litres of rocker sprayer irrigation up to March

T3: Five litres of rocker sprayer irrigation up to February

T4: Five litres of rocker sprayer irrigation up to January

T5: Five litres of fogger irrigation up to March

T6: Five litres of fogger irrigation up to February

T7: Five litres of fogger irrigation up to January

T8: Ten litres of basin irrigation up to March

T9: Ten litres of basin irrigation up to February

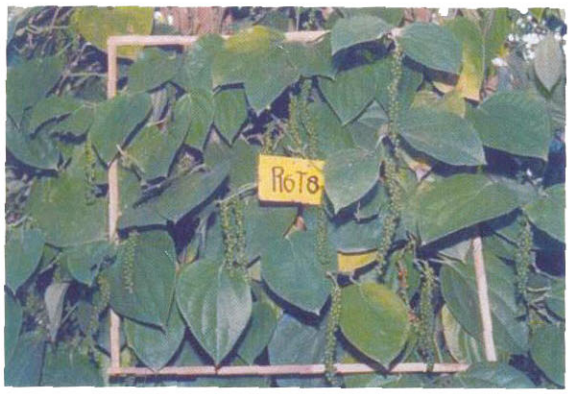
T10: Ten litres of basin irrigation up to January

T11: Irrigation throughout summer period

The irrigation during drought months in pepper could not exert any significant effect on the dry recovery percentage of berries during both years. Green yield and dry yield per vine registered significant improvement in the yield only in the second year of the experiment. However, highest yield was observed in plants treated with basin irrigation up to March (T_8) irrespective of the years (Fig. 5). The treatment plants showed 64 per cent improvement in green yield and 48 per cent improvement in the dry yield during 2002 compared to unirrigated vines (Plate 8). However, the yield obtained was statistically on par with basin irrigation up to February, rocker sprayer irrigation up to February and irrigation throughout summer period. Even though fogger irrigation up to March enhanced the growth characters of lateral, the improvement of yield was less compared to other treatments. This is probably because of the partitioning of more photosynthates to the vegetative parts compared to economic sink. Though summer irrigation failed to improve the vegetative characters significantly, the results indicated that irrigation exerted a pronounced effect on most of the yield contributing characters, which is in accordance with the reports made by Sadanandan (1996), IISR (1997), Satheeshan *et al.* (1998), Thankamani (2000) and AICRPS (2001).

In most of the characters, irrigation up to March recorded higher values compared to other two durations and continuous irrigation. Continuous irrigation recorded a lower yield though it was statistically on par with that of irrigation up to March. The result is in agreement with the reports already available in black pepper. Thankamani (2000) observed a higher yield in drip irrigation @ 16 litres per plant during October to March compared to that of the yield obtained from plants irrigated during October to May which indicated the requirement of a water stress period for induction of flowering and yield in pepper. Satheeshan *et al.* (1998) also observed a higher yield in field planted vine pepper var. Panniyur 1 when basin irrigated from October to March.

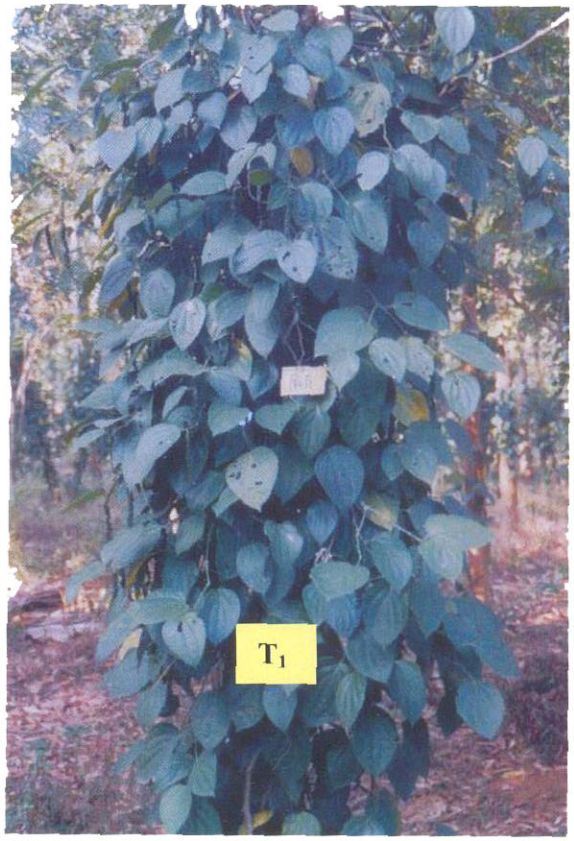
Analysing the overall performance, it was realized that the growth and yield characters of pepper vine recorded higher during 2002 compared to 2001. During the period of application of irrigation treatments (December- April), the year 2001 recorded 11 rainy days with total rainfall of 270.9 mm whereas, year 2002 recorded 6 rainy days with total rainfall of 67.1 mm (Appendices I and II). The data revealed that summer



A) Number of productive laterals in a vine under treatment basin irrigation up to March

B) Number of productive laterals in a vine under unirrigated control

C) A pepper vine under treatment basin irrigation up to March



D) A pepper vine under unirrigated control

Plate 8. Pepper vines under irrigation treatments

showers recorded was low during 2002 and in that particular year, December, January and February were completely free of rainfall. Analysing the yield data of Panniyur 1 (Irrigation experiment) and Panniyur 2 (Pruning experiment), it was found that Panniyur 1 expressed a considerable variation in dry yield per vine between years (0.73 kg and 1.50 kg for 2001 and 2002 respectively) while in Panniyur 2, which is a stable yielder, there was not much variation in dry yield per vine (1.51 and 1.59 kg for 2001 and 2002 respectively). Since Panniyur 1 and Panniyur 2 had experienced the same climatic situation, it was understood that summer rains had no pronounced impact on yield during the experimental period which is not in agreement with the report by Kannan *et al.* (1987). However, it is advisable not to make a conclusive statement with regard to this in a crop like black pepper with two years' data. The yield variation in Panniyur 1 may be due to its alternate bearing nature. Because of this nature of Panniyur 1, explanation of the effect of rainfall during drought period on the irrigation treatments also became complex. The irrigation experiment may be repeated in a stable yielding variety like Panniyur 2 to get a conclusive result.

5.1.2 Biochemical Characters

The growth and development in pepper is in a cyclic fashion. After harvest, the vines enter into a dormant stage and with the onset of South West monsoon, a sudden spurt in all metabolic activities leads to the production of new growth, which is referred as flushing in pepper. Panicles emerge on the axil of the new leaves followed by berry set and berry development. The sudden shift from the dormant vegetative phase to reproductive phase results in significant changes in various physiological and biochemical characters. The analysis of plant extracts for various parameters can help in better understanding of the metabolism to evaluate the change in the methods of management and performance of crop plants. The biochemical constituents at important physiological stages viz., before flushing, flushing and flowering and fruit set were studied and the results obtained are discussed below:

5.1.2.1 Leaf Chlorophyll

The application of summer irrigation had resulted in significant enhancement in the chlorophyll 'a' and total chlorophyll content over unirrigated plants. However,

irrigation could not influence the chlorophyll 'b' content of pepper leaves. Chlorophyll 'a' is directly related to photosynthetic efficiency of a plant rather than chlorophyll 'b'. Since water is having a role in photosynthesis, irrigation may have influenced the synthesis of chlorophyll 'a' compared to chlorophyll 'b'. Only the plants treated with basin irrigation up to March (T_8) registered significantly higher mean chlorophyll 'a' and total chlorophyll content (Fig. 6). Since the yield obtained was also highest in the treatment, the positive correlation between leaf chlorophyll content and yield reported in other crops (Mathew and Ramadasan, 1975; Anakaiah and Rao, 1991) was revealed in the present study also. Higher chlorophyll content in the plants may have helped them for more metabolite production leading to subsequent higher yield.

The chlorophyll 'a', 'b' and total chlorophyll content reduced in the new flushes at flowering from that of past season leaves and again increased at fruit set (Fig. 7a). The physiological necessity of food material for further growth and development substantiate the high chlorophyll content in the leaves prior to flushing. At flushing and flowering stage, the leaves are too young and chlorophyll may not have got stabilized in the leaves. But after panicle development, as the flowering proceeds to fruit set, the leaves become autotrophic, photosynthetically more active and attains a dark green colour due to increased chlorophyll content. Similar observation was reported at different physiological stages in cashew (Pushpalatha, 2000).

5.1.2.2 Total Phenol and Polyphenol Oxidase Activity

Irrigation failed to influence the mean total phenol content of pepper leaves. However, maximum content of phenol was noticed in plants treated with basin irrigation up to February (Table 6). The activity of total PPO also recorded significant enhancement in plants treated with basin irrigation up to February (Fig. 8). This may be due to the higher phenol content present in the leaves of the treatment plants.

In all the experimental plants, phenol content reduced significantly at flushing and flowering compared to pre flushing and further reduced at fruit set stage (Fig. 7b). This observation is in conformity with the findings of Sherlija and Unnikrishnan (1996) and Pushpalatha (2000) in cashew. The lower levels of phenols at flushing and flowering may be due to the fact that certain phenolics may get degraded to

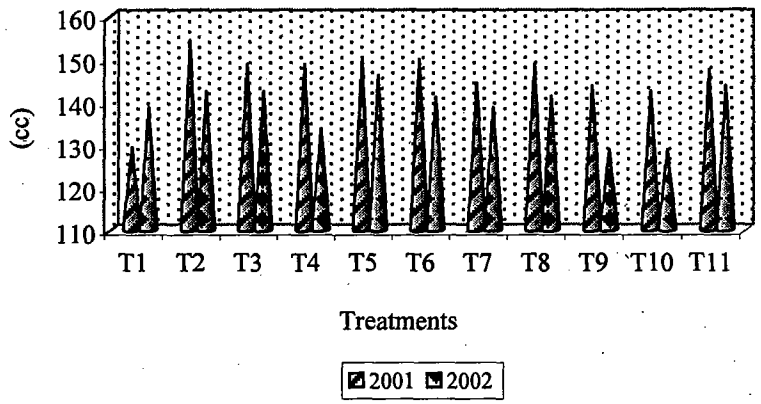


Fig. 4. Effect of irrigation on volume of 1000 green berries in black pepper var. Panniyur 1

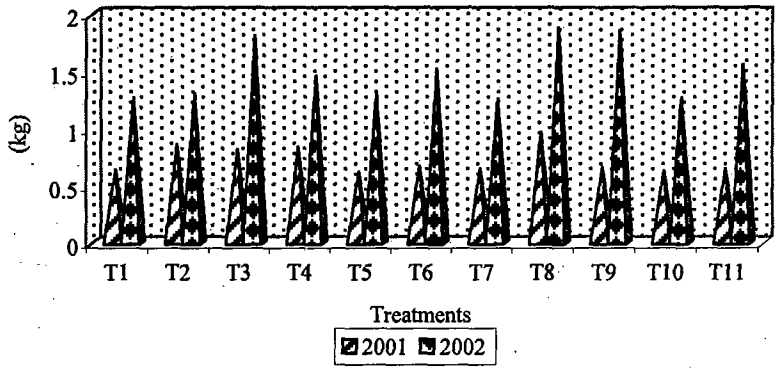


Fig. 5. Effect of irrigation on dry yield per vine in black pepper var. Panniyur 1

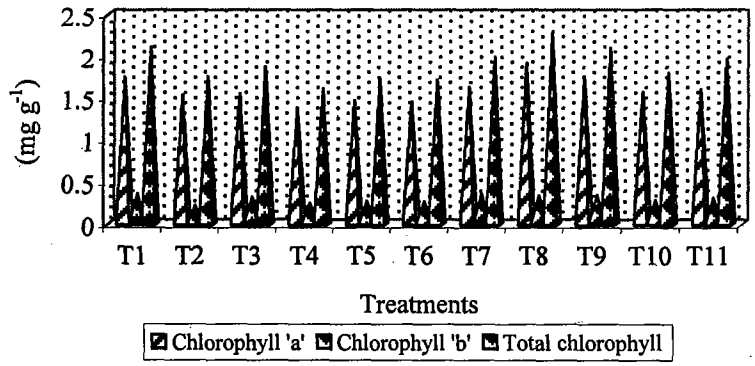


Fig. 6. Effect of irrigation on leaf chlorophyll content in black pepper var. Panniyur 1

T1: No irrigation (Control)

T2: Five litres of rocker sprayer irrigation up to March

T3: Five litres of rocker sprayer irrigation up to February

T4: Five litres of rocker sprayer irrigation up to January

T5: Five litres of fogger irrigation up to March

T6: Five litres of fogger irrigation up to February

T7: Five litres of fogger irrigation up to January

T8: Ten litres of basin irrigation up to March

T9: Ten litres of basin irrigation up to February

T10: Ten litres of basin irrigation up to January

T11: Irrigation throughout summer period

promote flowering. Also phenols serve as the intermediary compounds in the pathway of synthesizing compounds like carbohydrates, amino acids and aromatic derivatives. This also emphasis the further reduction in phenol content at fruit set. The reduction in phenol content at fruit set can also be attributed to the distribution of these compounds for the build up of secondary metabolites like oleoresin and essential oil in the berries at fruit set. Similar trend was also observed with regard to the activity of PPO in different physiological stages of black pepper (Fig. 7c).

5.1.2.3 Peroxidase Activity

Though the irrigation treatments recorded significant difference at different stages analysed, the mean peroxidase activity did not show any significant enhancement over unirrigated plants (Table 8). Prior to flushing, peroxidase activity was highest and it reduced in the new flushes at flowering stage and again increased at fruit set (Fig. 7d). The result is in conformity with the report made by Golodriga and Pucao (1963) that during early berry growth stage in grapes increased peroxidase activity was observed. Vora and Vyas (1974) also reported higher peroxidase activity whenever there was differentiation.

5.1.2.4 Nitrate Reductase Activity

The irrigation during drought months was found to affect significantly the activity of nitrate reductase in pepper leaves. The treatments did not record any definite trend in the activity at different stages analysed. However, the mean NRA was significantly higher in the plants treated with rocker sprayer and fogger methods of irrigation up to March (Fig. 9).

The activity of nitrate reductase was low in the past season leaves just before flushing and it increased drastically at flowering in the new flushes again reduced at fruit set stage (Fig. 7e). Since nitrate reductase is a substrate dependent enzyme, peak activity during flowering and minimum activity prior to flushing can be attributed to the levels of nitrogenous intermediates in the plant. The result is in conformity with the report on seasonal variation in the activity of nitrate reductase in pepper. Thomas (1990) observed two activity peaks in pepper, one in August and other in February.

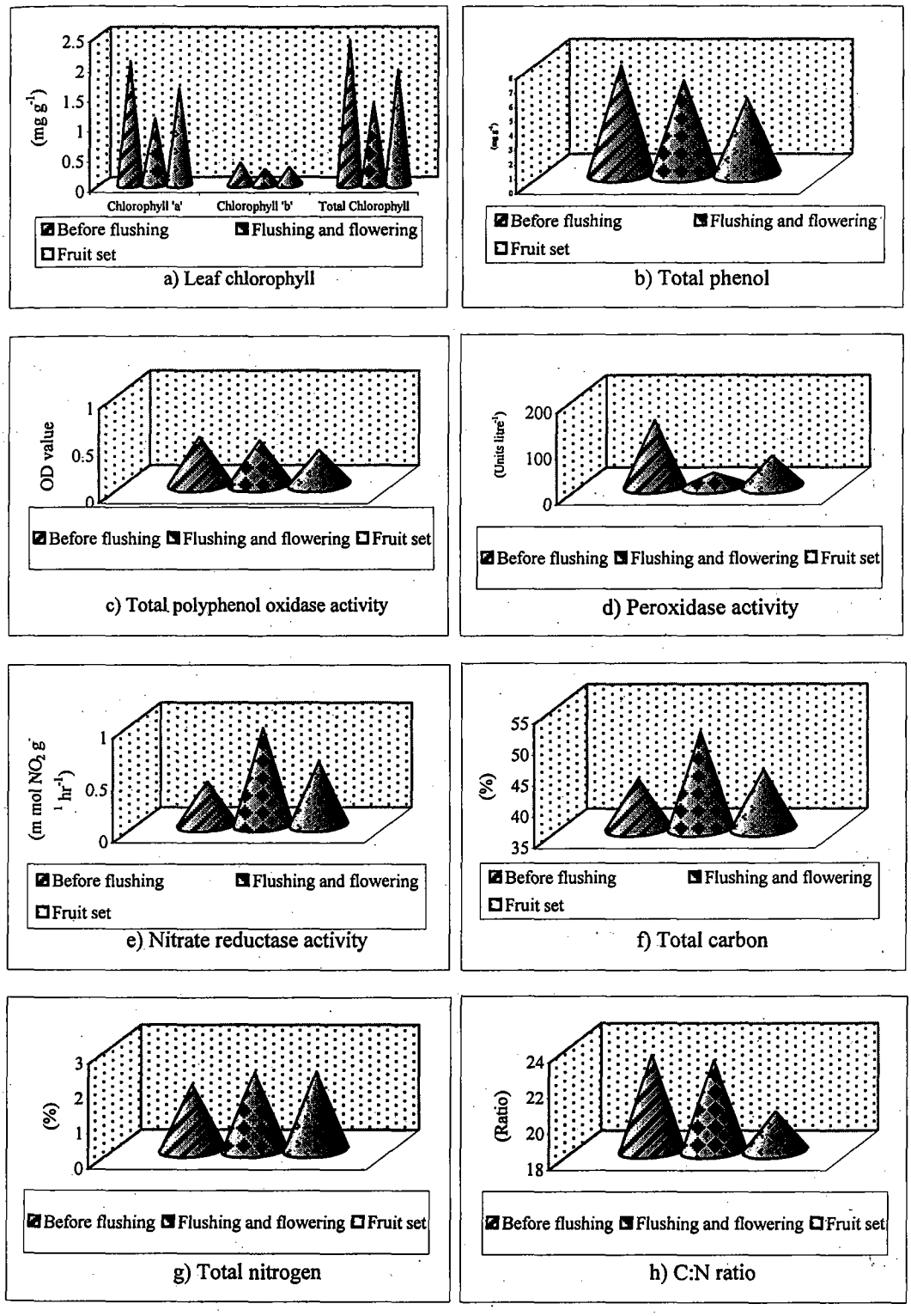


Fig. 7. Variation in biochemical characters of leaves at different physiological stages in black pepper

After February, the activity declined sharply up to May and then showed fairly high NRA in June coinciding with flushing and flowering, which declined further. Deckard *et al.* (1973) and Ramadevi (1986) observed peak activity of nitrate reductase at flowering stage in rice. In cashew and mango also nitrate reductase showed highest activity at flowering (Devi and Tyogi, 1991).

5.1.2.5 C:N Ratio

5.1.2.5.1 Total Carbon

Summer irrigation was found to enhance the mean total C content only in the plants treated with basin irrigation up to March (Table 10). It may be due to the higher assimilation of C in the leaves of the treatment plants. Prior to flushing and at flushing and flowering stages, basin irrigation up to March recorded significantly highest total C content (Fig.10). At fruit set stage, the reduction in C content from flowering to fruit set was more in basin irrigation up to March and February. This may be due to the better translocation of C assimilates in the leaves for berry set and berry filling.

The total C content in the leaves of all experimental plants recorded maximum at flowering in new flushes and decreased at berry set (Fig. 7f). The changes in total C content of leaves during different physiological stages can be attributed to the accumulation and utilization of C compounds like starch and carbohydrates. In pepper, as the spikes grows, the leaves on the current season shoots get matured and become photosynthetically more active. The pumping of carbohydrate reserves from the past season growth to newly developed lateral for fastening the physiological activities also may have resulted in the higher total C content at flowering stage. Translocation of nutrients from old to younger leaves has already been reported in mango (Chacko *et al.*, 1972) in response to renewal of growth. Greater accumulation of metabolites at the time of flower initiation was reported in several crops like mango (Chacko and Ananthanarayanan, 1982), pepper (Rajan, 1985) and cashew (Sherlija and Unnikrishnan, 1996; Pushpalatha, 2000). The leaves act as the storage organ for carbon metabolites and supply of these stored nutrients to the developing berries may be the reason for the decline in total C content at fruit set. High carbohydrate content in

reproductive flushes and greater depletion after fruit set was observed in mango (Veera and Rao, 1977) and cashew (Pushpalatha, 2000).

5.1.2.5.2 Total Nitrogen

The mean foliar N showed significant enhancement only with the irrigation treatment, fogger irrigation up to February (Fig. 11). No definite trend among the treatment was observed at different stages analysed (Table 10).

The N content in the leaves also showed the minimum content prior to flushing and increased at flushing and flowering and recorded maximum at fruit set stage (Fig. 7g). Nybe *et al.* (1989) registered two peaks for foliar N in June and October while the lowest level was in April. Nalini (1983) and Rajan (1985) also reported a gradual increase in the foliar N content from the second fortnight of May onwards showing peak in June-July. Simultaneously with panicle initiation, the leaves on the new lateral mature and N mobilized from past season growth may get stored in these current season growth for the ensuing berry set and development. This might be the reason for higher N content observed at flowering and fruit set stages in pepper.

5.1.2.5.3 C:N Ratio

Though the mean C:N ratio was not significantly affected by the irrigation treatments applied, enhancement in the ratio was noticed at pre flushing and flushing and flowering stages (Table 10). Plants treated with basin irrigation up to March recorded maximum C:N ratio prior to flushing while, basin irrigation up to February recorded highest C:N ratio at flushing and flowering. This suggests a possible biochemical basis for a heavy flowering in the treatment plants, considering the role of C:N ratio in flowering. The C:N ratio was higher at flushing and flowering stage and it reduced after fruit set (Fig. 7h). The result is in conformity with the reports of Nalini (1983) and Rajan (1985) that C:N ratio in pepper showed peak value in June coinciding with maximum flower bud differentiation activity. In mango also, maximum C:N ratio was observed at flowering (Shivasankara and Mathai, 1995). Reduced total C content and increased N content at fruit set may have resulted in low C:N ratio at fruit set.

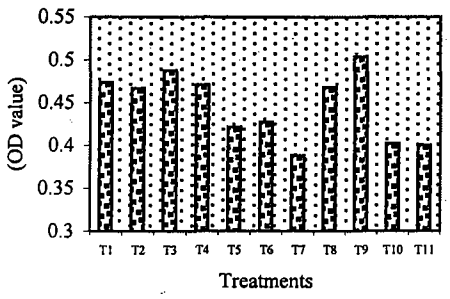


Fig. 8. Effect of irrigation on total polyphenol oxidase activity of leaves in black pepper var. Panniyur 1

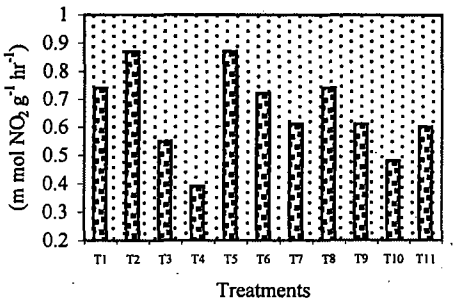


Fig. 9. Effect of irrigation on nitrate reductase activity of leaves in black pepper var. Panniyur 1

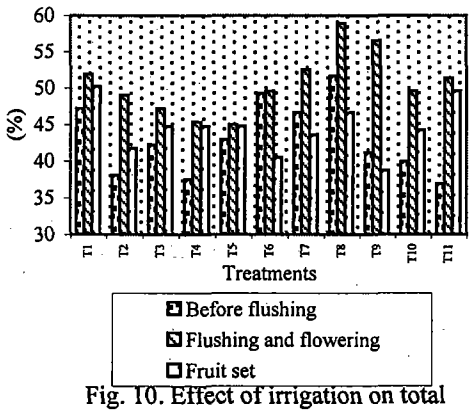


Fig. 10. Effect of irrigation on total carbon content of leaves in black pepper var. Panniyur 1

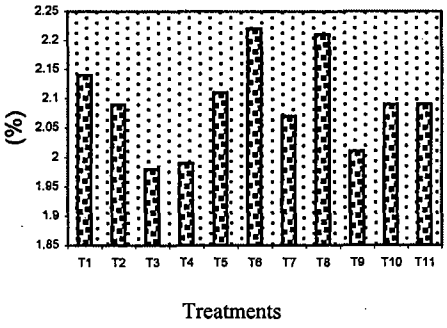


Fig. 11. Effect of irrigation on total nitrogen content of leaves in black pepper var. Panniyur 1

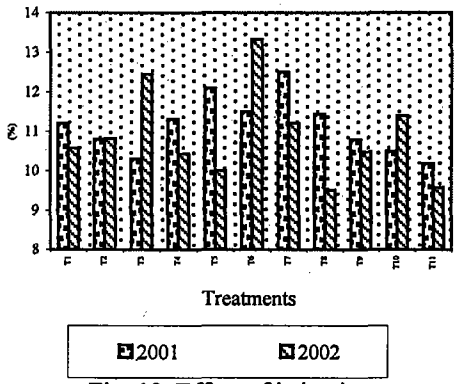


Fig. 12. Effect of irrigation on oleoresin content of berries in black pepper var. Panniyur 1

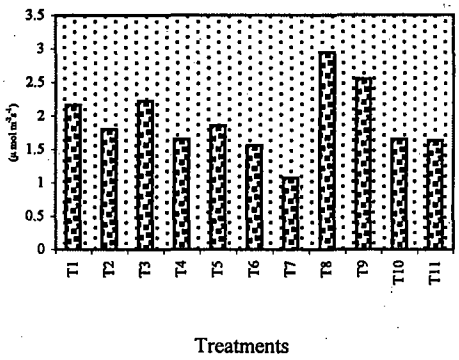


Fig. 13. Effect of irrigation on leaf photosynthetic rate in black pepper var. Panniyur 1

T1: No irrigation (Control)

T2: Five litres of rocker sprayer irrigation up to March

T3: Five litres of rocker sprayer irrigation up to February

T4: Five litres of rocker sprayer irrigation up to January

T5: Five litres of fogger irrigation up to March

T6: Five litres of fogger irrigation up to February

T7: Five litres of fogger irrigation up to January

T8: Ten litres of basin irrigation up to March

T9: Ten litres of basin irrigation up to February

T10: Ten litres of basin irrigation up to January

T11: Irrigation throughout summer period

5.1.2.6 Quality Parameters

Summer irrigation failed to enhance the quality parameters like essential oil and piperine content of berries. The treatments fogger and rocker sprayer irrigation up to February significantly enhanced the oleoresin content during 2002 (Fig.12). Satheeshan *et al.* (1998) reported increased oleoresin content with irrigation at IW/CPE ratio of 0.25. Thankamani (2000) also observed enhanced oleoresin content with the application of drip irrigation at the rate of 8 litres per plant.

5.1.3 Physiological Characters

An evaluation of the physiological parameters revealed that the plants treated with basin irrigation up to March exhibited a higher mean photosynthetic rate of leaves (Fig. 13). It exhibited a higher rate of photosynthesis at fruit set stage also. The higher photosynthetic rate observed in the treatment plants indicates their improved metabolic status, which may have resulted in improved assimilation and thus higher yield observed in them. This is in agreement with the report (Edson *et al.*, 1995) that single leaf photosynthesis at each development stage is positively correlated with crop load. The changes in other physiological parameters like PAR, stomatal conductance, leaf temperature, and transpiration rate are affected more by the atmospheric condition of the season at which observation was taken. Hence the changes in these parameters are explained with respect to their relation with photosynthetic rate. The mean stomatal conductance of the treatment plants showed a linear relationship with the phtosynthetic rate. This is in agreement with the report by Ehleringer and Bjorkman (1978) that there is a positive correlation between photosynthetic rate and stomatal conductance. Transpiration rate of the treatment plants also showed a positive correlation with the stomatal conductance and photosynthetic rate. Stomatal resistance exhibited an inverse relationship with photosynthetic rate and stomatal conductance.

The photosynthetic rate was very low prior to flushing and it increased drastically in the new leaves and recorded maximum at fruit set stage (Fig. 14a). The result is in agreement with the report in cashew that the transition from dormant stage of buds to flushing and flowering was characterized by a spurt in the photosynthetic rate of

leaves (Palanisamy and Yadukumar, 1993). The formation of new leaves and extension of shoot growth at this period may have increased the demand of photosynthates thereby resulting in enhanced photosynthetic rate. At fruit set, more photosynthates are required for the formation and filling up of new berries. The photosynthetic rate increases with the increase in sink demand. So the maximum photosynthetic rate observed at fruit set can be attributed to the increased sink demand at this stage.

Photosynthetically active radiation recorded highest at before flushing stage (Fig. 14b) may be because of the increased light availability during summer period compared to rainy months in which pepper flowers and sets berries.

Stomatal conductance followed a similar pattern as that of photosynthetic rate. The comparatively lower stomatal conductance observed prior to flushing (Fig. 14c) compared to other two stages may be due to the stress condition induced by the higher temperature and low moisture status at drought period. Similar report is also available in cocoa (Balasimha, 1999). In cashew, reduced stomatal conductance with increase in the duration of stress was noticed by Latha (1998).

The highest stomatal resistance recorded prior to flushing (Fig. 14d) can be attributed to the reduced soil moisture during this period compared to flushing and flowering and fruit set stages. Vasantha *et al.* (1990) reported that stomatal resistance increased with increase in water stress in black pepper.

The significantly higher leaf temperature observed prior to flushing (Fig. 14e) can be attributed to the higher atmospheric temperature prevailing during the period. Enzymatically controlled CO_2 fixation is influenced by the leaf temperature. Increase in leaf temperature above a limit may decrease the photosynthetic rate of leaves. The reduction in leaf temperature at flushing and flowering and fruit set stages may be due to the cloudy atmosphere and low atmospheric temperature prevailing during the rainy season. Satheeshan (2000) also observed significant difference in leaf temperature at different physiological stages of crop growth in pepper.

The variation in transpiration rate (Fig 14f) observed at different stages indicate the levels of stress prevailed during the development of laterals and leaves

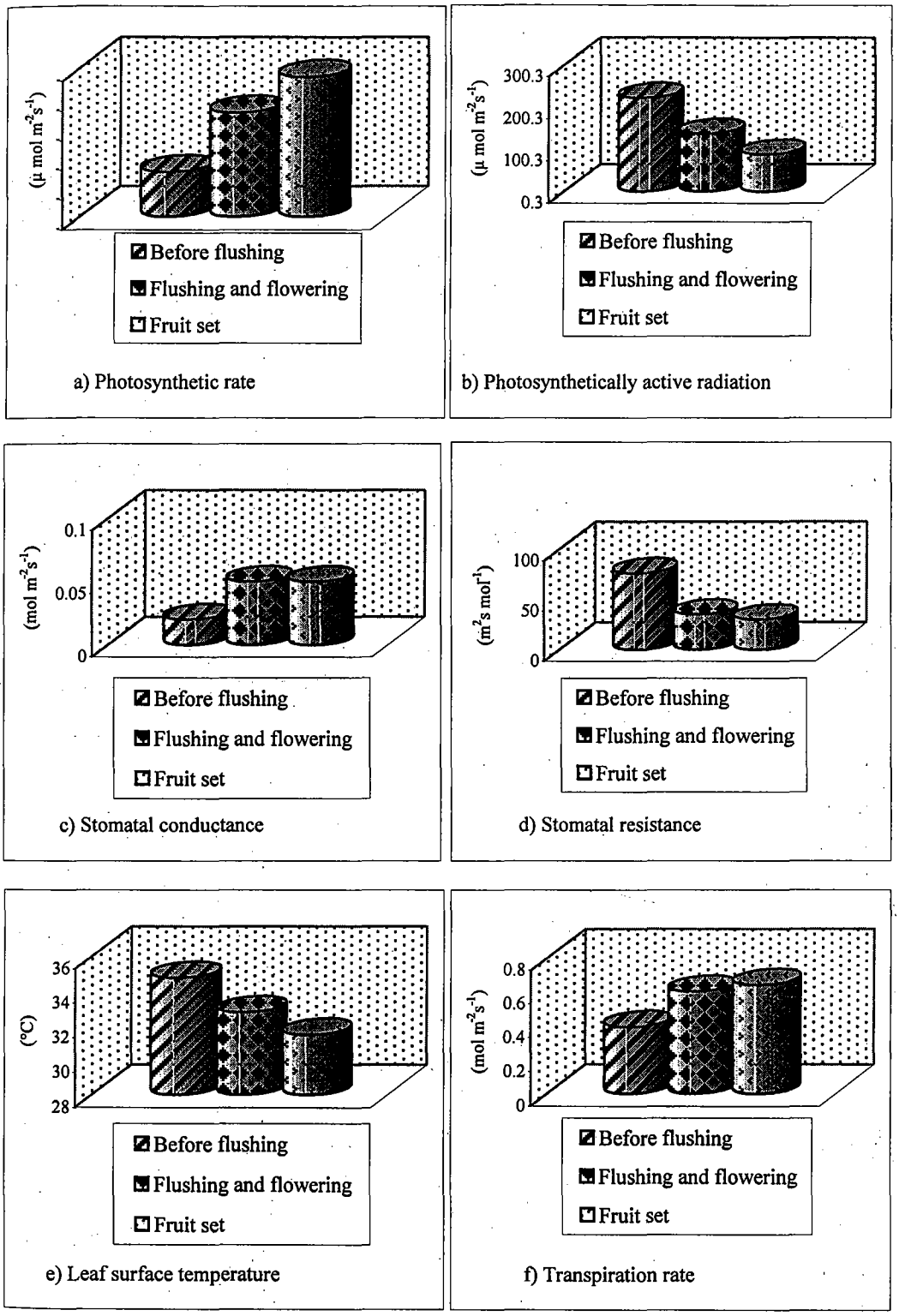


Fig. 14. Variation in the physiological characters of leaves at different physiological stages in black pepper

resulting from the seasonal and climatic effects. Seasonal variation in transpiration was also reported in cocoa by Balasimha (1999). The transpiration rate showed a similar pattern of change as in photosynthetic rate and stomatal conductance.

The leaf water potential did not record a significant change before and after the application of irrigation treatments. The result indicated that weekly irrigation of pepper vines during the experimental period failed to increase the water potential of leaves considerably (Table 18). The amount of water applied or the frequency of application may not be sufficient to increase the water potential during the drought months. However, a reduction in water potential was observed in the months of severe stress of drought. Such a reduction in the leaf water potential with the advancement of summer period was observed in coffee also (Venkataramanan *et al.*, 1998).

5.1.4 Economics of Treatments

The cost of cultivation recorded higher in 2002 due to the increase in the cost of inputs for the management and labour charge. Even though the cost of cultivation was high and price low, a high BCR was recorded during 2002 because of the higher yield and thus higher returns obtained. The highest cost observed in the case of rocker sprayer irrigation up to March is due to the higher labour requirement needed for the application of the treatment compared to others. The highest BCR was registered in the treatment, basin irrigation up to March. It is due to the higher yield obtained from the plants with the application of the treatment compared to others.

Considering the yield improvement, feasibility of application and the economics of treatments (BCR), the basin irrigation up to March was found better compared to other treatments. Moreover, incidence of diseases particularly *Phytophthora* and pests were not observed during application period compared to the report by Satheeshan (1998) that weekly summer irrigation at an IW/CPE ratio of 0.25 (100 litres of water) increased the incidence of foot rot. However, the observations have to be continued for a few more years before conclusions are arrived at and recommendations are made.

5.2 EFFECT OF PLANT GROWTH REGULATORS ON FLOWERING AND YIELD IN BLACK PEPPER

The plant growth regulators play vital roles in the growth and development of crop plants. They are commercially exploited in various crops for enhancing productivity. The present investigation aimed to study the effect of growth regulators for increasing the growth and yield attributes of pepper vine thereby leading to higher productivity. The results obtained in the study are discussed hereunder:

5.2.1 Morphological Characters

An evaluation of the results indicated that among vegetative characters, growth regulators could influence only leaf area per lateral and lateral length. The growth characters of lateral like number of leaves, internodal thickness, angle of insertion of lateral to the main stem and spike to leaf ratio were unaffected by the application of growth regulators. Of all the vegetative parameters, the number of leaves and their size form the prominent factors that influence growth and yield of a crop. This points to the quantity of photosynthates that are accumulated by the plant. Though not significant, number of leaves per lateral was found 39 per cent more in the growth regulator treatment GA_3 100 ppm (T_3) and 30 per cent more in 150 ppm (T_5) and 200 ppm (T_6) of kinetin over the absolute control (Fig. 15a). This is contradictory with the report in grape vines that application of 100 ppm GA_3 decreased the leaf number compared to untreated grape vines (Khurshid *et al.*, 1992).

The leaf area per lateral was enhanced by the application of cytokinins (150 ppm and 200 ppm of kinetin and 250 ppm BAP) and GA_3 (100 ppm). The application of cytokinins enhanced the leaf area per lateral by 1.5 and 1.4 times respectively for kinetin and BAP over both water spray and absolute control. (Fig. 15b). Leaf growth and development are under the control of endogenous ratios of gibberellins to cytokinins (Letham *et al.*, 1982; Renfroe and Brown, 1983). Foliar application of gibberellins accelerates the cell loosening effects of auxins on cell walls (Jones and Macmillan, 1984; Takabashi *et al.*, 1986) and positively affects vegetative growth. It

brings about cell elongation and results in broader and elongated leaves and thus increases the photosynthetic area in various crop plants (Mahmoud, 1989; Inoue, 1990).

The typical functions of cytokinins include cell division and expansion, which mark the basic steps of growth. A combination spray of gibberellins and BA applied on to the buds of four year old field grown trees of mangosteen, significantly increased the number of new flushes (leaves) as well as leaf area (Wiebel *et al.*, 1992). Zhu *et al.* (1989) had reported that application of BAP at 100 ppm and 200 ppm concentrations accelerated the auxillary bud sprouting in Satsuma mandarin. Improved leaf area in lemon was also reported with the application 25 ppm BA (Thukral *et al.*, 1994).

The significant increase in the lateral length observed as a result of spray with growth regulators viz; 250 ppm BAP and 100 ppm GA_3 (Fig. 15c) is in accordance with the reports in grape vines (Mahmoud, 1989), citrus (Inoue, 1990) and lemon (Thukral *et al.*, 1994). The enhanced lateral length in GA_3 can be attributed to their characteristic increase in growth through cell elongation particularly at internodal region (Davis and Holmer, 1962; Ak *et al.*, 1995).

The higher number of spike bearing laterals produced as a result of cytokinin treatments, BAP 250 ppm and 300 ppm can be attributed to their major role in shoot production (Fig. 15d). Zhu *et al.* (1989) and Inoue and Ikoma (1991) had reported increased number of vegetative shoots and percentage of sprouting nodes in mandarin compared to control plants.

The foliar application of 250 ppm BAP was found to increase the spike production per lateral (Fig. 15e). Though not significant, spike to leaf ratio also recorded higher in plants treated with 250 ppm BAP (Fig. 15f) in pepper. The positive effect of cytokinins on inflorescence production was evidenced during the present investigation. Exogenous application of growth regulators might have either triggered the activity or substituted the role of naturally occurring flowering hormone or response. The favourable effects of cytokinins on the inflorescence production had been reported earlier by several workers (Nakayamma *et al.*, 1962; Maheshwari and Venkataraman, 1966; Usha, 1984). The application of GA_3 especially 100 ppm, had increased the spike

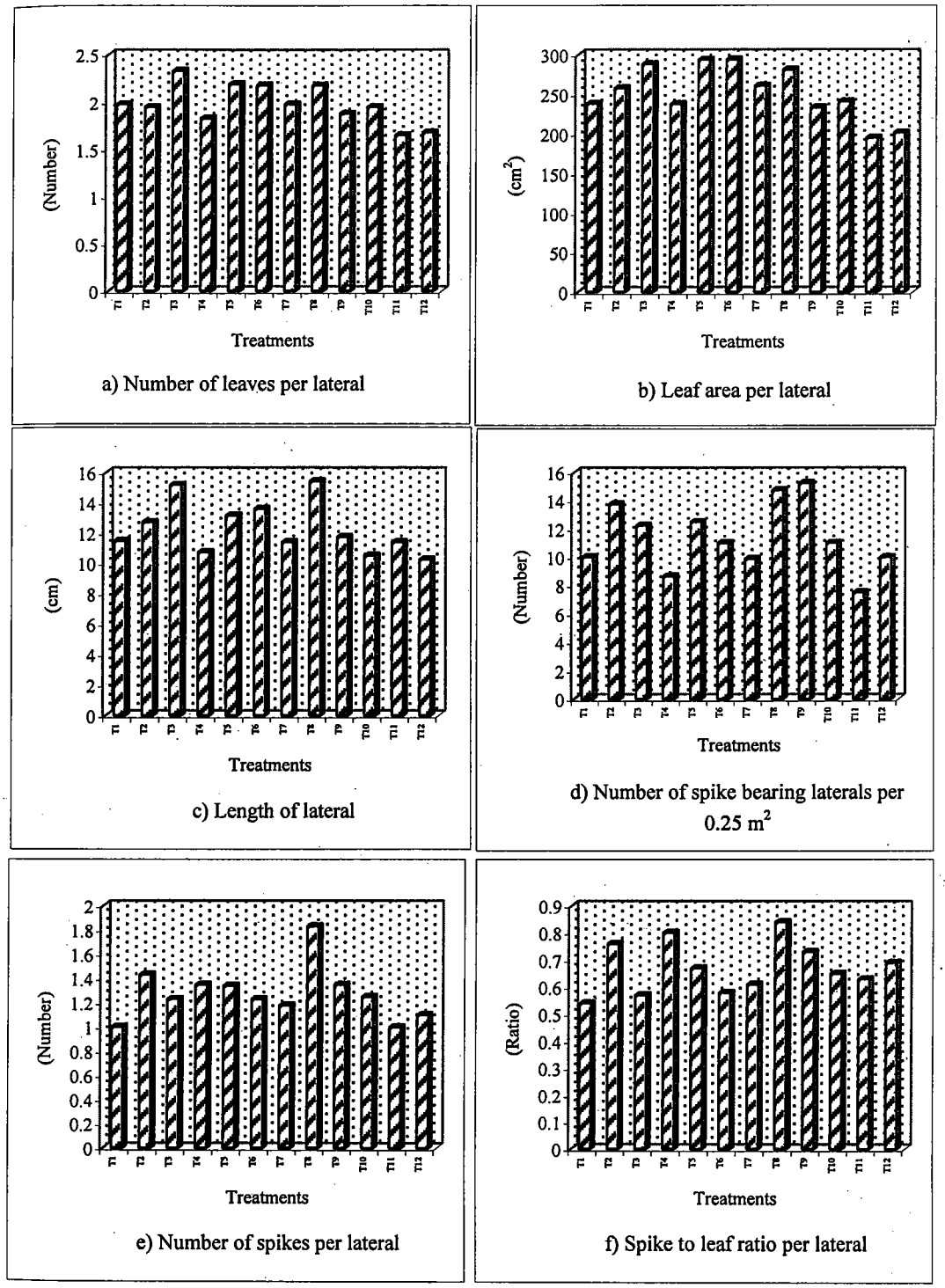
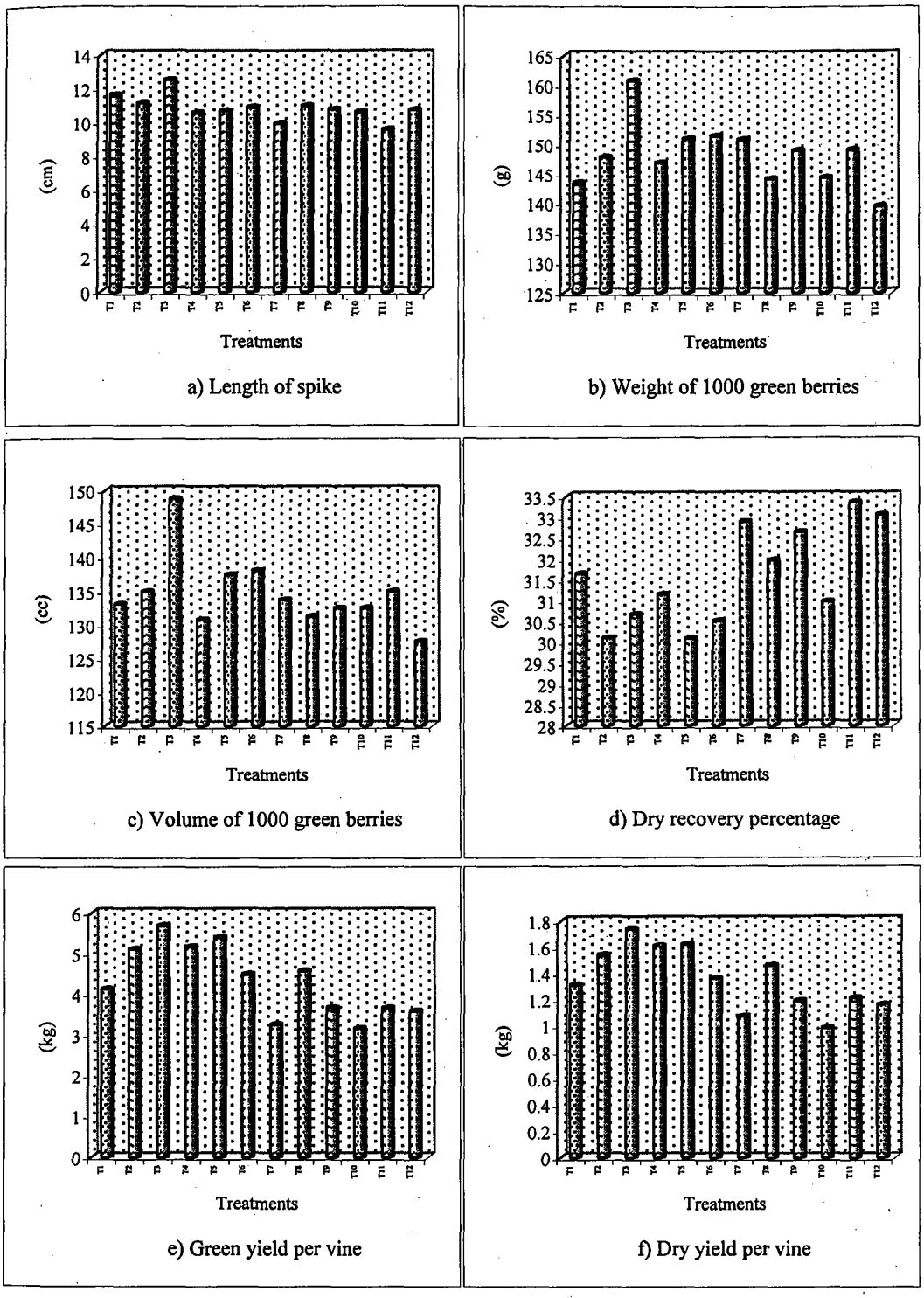


Fig. 15. Effect of growth regulators on growth and yield characters of lateral in black pepper var. Panniyur 2

length remarkably over plants sprayed with water and absolute control (Fig. 16a). This can be attributed to the role of gibberellins in cell elongation. The other growth regulators including auxin treatment failed to register significant effect on spike length over absolute control. Earlier trial in pepper by Geetha (1981) with different concentrations of auxins could not bring about any significant effect on spike length of black pepper.

None of the growth regulators applied could increase the number of well developed berries per spike and spike compactness significantly over absolute control. This is in conformity with the report already made by Geetha (1981). The foliar spray of 100 ppm GA_3 was found to enhance the weight of green pepper berries (Fig. 16b). Though not significant berry volume also recorded higher value with the application of 100 ppm GA_3 (Fig. 16c). The enhancement of berry weight and volume by different growth regulators like Planofix (Pillai *et al.*, 1977), 2,4-D, Vardhak (Geetha, 1981), GA_3 and NAA (Salvi and Desai, 1989) had reported earlier in black pepper.

All the growth regulator treatments resulted in lower percentage recovery of dry berries compared to absolute control and plants sprayed with water (Fig. 16d). This is in agreement with the observation made on dry recovery percentage by Geetha (1981) with auxin spray. Growth regulators are known to enhance synthesis of hydrophilic substances (Pande and Sinha, 1972). This may have resulted in increased water content of berries leading to lower recovery percentage while drying compared to control plants. Growth regulator treatments viz., 50 ppm GA_3 (T_2), 100 ppm GA_3 (T_3), 100 ppm kinetin (T_4) and 150 ppm kinetin (T_5) improved the green and dry yield (Fig. 16e and Fig. 16f). The maximum yield was noticed in plants treated with 100 ppm GA_3, which enhanced the green and dry yield by 58.94 per cent and 50 per cent respectively over absolute control. The enhancement of yield by growth regulators in a number of crops has been already reviewed. It may be due to the efficient translocation of assimilates towards the reproductive parts and increase in the efficiency of utilizing photosynthetic products. Growth regulators are known to enhance the activity of enzymes involved in the assimilation and translocation (Deboer and Feierabend, 1974). The increased yield can also be due to the increased leaf area and chlorophyll content resulting in proportionate increase in the yield contributing characters.



T_1: GA_3 25 ppm T_4: Kinetin 100 ppm T_7: BAP 200 ppm T_{10}: NAA 50 ppm
T_2: GA_3 50 ppm T_5: Kinetin 150 ppm T_8: BAP 250 ppm T_{11}: Water spray
T_3: GA_3 100 ppm T_6: Kinetin 200 ppm T_9: BAP 300 ppm T_{12}: No spray

Fig. 16. Effect of growth regulators on spike characters, berry characters and yield of balck pepper var. Panniyur 2

5.2.2 Biochemical Characters

The results obtained on the effect of growth regulators on various biochemical parameters are discussed below:

5.2.2.1 Leaf Chlorophyll

Chlorophyll plays a primary role in the absorption of energy for photosynthesis and therefore, the effect of growth regulators on chlorophyll synthesis or degradation can also indirectly affect photosynthesis. The application of growth regulators was found to enhance the chlorophyll 'a', 'b' and total chlorophyll contents of pepper leaves. The growth regulator treatments 100 ppm GA_3 and 250 and 300 ppm of BAP were efficient enough to increase chlorophyll 'a' content significantly over untreated plants while, 100 ppm GA_3 alone improved the chlorophyll 'b' and total chlorophyll (Fig. 17a). The maximum content of chlorophyll parameters was registered in plants treated with 100 ppm GA_3. The results corroborate with the reports made in chickpea (Bishnoi and Krishnamoorthy, 1992), mustard (Saran *et al.*, 1992), tree species (Naidu and Swamy, 1995) and aonla (Dhankar *et al.*, 1997). The increased chlorophyll content in GA_3 applied plants was attributed to the increase in cell number in petioles, leaves and stem which in turn increases the chloroplast count (Venkataramaiah and Swamy, 1981). It has been also suggested that application of growth regulators increases the availability of assimilates which in turn may cause prolonged chlorophyll synthesis (Treharne and Stoddart, 1968).

The enhanced chlorophyll content obtained with BAP treatments is also in agreement with the results of Balasimha *et al.* (1977) in *Phaseolus radiatus* and Goswami and Srivastava (1988) in sunflower. The enhancement of leaf chlorophyll by cytokinins can be attributed to increased synthesis or decreased chlorophyll degradation. cytokinins were found to lower the chlorophyllase activity (Purohit, 1982). Also Kaul and Sabharwal (1974) reported that cytokinins bring about a marked increase in the α amino levulinic acid dehydratase activity which catalyzes the formation of building blocks for chlorophyll in tobacco. The chlorophyll 'a', 'b' and total chlorophyll were

found higher at fruit set stage than at flushing and flowering. The probable reasons for the change have been discussed under section 5.1.2.1.

5.1.2.5 Total Phenol and Polyphenol Oxidase Activity

In general, all the growth regulators except the highest concentrations of cytokinins (200 ppm kinetin and 300 ppm BAP) reduced the total phenol content of pepper leaves (Fig. 17b). It has been proved that phenols are having nonspecific hormonal properties and they interfere with the action of growth hormones. Antagonizing effect between phenols and growth hormones was observed in peas (Laloraya *et al.*, 1980). The total phenol content recorded was higher at flushing and flowering stage and it reduced at fruit set stage. The probable reasons for the reduction in total phenol content at fruit set stage have already been discussed elsewhere in this chapter (5.1.2.2).

Plant growth hormones regulate the synthesis and activity of several enzymes taking part in metabolic pathways. They either retard or promote the activity of an enzyme (Purohit, 1982). In the present study, it was found that application of growth regulators generally reduced the activity of PPO. Only the lowest level of kinetin could enhance the PPO activity over untreated plants. The higher concentrations of kinetin, all levels of GA_3 and BAP reduced the enzymatic activity in general (Fig. 17c). Henry and Jordan (1977) and Jennings and Duffus (1977) also observed depressed activity of PPO with the application of GA_3 in peas and barley respectively.

5.2.2.3 Peroxidase Activity

The application of growth regulators reduced the activity of peroxidase except BAP treatments (200, 250 and 300 ppm) and 100 ppm GA_3. The activity was found highest in the plants treated with 250 ppm BAP (Fig. 17d). The enhanced activity of peroxidase with 100 ppm GA_3 and BAP application observed in the present study could be explained in the context of findings by several workers (Mc Cune and Galston, 1959; Harvey and Murray, 1968; Gayler and Glasziou, 1969; Sharma *et al.*, 1977; Panday and Sharma, 1984). The enhanced activity of the enzyme may be due to the retardation of the degradation of an existing enzyme or due to its *denovo* synthesis. The

activity of peroxidase was found higher at fruit set compared to flushing and flowering stage. The increased activity of peroxidase at fruit set stage has already discussed in the section 5.1.2.3.

5.2.2.4 Nitrate Reductase Activity

Nitrate reductase in leaves is the first in series of enzymes that reduce nitrate to ammonia which in turn is incorporated in to amino acid and then in to proteins. The results indicated that application of growth regulators like GA_3, kinetin and NAA enhanced the activity of nitrate reductase. Though 50 ppm NAA (T_{10}) exhibited maximum activity at flowering stage, i.e., soon after spraying, it failed to maintain its superiority at fruit set stage indicating that the influence of NAA on NRA is of short span in nature. While GA_3 and kinetin application maintained higher activity in the treatment plants at fruit set stage also (Fig. 17e). Enhanced activity of nitrate reductase by cytokinins is an indirect effect by retarding the degradation of a pre existing enzyme or through the enhancement of its activity (Guadinova, 1990). He observed a three fold increase in the activity when treated with kinetin. The result is also in accordance with other reports made by Rothbejerano and Lips (1970) and Gunther (1974). The higher NRA observed in the flushing and flowering period in pepper has already been discussed in 5.1.2.4.

5.2.2.5 C:N Ratio

It has been suggested that the application of growth regulators increases the availability of assimilates. The result also revealed that higher levels of GA_3 (T_2 and T_3) and BAP (T_8 and T_9), lower levels of kinetin (T_4 and T_5) and 50 ppm NAA enhanced the total C content of pepper leaves. The maximum C content was noticed in plants treated with 100 ppm GA_3. The enhanced C content can be attributed to the role of plant hormones in photosynthesis and C metabolism through the activation of enzymes involved in these processes. Of the many enzymes involved in carbohydrate metabolism, α amylase and invertase have exhibited either activation or induction by plant hormones. Obata and Suzuki (1976) stated that GA_3 is required for both induction and secretion of α amylase. Since linked with RNA and protein synthesis, gibberellins

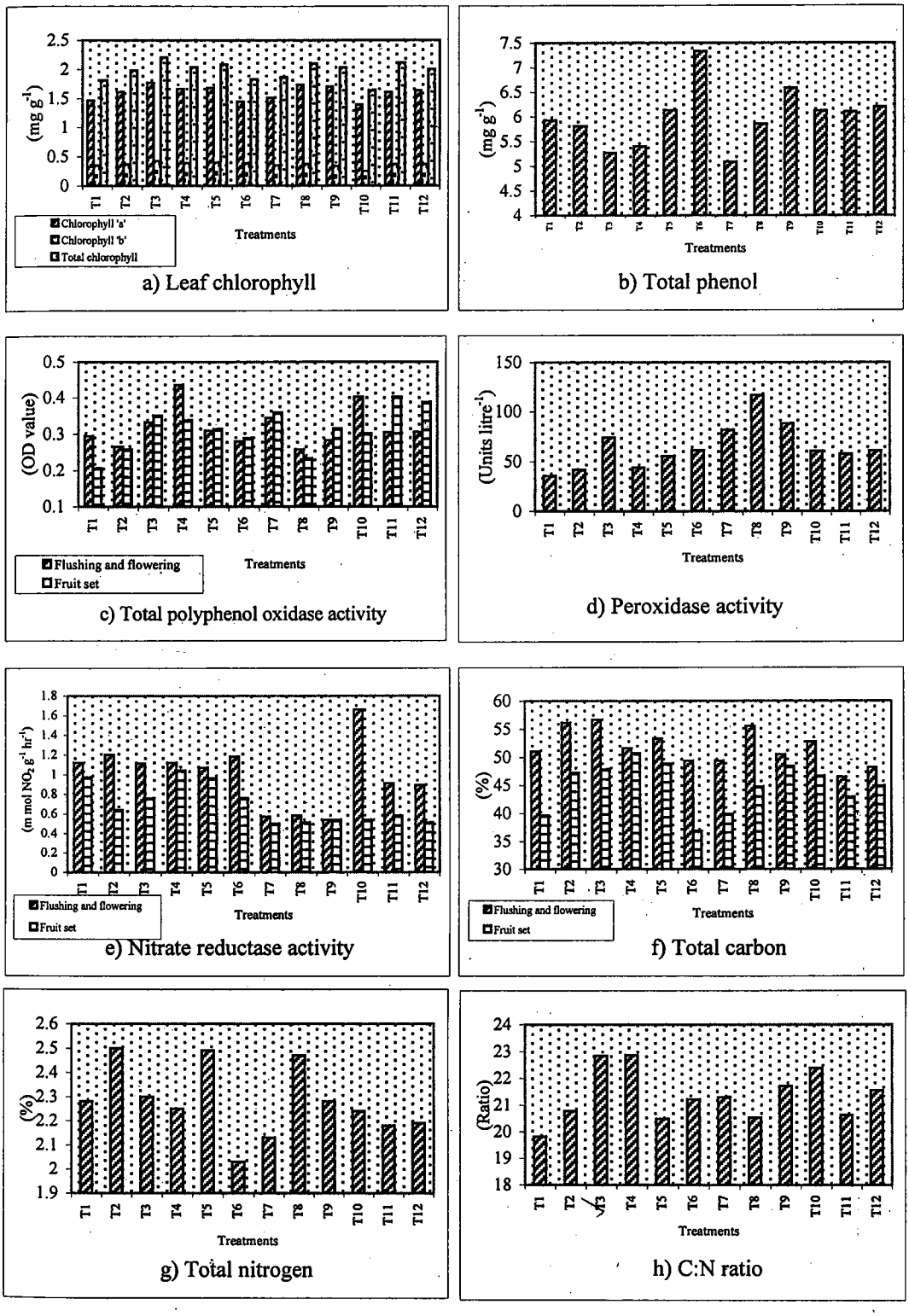
and cytokinins activate a number of hydrolytic enzymes leading to increased mobilization of C assimilates. Significant reduction of C content observed in 50 and 100 ppm GA_3 and 250 ppm BAP (T_2, T_3 and T_8) at fruit set (Fig. 17f) may be due to the translocation of C assimilates from the leaves for the setting and filling of berries. The higher total C content observed at flushing and flowering stage has discussed already elsewhere in the chapter (5.1.2.5).

The application of growth regulators was found to enhance the foliar N content of pepper. The growth regulator treatments, GA_3 (25, 50 and 100 ppm), kinetin (100 and 150 ppm) and BAP (250 and 300 ppm) resulted in higher levels of N (Fig. 17g). This might be due to the role of plant hormones in various aspects of N metabolism. Starting from the nitrate reduction they are involved in nucleic acid, amino acid and protein metabolism (Purohit, 1982). The higher N content observed at fruit set stage has already been discussed under experiment I.

The C:N ratio was also influenced positively by the application of 100 ppm GA_3 (T_3) and 100 ppm kinetin (T_4) (Fig. 17h). This can be explained in terms of their effect on the total C and total N of the leaves. The higher C:N ratio observed at flushing and flowering is discussed earlier under section 5.1.2.5.

5.2.2.6 Quality Parameters

Among the quality parameters, only essential oil content was significantly improved by the application of growth regulators. The 150 ppm kinetin treatment alone enhanced the essential oil content (3.5 per cent) over water spray and absolute control (Table 28). The role of growth regulators on the enhancement of oil content of pepper is nil. However, cytokinins have found use in the improvement of oil content in other crops like groundnut (Pande and Sinha, 1972) and soyabean (Kumar, 1998). This is probably due to their role in the pathway of oil synthesis. Geetha (1981) reported that application of NAA 150 ppm enhanced the oleoresin content (14.2 per cent). But here none of the growth regulators could increase the oleoresin content over absolute control. Similarly, piperine content was also found unaffected by the application of growth regulators.



T_1: GA_3 25 ppm T_4: Kinetin 100 ppm T_7: BAP 200 ppm T_{10}: NAA 50 ppm

T_2: GA_3 50 ppm T_5: Kinetin 150 ppm T_8: BAP 250 ppm T_{11}: Water spray

T_3: GA_3 100 ppm T_6: Kinetin 200 ppm T_9: BAP 300 ppm T_{12}: No spray

Fig. 17. Effect of growth regulators on biochemical characters of leaves of black pepper var. Panniyur 2

5.2.3 Physiological Characters

The application of growth regulators also manifested a significant effect on various physiological parameters analysed.

5.2.3.1 Photosythetic Rate and Photosynthetically Active Radiation

Apart from having an influence on the phenotype, plant hormones play a pivotal role in many physiological processes including photosynthesis. In the present study also all the growth regulator treatments applied, enhanced the mean photosynthetic rate of leaves (Fig. 18a). The maximum rate was noticed in plants treated with 100 ppm GA_3 (T_3). Dhindsa (1978) also observed an increased photosynthetic rate with the external application of gibberellins. The plant hormones are known to exert their influence on the enzymes associated with photosynthesis (Deboer and Feierabend, 1974) by increasing the synthesis, inhibiting the degradative process or by activating the enzymes. Cytokinins are said to be involved in the maintenance of photosynthetic apparatus. Experimental evidences strengthen the fact that treatment with cytokinins stimulates photosynthesis (Adedipe *et al.*, 1971) by promoting chloroplast synthesis, chloroplast replication and maturation (Parthier, 1979; Caers *et al.*, 1985). In the case of kinetin and BAP, medium concentration of the chemical recorded maximum photosynthetic rate. The same hormone may either promote or inhibit the rate of photosynthesis depending up on developmental stage, concentration and environmental factors (Higgins and Jacobson, 1978).

The mean PAR recorded the highest value in plants treated with 150 ppm kinetin (Table 30). No definite relationship between photosynthetic rate and PAR was observed.

5.2.3.2 Stomatal Conductance and Stomatal Resistance

The plants treated with 100 ppm GA_3 (T_3), 150 ppm kinetin (T_5) and 250 ppm BAP (T_8) enhanced the stomatal conductance compared to untreated plants (Fig. 18b). The treatments showed a trend similar to the case of photosynthetic rate. Cytokinins are known to be involved in the stomatal opening mechanism. Higher

endogenous levels had shown to be related to high stomatal conductance in crop plants (Pospisilova *et al.*, 1995). The exogenous application of GA_3 results in an increase in the osmotic potential of the cell sap, which ultimately leads to a reduction in water potential. Water moves from a gradient of higher water potential to a gradient of low water potential resulting in the increased turgidity of the cell. The increased cell turgidity leads to stomatal opening and hence results in increased stomatal conductance (Gobbur, 1997).

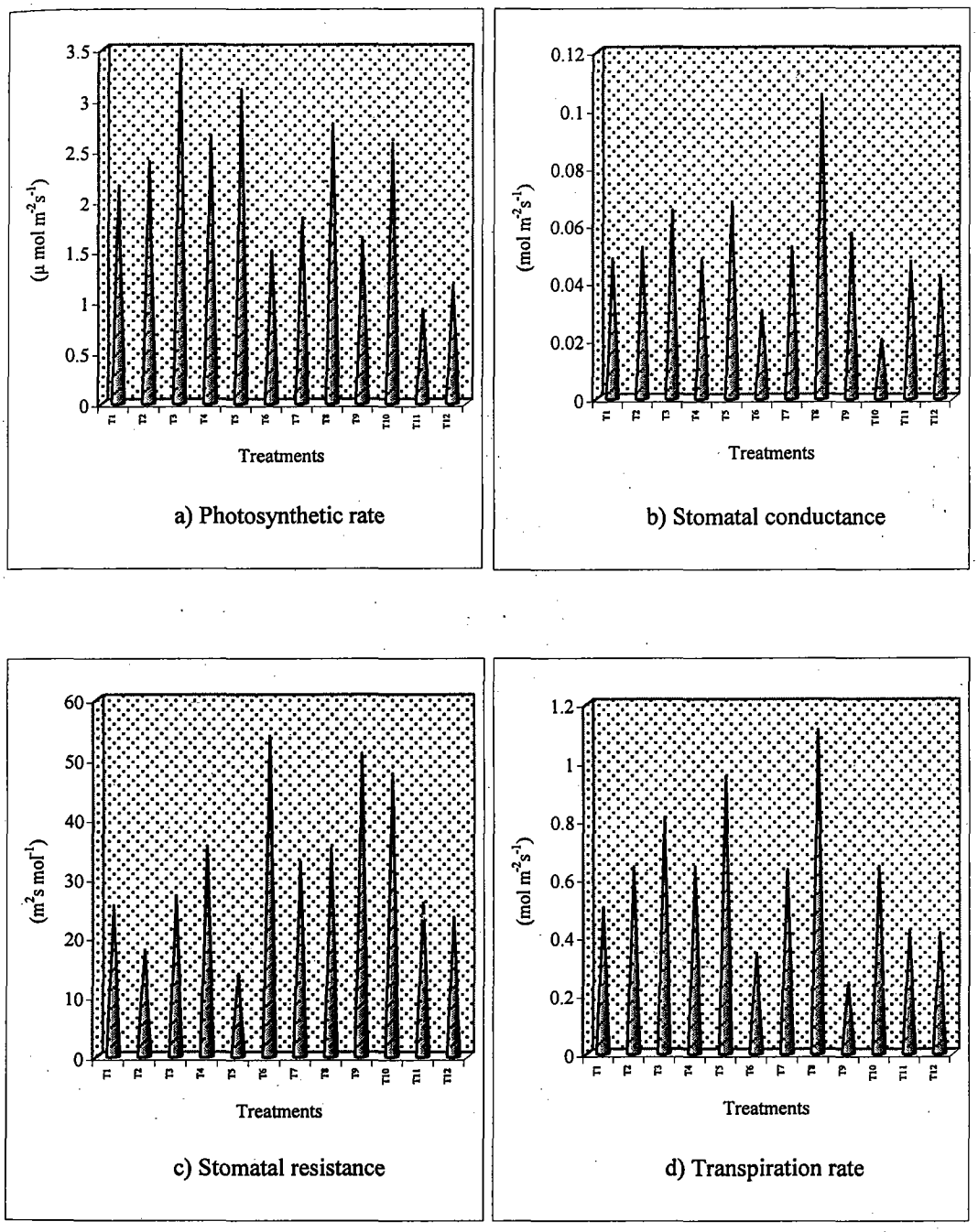
The stomatal conductance and stomatal resistance are inversely related. The higher stomatal resistance observed in plants treated with 200 ppm kinetin (T_6) and 300 ppm BAP (T_9) (Fig. 18c) can be attributed to the low stomatal conductance recorded in their leaves.

5.2.3.3 Leaf Surface Temperature and Transpiration Rate

The application of growth regulators could not influence the leaf surface temperature of the experimental plants. Gobbur (1997) also observed a nonsignificant effect of GA_3 on the leaf temperature of watermelon. But it resulted significant increase in the transpiration rate of treated plants (Fig. 18d). The mean transpiration rate recorded was higher in plants treated with 250 ppm BAP, 150 ppm kinetin and 100 ppm GA_3. It can be attributed to their decreased stomatal resistance and increased stomatal conductance as a result of growth regulator application. The increased cell turgidity leading to stomatal opening in the case of GA_3 application (Gobbur, 1997) and increased stomatal conductance in the case of BAP might have resulted in high transpiration rate of pepper leaves. The leaves of watermelon also exhibited a higher transpiration rate as a result of GA_3 application (Gobbur, 1997).

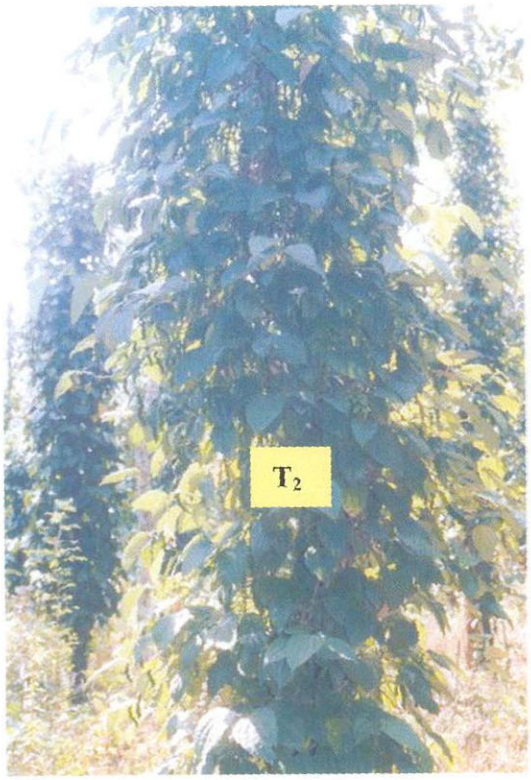
5.2.4 Economics of Treatments

The total cost was found higher in kinetin and BAP treatments, due to the high cost of the pure chemical applied (Kinetin: 994 Rs g^{-1} and BAP: 175 Rs g^{-1}). Though the price of BAP was comparable with that of GA_3 (149 Rs g^{-1}), the relative amount of chemical needed was more in BAP treatments. This has resulted in low BCR of kinetin and BAP treatments, though the yield and thus returns were higher with the

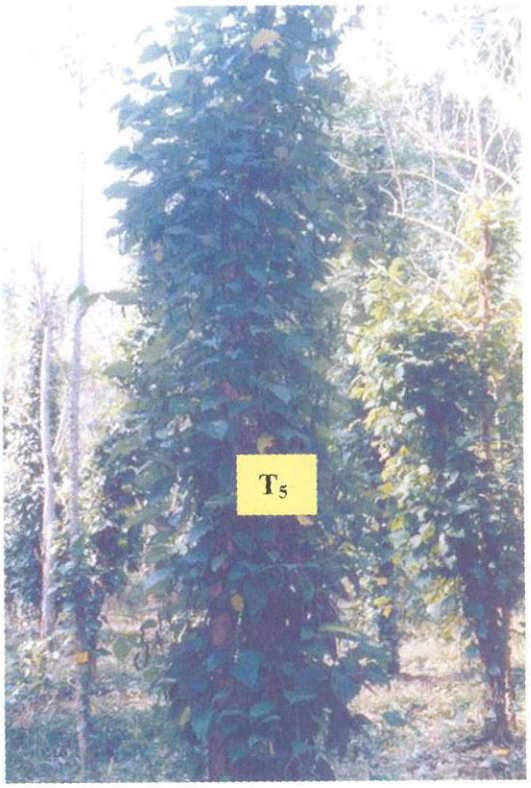


T_1: GA_3 25 ppm T_4: Kinetin 100 ppm T_7: BAP 200 ppm T_{10}: NAA 50 ppm
T_2: GA_3 50 ppm T_5: Kinetin 150 ppm T_8: BAP 250 ppm T_{11}: Water spray
T_3: GA_3 100 ppm T_6: Kinetin 200 ppm T_9: BAP 300 ppm T_{12}: No spray

Fig. 18. Effect of growth regulators on physiological characters of leaves of black pepper var. Panniyur 2

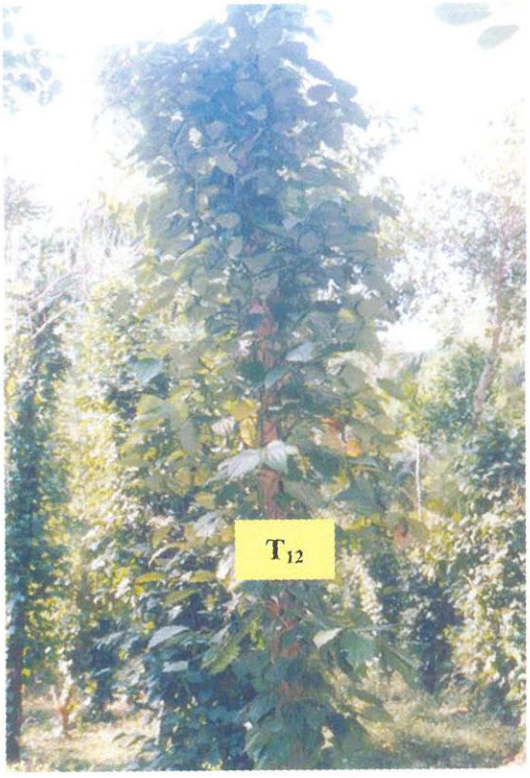


A) GA_3 50 ppm



B) Kinetin 150 ppm

C) BAP 250 ppm



D) No spray (Absolute control)

Plate 9. Pepper vines under growth regulator treatments

treatment applications. Among the growth regulators, NAA showed low total cost because of the relatively low price compared to other growth regulators applied. The water sprayed plants registered higher total cost compared to absolute control due to the spraying cost involved. Among the growth regulator treatments, GA_3 treatments showed higher BCR and maximum was observed in 50 ppm. Though the total returns obtained from 100 ppm GA_3 was higher, BCR recorded was low due to the double cost of the chemical compared to 50 ppm. From the study, the economically feasible growth regulator treatment was found to be 50 ppm GA_3.

An appraisal of the efficacy of different plant growth regulators revealed that within each growth regulator tried, the treatments viz., 50 and 100 ppm of GA_3, 150 and 200 ppm of kinetin, and 250 and 300 ppm of BAP were more or less equal in improving most of the vegetative and reproductive characters of black pepper. Hence it can be concluded that percentage enhancement of growth and yield attributes is low in the highest concentration of the chemical when compared with that of the lower level. Considering the costlier nature of growth regulators, the preferable concentrations of the efficient growth regulators in pepper revealed from the present study are 50 ppm GA_3, 150 ppm kinetin and 250 ppm BAP (Plate 9). However, the study on economics of the treatments showed that BCR of 150 ppm kinetin and 250 ppm BAP were lower than one. Hence the most preferable and efficient growth regulator treatment for black pepper revealed from the present study is 50 ppm GA_3.

5.3 EXPERIMENT III: EFFECT OF PRUNING OF LATERALS ON YIELD OF BLACK PEPPER

Pruning refers to the judicious removal of any plant part and its aim is to properly distribute the bearing wood over the vine and also to regulate the crop maintaining its vitality for consistent productivity. Pruning induces healthy new shoots from older wood and hence it is particularly effective in plants, which bear fruits on current season shoots. The black pepper vine is capable of producing spike on each leaf axil of the current season laterals. Therefore induction of new growth as a result of pruning can be a way for higher production in pepper. The results obtained on the present investigation are discussed here under:

5.3.1 Morphological Characters

The pruning treatments failed to have a significant effect on most of the morphological characters like internodal thickness of lateral, angle of insertion of lateral, number of spike bearing laterals per 0.25 m^2, number of spikes per lateral, spike to leaf ratio per lateral, number of berries per spike, spike compactness, weight and volume of green berries, green yield per lateral, green yield and dry yield per vine. However, pruning exerted a significant effect on vegetative characters like number of leaves, leaf area per lateral and lateral length during 2001. Though nonsignificant during 2002, these characters recorded maximum in one node pruned plants during both years (Table 35). Number of spike bearing laterals, green yield per lateral, green yield and dry yield per vine also recorded maximum in one node pruned plants (Table 38).

Since leaves are the photosynthesizing parts of the plants, its number and area will be having a decisive role in the final yield of a crop. The reserved nutrients present in the laterals can play a crucial role in the reproductive phase. So higher number of leaves, higher leaf area per lateral and lateral length observed in one node pruned plants may have resulted in higher yield compared to two node pruned and unpruned plants. Even though the effect was not so prominent, the residual effect of pruning or the repetition of pruning in the coming years can bring about significant result on the total yield. Hence a more detailed study for a few more years is required to confirm the result. Though in grapes, a viny crop like black pepper, pruning had resulted in better vegetative and reproductive characters with a higher yield (Dujaili, 1989; Sims *et al.*, 1990; Hugelschaffer *et al.*, 1994), such a pronounced effect was not observed in pepper in the present study.

Kurien (1982) reported that pruning of hanging shoots increased the number of laterals, number of spikes and lateral length in black pepper. However, he obtained a nonsignificant result on various spike and berry characters. In the present study, significant increase in the spike length was observed in two node pruned plants in the first year of pruning while during second year, control plants produced longer spikes (Table 37). Similar trend was observed in other spike characters such as number of berries per spike and spike compactness. This may be probably due to the fact that two

node pruning may have encouraged the spike characters favourably during first year by diverting the reserved nutrients for enhancing the spike characters at the expense of vegetative growth. But the repetition of two node pruning treatment in the second year might have affected the vigour of the vine in a negative manner leading to the utilization of reserved nutrients and photosynthates more towards the building up of new frame work in the succeeding season. Thereby resulting in a reduction in the spike characters compared to control plants during second year of the experiment. The results show that increase in the number of nodes in pruning i.e., severity of pruning can negatively affect the pepper production in subsequent year. The performance of one node pruned plants maintained almost the same favourable trend on vegetative and reproductive characters during both seasons even though its effect was statistically nonsignificant

All the morphological characters including vegetative, spike and berry characters were slightly higher during 2002 than 2001. This must have resulted in higher yield per vine in 2002. The change in yield and associated characters between years can be attributed to the change in the environmental factors prevailed during the period (Appendix I and Appendix II). The weather parameters especially rainfall can affect the number of flushes produced in pepper and its growth habit, ultimately affecting the yield.

5.3.2 Biochemical Characters

A perusal of the data indicated that pruning did not influence the chlorophyll content of pepper leaves (Table 39) similar to the case of grapevines (Mc Artney and Ferree, 1999). The result is not in agreement with the report available in mango (Schaffer and Gaye, 1989) and mulberry (Murali, 1994) that pruning increased leaf chlorophyll content.

The total phenol content and PPO activity were significantly higher in the leaves of pruned plants compared to unpruned plants. Two node pruned plants recorded higher phenol content and PPO activity compared to one node pruned plants (Fig. 19a and Fig. 19b). Chacko (1968) and Saidha (1980) also reported increased phenol content in mango as a result of pruning. Phenols are the secondary metabolites, which are being produced more under stress or diseased condition as a part of defense mechanism in

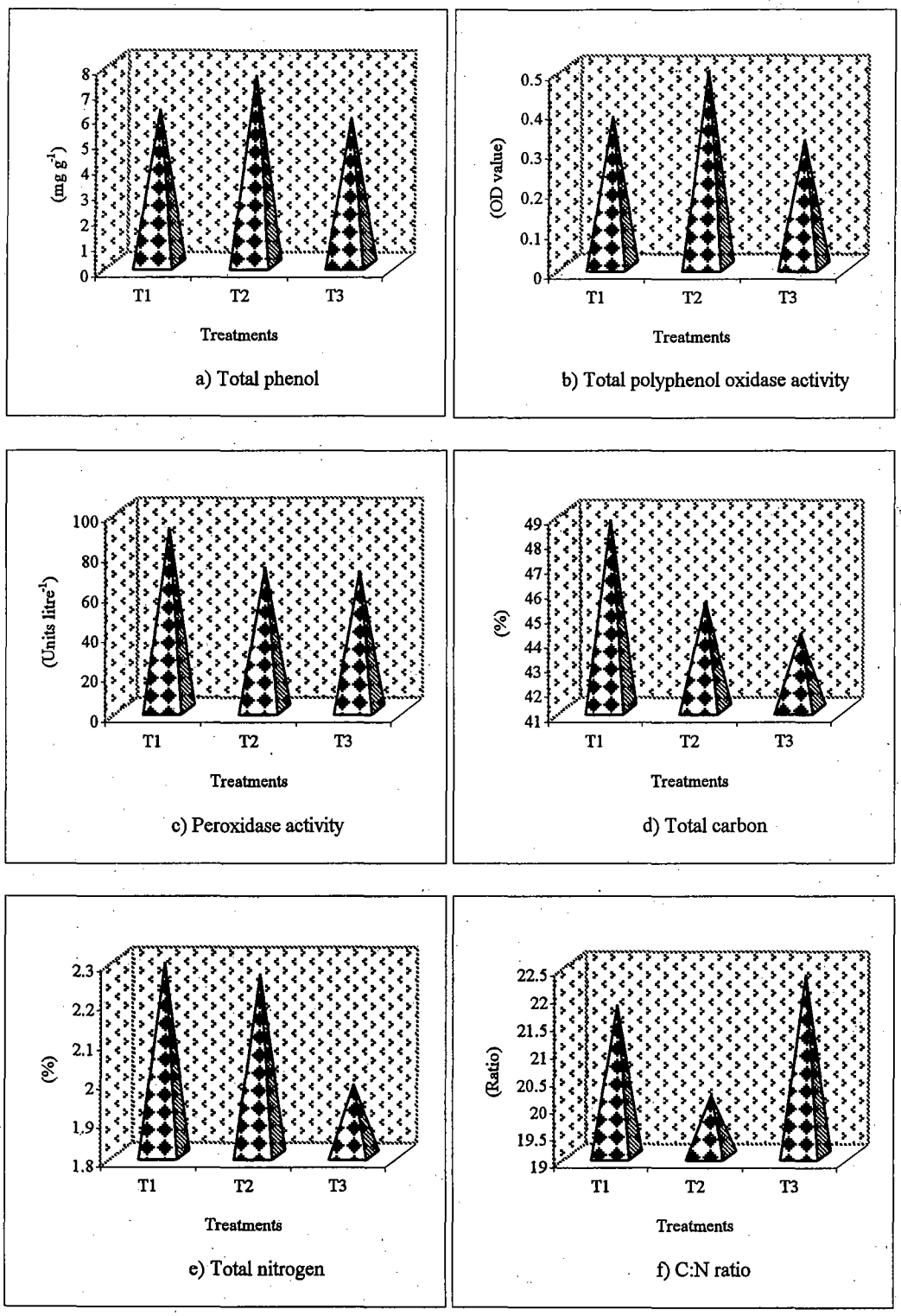
plants. So higher content of phenol in pruned laterals can be taken as a plant response to pruning. Polyphenol oxidases are the enzymes, which catalyze the aerobic oxidation of phenolic substrates to quinines. Hence the higher activity of PPO in pruned plants is justifiable.

One node pruned plants exhibited significantly higher peroxidase activity compared to unpruned plants (Fig. 19c). The enzyme is involved in several metabolic pathways including defense mechanism of crop plants. The increased activity of one node pruned plants may be a plant response to pruning. Pruning did not influence NRA of black pepper leaves.

The results indicated that pruning increased the total C content in the leaves of one node pruned plants (48.67 per cent) over unpruned plants (Fig. 19d). Similarly Saidha (1980) also observed increased dry matter content in mango as a result of pruning. The bud break and subsequent growth of shoots after pruning require carbohydrates as a source of energy (Kandiah, 1975). The starch reserves from other plant parts like stem and roots may have transported to the site of pruning, thereby increasing the total carbon content in one node and two node pruned plants prior to flushing. Wijeratne and Premathunga (2002) reported sharp decline in the root reserves soon after pruning in tea. Pruning increased the N content of pepper leaves significantly compared to unpruned plants (Fig. 19e). Murali (1994) also reported enhanced N content of newly formed leaves after pruning in mulberry. It may be because of the fact that pruning acted as an impulse to mobilize more N in different forms from past season growth to the newly formed leaves compared to unpruned plants. Though it increased the total C and N content, pruning failed to produce any significant enhancement on the C:N ratio of pepper leaves.

The variations in biochemical constituents at different stages were similar to that of experiment I and possibilities for the changes are already discussed in the section 5.1.2.

The effect of pruning on quality parameters like essential oil, oleoresin and piperine were found nonsignificant during both seasons of pruning. This is in



T_1: Pruning the laterals to one node below the point of harvest

T_2: Pruning the laterals to two nodes below the point of harvest

T_3: No pruning

Fig. 19. Effect of pruning on biochemical characters of leaves in black pepper var. Panniyur 2

accordance with the observation made by Kurien (1982) that pruning in pepper failed to improve the quality parameters of berries.

5.3.3 Physiological Characters

Among physiological parameters, only photosynthetic rate recorded significant enhancement in pruned plants compared to unpruned plants (Table 43). The mean photosynthetic rate recorded was maximum in one node pruned plants. Pruning did not influence PAR, stomatal conductance, stomatal resistance, leaf surface temperature and transpiration rate. The physiological parameters at different stages recorded variations similar to that observed in experiment I. The details of the changes are discussed in section 5.1.3 (Fig. 14).

5.3.4 Economics of Treatments

Higher total cost observed during 2002 is due to the higher cost of inputs and labour charge compared to 2001. Even though there was not much variation in the yield obtained between years, the higher returns recorded during 2001 is due to the higher market price obtained per kg of black pepper compared to 2002. The BCR was higher in 2001 compared to 2002 due to the higher returns and lower total cost of cultivation. The one node pruning showed higher BCR compared to two node pruning treatment. However, the highest BCR was shown by control treatment.

5.4 CORRELATION AND PATH ANALYSIS

The results obtained on the correlation and path analysis are discussed below:

5.4.1 Morphological Characters

The productivity of a plant is the net result of an integrated set of complex characters, which are interrelated. Therefore nature of correlation between yield and the component characters assumes significance in early selection for crop improvement.

The results of the correlation studies revealed that the characters of the vines such as angle of insertion of the lateral to the main stem, number of berries per spike, spike length, berry weight, berry volume and green yield per vine recorded significant positive correlation with dry berry yield in pepper. This is in conformity with the findings of Mathai (1983), Ibrahim *et al.* (1985) and Sujatha (1991) in black pepper. Since most of these characters are having direct influence on yield, such positive correlation could be anticipated. Since leaf lamina is the major photosynthetic organ of the plant to intercept sunlight, the productivity of a plant depends on its leaf surface area (Edwards and Walkers, 1983). As the intensity of sunlight incident on the leaves is dependent up on their horizontality, the angle of insertion of lateral to the main stem has a direct bearing on the photosynthetic efficiency and hence the yield of pepper vines (Nambiar *et al.*, 1978).

Path coefficient analysis of the yield contributing characters (Table 48) revealed that only green yield per vine recorded high positive direct effect on the dry yield of pepper. All other morphological characters influenced the dry yield indirectly through green yield per vine. The characters like angle of insertion of lateral to the main stem, number of berries per spike, spike length, and berry weight recorded high positive indirect effect on yield through green yield which explains their high correlation with dry yield.

5.4.2 Biochemical Characters

Among biochemical characters, only chlorophyll 'a' expressed significant positive correlation with dry yield (Table 44). A positive correlation between leaf chlorophyll content and yield has been reported in several crops (Agarwal and Prakash, 1980; Naidu and Swamy, 1995; Satheeshan, 2000). Since chlorophyll pigments being the site of synthetic processes, its quantity could influence the photosynthesis and ultimately yield. In the experiments, the treatments which had resulted in highest yield, also showed higher chlorophyll content. Basin irrigation up to March in experiment I and 100 ppm GA_3 in experiment II recorded highest chlorophyll content.

The significant positive correlation observed between foliar N and chlorophyll with total C content can be due to the influence of these factors on the leaf

photosynthetic rate and C assimilation. Leaf chlorophyll, total phenol and polyphenol oxidase enzyme showed significant correlation with quality parameters like piperine and essential oil content. This is in accordance with the suggestion made by Shaukathali (1997) that phenols are involved in the biosynthesis of essential oil and piperine content in the berries of black pepper.

5.4.3 Physiological Characters

It was observed that dry pepper yield was positively correlated with photosynthetic rate (Table 44). Vasanthakumar (1986) in cardamom and Mathai *et al.* (1988) and Satheeshan (2000) in black pepper also obtained positive correlation between photosynthetic rate and dry yield. The result suggests that the average seasonal photosynthetic rate of leaves in the lateral would be a good indicator of the yielding ability and can be included as a selection criterion in breeding programmes. In all the three experiments, the treatment plants which showed higher photosynthetic rate, also recorded higher yield.

The positive effect of transpiration rate on dry yield may be due to its positive correlation with photosynthetic rate. Palanisamy *et al.* (1994) also observed a significant positive correlation between transpiration rate and yield in cashew. The significant positive correlation noticed between the stomatal conductance and photosynthesis is in agreement with the findings made by Ehleringer and Bjorkman (1978). The stomatal resistance and leaf surface temperature expressed negative correlation with photosynthetic rate probably due to their negative relation with stomatal conductance.

5.5 INTERCEPTION OF LIGHT

From Table 49, it is clear that percentage light availability in the experimental fields of Panniyur 1 and Panniyur 2 did not vary much at different physiological stages. Though the light availability in the open condition varied in the different months or stages observed, the corresponding change would be there in the available light under the experimental plants also. This may be the probable reason for the percentage of light remained without much change at different stages observed.

The present investigations to improve the productivity of black pepper by summer irrigation, growth regulator application and pruning had come out with practicable results. The basin irrigation @ 10 litres $vine^{-1}$ $week^{-1}$ was selected as best treatment among the irrigation treatments given. This particular treatment had an additional advantage of no incidence of *Phytophthora* and pests over 100 litres of basin irrigation recommended in the Package of Practices of Kerala. The treatment also recorded highest BCR. Black pepper responded well to the application of growth regulators. Based on relative efficiency and improvement of growth and yield characters, 50 ppm GA_3, 150 ppm kinetin and 250 ppm BAP were selected as efficient growth regulators in pepper. However, study on economics of the treatments showed that BCR of 150 ppm kinetin and 250 ppm BAP were lower than one. Hence the most preferable and efficient growth regulator treatment for black pepper revealed from the present study is 50 ppm GA_3. The pruning failed to have a significant effect on the yield of black pepper. However, vegetative characters like production of leaves per lateral, leaf area per lateral and lateral length were enhanced by one node pruning in the first year. one node pruned plants also maintained a favourable trend on most of the vegetative and reproductive characters during both seasons even though its effect was statistically nonsignificant. There exists a possibility of yield improvement in subsequent years. But it requires further studies. All these findings are opened up new lines of farmer friendly research knots for the future.

Summary

6. SUMMARY

Experiments of the research project entitled "Physiomorphological and biochemical responses of black pepper (*Piper nigrum* L.) to irrigation, pruning and hormone application for flushing, flowering and berry set" were conducted during 2000-2003 at pepper garden, Department of Plantation Crops and Spices, College of Horticulture, Vellanikkara. The salient results obtained are summarized below:

6.1 EXPERIMENT I: EFFECT OF IRRIGATION ON YIELD OF BLACK PEPPER

Summer irrigation failed to have a pronounced effect on most of the growth and yield characters of lateral such as number of leaves per lateral, leaf area per lateral, length of lateral, internodal thickness of lateral, angle of insertion of lateral to the main stem, time of spike initiation of lateral, number of spikes per lateral and spike to leaf ratio per lateral during both 2001 and 2002. However, with respect to the production of spike bearing laterals, the treatments fogger irrigation up to February and March and basin irrigation up to March registered significantly higher values compared to unirrigated control plants during 2001. During 2002, plants treated with rocker sprayer and fogger irrigation up to March and irrigation throughout summer period recorded higher number of spike bearing laterals.

The irrigation treatments increased the number of well developed berries per spike and spike compactness during 2002 but failed to influence the spike length significantly. The plants treated with fogger irrigation up to March, basin irrigation up to February and March, and irrigation throughout summer period recorded significantly higher number of well developed berries over control plants. The maximum number of berries and spike compactness were observed in the plants treated with rocker sprayer irrigation up to March.

Irrespective of years, berry weight was significantly influenced by summer irrigation while berry volume was enhanced considerably only during 2001. During 2001, the plants treated with rocker sprayer irrigation up to March recorded highest berry weight whereas, the treatment basin irrigation up to March resulted in maximum berry weight in the subsequent year. All treatments expressed superiority on berry

volume during 2001 but they failed to maintain the statistical significance in the subsequent year.

The irrigation during drought months could not exert a significant effect on the dry recovery percentage. Green yield and dry yield were enhanced significantly by the treatments only during 2002. However, the plants irrigated by basin method up to March, expressed its superiority both during 2001 and 2002. The treatment plants showed 64 per cent and 48 per cent enhancement in the green yield and dry yield per vine respectively compared to unirrigated control plants during 2002. In general, growth and yield performance of the experimental plants were better during 2002 compared to 2001. The yield recorded was almost double during 2002 compared to that of 2001.

Significant effect of irrigation treatments was noticed in most of the biochemical parameters analysed. The plants treated with basin irrigation up to March enhanced chlorophyll 'a', total chlorophyll and total C content of pepper leaves. Poly phenol oxidase activity recorded highest in plants treated with basin irrigation up to February. The irrigation during drought months was also found to affect the activity of nitrate reductase. The treatments, rocker sprayer and fogger methods of irrigation up to March resulted in higher NRA compared to other treatments. The foliar N content recorded was highest in the treatment, fogger irrigation up to February. However summer irrigation failed to enhance the biochemical characters like chlorophyll 'b', total phenol, peroxidase activity and C:N ratio of pepper leaves over control plants.

The biochemical analysis revealed a significant variation on all the three stages analysed. The chlorophyll 'a', 'b' and total chlorophyll contents reduced in the new flushes at flowering from that of past season leaves and again increased at fruit set. The total phenol content and polyphenol oxidase activity reduced significantly at flushing and flowering and further reduced at fruit set stage. Peroxidase activity was found highest prior to flushing and it reduced in the new flushes at flowering stage and again increased at fruit set stage while NRA showed a reverse trend. The activity was low in the past season leaves just before flushing and it increased drastically at flowering in the new flushes and again reduced at fruit set stage. The total C content in the experimental plants was maximum at flowering stage and it showed a declining

trend at fruit set. The foliar N content was lowest prior to flushing and it increased in the new flushes at flushing and flowering and fruit set stages. The higher level of C:N ratio coincided with flushing and flowering stage in pepper and it reduced further at fruit set stage.

Among the quality parameters, only oleoresin content was significantly influenced by the application of irrigation in second year of the experiment. The treatment fogger irrigation up to February resulted in highest oleoresin content of pepper berries (13.32.per cent). The essential oil and piperine content were unaffected by the application of treatments during both years of study.

With regard to physiological parameters, the plants treated with basin irrigation up to March showed highest photosynthetic rate of leaves (2.94 μ mol m^{-2} s^{-1}). The stomatal conductance and transpiration rate of plants showed a linear relation with photosynthetic rate and recorded maximum in plants treated with basin irrigation up to March. Stomatal resistance of the treatment plants exhibited an inverse relation with stomatal conductance and photosynthetic rate registered by them. The irrigation during summer period did not record a significant effect on leaf water potential of the treatment plants measured before and after the application. However, a decrease in leaf water potential was observed in the months of severe stress.

The photosynthetic parameters also registered significant changes at pre flushing, flushing and flowering and fruit set stages. The photosynthetic rate was very low prior to flushing and it increased considerably in the new leaves and recorded maximum at fruit set stage. The PAR intercepted by the leaves of the experimental plants was highest prior to flushing compared to flushing and flowering and fruit set stages. Stomatal conductance was low at pre flushing stage and it recorded significantly higher at flushing and flowering and fruit set stages. The stomatal resistance registered maximum value prior to flushing and it declined after flushing and recorded least at fruit set stage. Similar to stomatal resistance, the leaf surface temperature also was highest prior to flushing and reduced at flushing and flowering and fruit set stages. Transpiration rate recorded was higher at flushing and flowering and fruit set stages compared to before flushing stage.

The study on economics of treatments showed that the year 2002 recorded higher BCR in all the treatments compared to 2001 because of the higher yield obtained during the year. The maximum return was observed in the treatment, basin irrigation up to March irrespective of the years. The BCR recorded maximum in the treatment, basin irrigation up to March (1.92) in 2001 and basin irrigation up to February during 2002. However, mean BCR was highest in the treatment basin irrigation up to March (2.50) compared to control (1.95).

Analysing the overall performance of the treatments, it was difficult to conclude the best treatment. However, considering the yield improvement, feasibility of application and BCR, the treatment basin irrigation up to March was found better compared to other treatments. The practical significance of the result is that, this particular treatment requires only 10 litres of irrigation water compared to 100 litres recommended (adhoc) in the Package of Practices for black pepper which is very economic particularly in the drought season. Moreover, incidence of diseases particularly *Phytophthora* and pests were not observed during the treatment application period. However, further research is warranted in this line for getting conclusive results.

6.2 EXPERIMENT II: EFFECT OF PLANT GROWTH REGULATORS ON FLOWERING AND YIELD IN BLACK PEPPER

Foliar application of growth regulators was found to enhance the vegetative parameters like leaf area per lateral and lateral length in black pepper. The application of 150 ppm and 200 ppm of kinetin, 250 ppm BAP and 100 ppm GA_3 recorded significantly higher leaf area. Both concentrations of kinetin enhanced the leaf area by 1.5 times over unsprayed plants. The growth regulator treatments, 250 ppm BAP and 100 ppm GA_3 produced longer laterals compared to control plants and lateral length recorded maximum in plants treated with BAP 250 ppm (15.43 cm). Enhancement in the production of spike bearing laterals was noticed with the application of 250 and 300 ppm of BAP with maximum number of spike bearing laterals in the plants treated with 300 ppm BAP (15.25). The number of spikes per lateral also registered enhancement with the application of 250 ppm BAP. The other growth and yield characters of lateral viz., number of leaves per lateral, internodal thickness of lateral, angle of insertion of

lateral to the main stem and spike to leaf ratio per lateral were not influenced significantly by the application of growth regulators.

The application of GA_3 treatments (T_1, T_2 and T_3) resulted in longer spikes and 100 ppm was the superior (12.53 cm) treatment compared to control. The number of berries a fortnight after anthesis and number of well developed berries per spike were found unaffected by the application of growth regulators. Weight of green berries recorded significant enhancement with the application of GA_3. Though not significant, berry volume also recorded maximum with 100 ppm GA_3 application.

Application of growth regulators resulted in lower recovery percentage of berries compared to absolute and water sprayed control plants. The growth regulator treatments viz., 50 and 100 ppm of GA_3 and 100 and 150 ppm of kinetin significantly improved the green yield and dry yield per vine. The 100 ppm GA_3 was the superior treatment which had resulted 50 per cent enhancement in the dry yield over absolute control.

The biochemical characters were also influenced by the application of growth regulators. The 100 ppm GA_3 and 250 ppm and 300 ppm of BAP enhanced the chlorophyll 'a' content of the treated plants. Maximum content of chlorophyll 'a', 'b' and total chlorophyll were recorded in the plants treated with 100 ppm GA_3. Among the growth regulators applied, only 200 ppm kinetin and 300 ppm BAP registered significantly higher total phenol content. Rest of the treatments were found to reduce the total phenol content of leaves compared to control plants. The growth regulator treatment 100 ppm kinetin only could increase the PPO activity of black pepper leaves. Rest of the growth regulator treatments reduced the activity of PPO. The activity of peroxidase showed a general reduction with growth regulator application except BAP treatments and 100 ppm GA_3 whereas, nitrate reductase recorded enhanced activity with all growth regulators except BAP. The maximum NRA was observed in plants sprayed with 50 ppm NAA (1.10 mmol g fresh weight^{-1} hour^{-1}).

The total C content of leaves was found increased with the application of 50 and 100 ppm of GA_3, 250 and 300 ppm of BAP, 100 and 150 ppm of kinetin and 50

ppm NAA. The maximum C content was recorded in plants treated with 100 ppm GA_3 (52.26 per cent). The total C content increased with increased concentration of GA_3 while it reduced with the highest concentration of kinetin (200 ppm). The foliar N was highest with the application of 50 ppm GA_3. In all the growth regulators, medium concentration of the chemical recorded higher N content. The variation in most of the biochemical constituents at flushing and flowering and fruit set stages did not record any marked deviation from that observed in experiment I.

The growth regulator treatments were also found to manifest their influence on physiological parameters like photosynthetic rate, stomatal conductance, stomatal resistance and transpiration rate. All growth regulators enhanced the photosynthetic rate. The maximum rate of photosynthesis was observed with the application of 100 ppm GA_3 (3.49 μ mol m^{-2} s^{-1}). The photosynthetic rate showed an increasing trend with increased concentration of GA_3, while in the case of kinetin and BAP, medium concentration of the chemicals (150 ppm kinetin and 250 ppm BAP) recorded maximum rate. The mean PAR recorded highest in plants treated with 150 ppm kinetin. No definite relationship between photosynthetic rate and PAR was observed. The stomatal conductance was significantly high in plants treated with 100 ppm GA_3, 150 ppm kinetin and 250 ppm BAP. It increased with increased concentration of GA_3, but BAP and kinetin recorded high stomatal conductance with medium level of concentration. The growth regulators except GA_3 enhanced the stomatal resistance over untreated plants. The maximum stomatal resistance was noticed in plants treated with 200 ppm kinetin (53.81 m^2 s mol^{-1}). The highest concentration of both kinetin and BAP resulted in maximum stomatal resistance. Growth regulators did not express any influence on leaf surface temperature. However, transpiration rate was enhanced with the application of growth regulators and it exhibited maximum in plants treated with 250 ppm BAP.

Study on economics of treatments revealed highest BCR in absolute control treatment. Among growth regulator treatments, only GA_3 treatments exhibited a BCR higher than one and it was maximum in 50 ppm GA_3.

From the investigations on plant growth regulators, it was found that 50 and 100 ppm of GA_3, 150 and 200 ppm of kinetin and 250 and 300 ppm of BAP were better

treatments in improving the vegetative and reproductive characters of black pepper. Considering the relative efficiency and BCR, 50 ppm GA_3 was concluded as the efficient and economic treatment among growth regulators in black pepper.

6.3 EXPERIMENT III: EFFECT OF PRUNING OF LATERALS ON YIELD OF BLACK PEPPER

The trials on pruning experiment conducted during 2001 and 2002 failed to influence most of the morphological characters. The internodal thickness of lateral, angle of insertion of lateral to the main stem, time of spike initiation of lateral, number of spike bearing laterals per 0.25 m^2, number of spikes per lateral, spike to leaf ratio per lateral, number of berries per spike, spike compactness, berry weight and berry volume were found unaffected by pruning. A significant effect of pruning was observed in the characters like number of leaves, leaf area per lateral and lateral length during 2001 but the effect became nonsignificant in the subsequent season. All these parameters recorded were highest in one node pruned plants. Significant increase in the spike length was observed in two node pruned plants in first year of pruning while during second year, control plants produced longer spikes. Similar trend was observed in the case of number of berries per spike and spike compactness. Green yield per lateral, green yield and dry yield per vine were also not affected significantly with the pruning treatment during both years. However, maximum yield was noticed in one node pruned plants. The growth and yield characters recorded by the experimental plants were generally high during 2002 compared to 2001.

Pruning was also found to affect the total phenol, polyphenol oxidase activity, peroxidase activity, total C and total N content of pepper leaves. Two node pruned plants registered highest total phenol and polyphenol oxidase activity followed by one node pruned plants. The activity of peroxidase recorded highest in one node pruned plants (91.0 units $litre^{-1}$). The total C content was also maximum in one node pruned plants. The foliar N level recorded significantly higher in one node pruned plants compared to unpruned plants and no remarkable variation was observed between one node and two node pruned plants. However, pruning could not exert significant effect on leaf chlorophyll content, NRA and C:N ratio of pepper leaves. The quality

parameters like essential oil, oleoresin and piperine content were also unaffected by pruning.

Among physiological parameters, only photosynthetic rate registered significantly higher value in pruned plants and mean photosynthetic rate was maximum in one node pruned plants (2.93 μmol m^{-2} s^{-1}). The PAR intercepted recorded maximum in control plants. The stomatal conductance, stomatal resistance, leaf surface temperature and transpiration rate were not influenced by pruning. The BCR recorded maximum in control plants followed by one node pruned plants.

During first year of the experiment, pruning significantly enhanced the characters like number of leaves per lateral, leaf area per lateral, lateral length and spike length but it failed to get a significant effect during second year of pruning. However, one node pruned treatment expressed higher values in most of the growth and yield characters. Hence a few more years' observation is needed before making a conclusive result. The repetition of the two node pruning in second year of the experiment was found to reduce the growth and yield characters indicating that severity of pruning can adversely affect black pepper production.

The results of the correlation studies revealed significant positive correlation of angle of insertion of lateral to the main stem, number of berries per spike, spike length, berry weight, berry volume and green yield per vine with dry berry yield whereas, internodal thickness of lateral, length of lateral and spike compactness registered significant negative correlation. Among biochemical and physiological parameters, chlorophyll 'a', photosynthetic rate and transpiration rate showed significant positive correlation with dry yield. The path coefficient analysis of the morphological studies revealed that out of the 15 characters analysed, nine characters showed positive direct effect on yield. Only green yield per vine expressed highest positive direct effect on dry yield. Other morphological characters showed indirect effects on dry yield through green yield per vine.

The mean percentage of light infiltrated in the experimental fields of Panniyur 1 and Panniyur 2 did not show much variation between the different stages observed.

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*Originals not seen

Appendices

APPENDIX I

Monthly weather data during the experimental period (2000-2001)

Month	Temperature maximum (^{0}C)	Temperature minimum (^{0}C)	Relative humidity mean (%)	Mean sun shine hours	Total rain fall (mm)	Number of rainy days
December	30.4	22.0	59	7.9	11.2	2
January	32.6	23.2	56	8.0	0	0
February	34.5	22.9	67	8.0	12.2	1
March	34.9	24.0	69	8.2	4.4	0
April	34.2	24.7	75	6.5	243.1	8
May	32.3	24.5	81	6.4	192.6	22
June	28.4	23.1	87	1.9	676.2	23
July	29.0	22.7	85	2.4	477.7	19
August	27.5	23.1	87	3.6	253.2	21
September	30.8	23.2	79	5.3	200.9	6
October	30.1	23.0	81	4.7	215.8	8
November	31.6	23.1	72	6.2	115.8	6

APPENDIX II

Monthly weather data during the experimental period (2001-2002)

Month	Temperature maximum (^{0}C)	Temperature minimum (^{0}C)	Relative humidity mean (%)	Mean sun shine hours	Total rain fall (mm)	Number of rainy days
December	29.5	22.2	60	8.1	0.0	0.0
January	32.8	22.7	62	8.1	0.0	0.0
February	34.3	23.0	50	8.1	0.0	0.0
March	36.3	24.1	63	8.2	16.3	2.0
April	35.0	24.8	71	7.8	50.8	4.0
May	32.6	24.5	87	5.8	308.4	12.0
June	30.0	23.3	86	2.7	533.5	22.0
July	29.8	23.1	84	3.4	354.2	21.0
August	28.9	22.9	86	3.1	506.6	19.0
September	31.1	23.0	77	7.8	124.0	8.5
October	30.8	23.2	83	4.4	387.7	19.0
November	31.8	23.4	71	6.3	22.1	3.0

PHYSIOMORPHOLOGICAL AND BIOCHEMICAL RESPONSES OF BLACK PEPPER (*Piper nigrum* L.) TO IRRIGATION, PRUNING AND HORMONE APPLICATION FOR FLUSHING, FLOWERING AND BERRY SET

By

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ABSTRACT OF THE THESIS

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ABSTRACT

The present investigations on "Physiomorphological and biochemical responses of black pepper (*Piper nigrum* L.) to irrigation, pruning and hormone application for flushing, flowering and berry set" were conducted under three experiments at pepper garden, Department of Plantation Crops and Spices, College of Horticulture, Vellanikkara during 2000-2003.

The first experiment was conducted with an objective to elucidate the effect of dry spell on yield of black pepper by substituting irrigation at periodic intervals from December to April for two consecutive years starting from 2000. The summer irrigation was found to improve the production of spike bearing laterals and well developed berries, spike compactness, weight and volume of green berries, green yield and dry yield per vine. The plants irrigated @ 10 litres per vine per week by basin method up to March showed 48 per cent enhancement in dry yield per vine compared to unirrigated plants.

Significant effect of irrigation treatments was also observed on biochemical parameters like chlorophyll 'a', total chlorophyll, polyphenol oxidase activity (PPO), nitrate reductase activity (NRA), total C, and total N. Among quality parameters, only oleoresin content was influenced by the application of irrigation treatments with maximum content in plants treated with fogger irrigation up to February. With respect to physiological parameters, the plants treated with basin irrigation up to March registered highest photosynthetic rate. The irrigation during summer period did not record a significant effect on the leaf water potential of the treatment plants measured before and after the application of irrigation.

The maximum BCR was recorded with the treatment basin irrigation up to March. Basin irrigation @10 litres $week^{-1}$ $vine^{-1}$ up to March was concluded as the best among the treatments given. Since continuous irrigation did not have much pronounced effect on yield compared to basin irrigation up to March, it was understood that a short span of dry period just before flushing and flowering is needed for better yield in black pepper.

The second experiment aimed at improving the yield and quality of black pepper with the application of different growth regulators at spike initiation period. Growth regulators were found to enhance most of the morphological parameters like leaf area per lateral, lateral length, number of spike bearing lateral per 0.25 m^2, spike production per lateral, spike length, 1000 green berry weight, green and dry yield per vine. All growth regulator treatments resulted in lower recovery percentage of berries compared to untreated plants. The highest yield was noticed with the application of 100 ppm GA_3 that enhanced the dry yield 50 per cent over absolute control.

The growth regulators enhanced biochemical characters like, chlorophyll content, NRA, total C, total N and C:N ratio. All growth regulator treatments except 200 ppm kinetin and 300 ppm BAP reduced the total phenol content. In general, reduced activity of PPO and peroxidase were noticed with most of the growth regulator treatments. Essential oil content of berries was improved with the application of 150 ppm kinetin. The physiological parameters like photosynthetic rate, stomatal conductance and transpiration rate also increased with the application of growth regulators.

Among the growth regulator treatments, only GA_3 treatments showed a BCR higher than one. Based on relative efficiency and improvement in growth and yield characters, 50 ppm GA_3, 150 ppm kinetin, and 250 ppm BAP were selected as efficient growth regulators. However, considering the BCR, among the growth regulators tried, 50 ppm GA_3 was concluded as the economically feasible growth regulator for improving growth and yield characters of black pepper.

The third experiment was conducted to study the influence of pruning on growth and yield of black pepper. The study revealed that pruning failed to enhance almost all morphological characters observed. However, one node pruning significantly enhanced the number of leaves per lateral, leaf area per lateral and lateral length during 2001 but failed to maintain the statistical significance in the subsequent year. One node pruning also expressed higher values with regard to the production of spike bearing laterals, green yield and dry yield per vine. Significant increase in spike length was

observed in two node pruned plants in the first year of pruning while in the second year, control plants produced longer spikes. Similar trend was observed in number of berries per spike and spike compactness also. Results indicated that two node pruning negatively affects yield characters in pepper. Though pruning failed to have a significant effect, one node pruned treatment expressed higher values in most of the growth and yield characters during both years of study.

Pruning could not influence leaf chlorophyll, NRA, C:N ratio, and quality parameters in black pepper whereas, total phenol content, PPO activity and foliar N registered higher values in pruned plants. Two node pruned plants showed highest phenol content and polyphenol oxidase activity while one node pruned plants exhibited maximum peroxidase activity. Among physiological parameters, only photosynthetic rate was significantly influenced by pruning and one node pruned plants recorded maximum photosynthetic rate. The BCR was higher in one node pruning treatment compared to two node pruning but the highest BCR was recorded in control treatment.

Correlation analysis of morphological, biochemical and physiological characters with dry yield revealed that the characters like angle of insertion of lateral to the main stem, number of berries per spike, spike length, berry weight, berry volume, green yield per vine, chlorophyll 'a', photosynthetic rate and transpiration rate had significant positive correlation with dry yield per vine. Path coefficient analysis of morphological characters revealed that only green yield per vine registered high positive direct effect on dry yield. All other characters influenced the dry yield indirectly through green yield per vine.