BIOCHEMICAL AND BIOLOGICAL BASES OF RESISTANCE IN SOLANACEOUS VEGETABLES AGAINST BACTERIAL WILT INCITED BY *RALSTONIA SOLANACEARUM* (SMITH) YABUUCHI *ET AL.*

By

T. SHEELA PAUL

THESIS

Submitted in partial fulfilment of the requirement for the degree

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Kerala Agricultural University

Department of Plant Pathology

COLLEGE OF HORTICULTURE

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DECLARATION

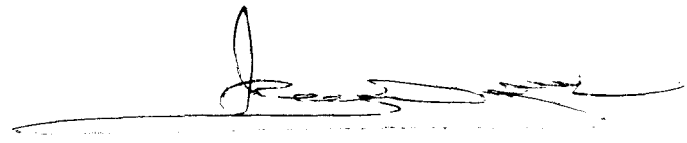
I hereby declare that this thesis entitled "**Biochemical and biological bases of resistance in solanaceous vegetables against bacterial wilt incited by *Ralstonia solanacearum* (Smith) Yabuuchi *et al.***" is a bonafide record of research work done by me during the course of research and that the thesis 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.

Vellanikkara,
10.3.98.

T.Sheela Paul.

CERTIFICATE

Certified that this thesis entitled "**Biochemical and biological bases of resistance in solanaceous vegetables against bacterial wilt incited by *Ralstonia solanacearum* (Smith) Yabuuchi *et al.***" is a record of research work done independently by Smt.T. Sheela Paul under my guidance and supervision and that it has not previously formed the basis for the award of any degree, diploma, fellowship or associateship to her.



Vellanikkara,
10.3.98.

Dr. James Mathew,
Chairman, Advisory Committee,
Professor & Head,
Dept. of plant pathology,
College of Horticulture.

CERTIFICATE

We, the undersigned, members of the Advisory Committee of Smt. T. Sheela Paul, a candidate for the degree of Doctor of Philosophy in Agriculture, agree that the thesis entitled " **Biochemical and biological bases of resistance in solanaceous vegetables against bacterial wilt incited by *Ralstonia solanacearum* (Smith) Yabuuchi *et al.*** " may be submitted by Smt. T. Sheela Paul, in partial fulfilment of the requirement for the degree.

Dr. James Mathew,
Chairman, Advisory Committee,
Professor and Head,
Dept. of Plant Pathology.

Dr. Koshy Abraham,
Associate Professor,
Dept. of Plant Pathology.

Dr. M.V. Rajendran Pillai,
Associate Professor,
Dept. of plant pathology

Dr.A. Augustin,
Assistant Professor(Biochemistry),
AICRP on M&AP

Dr.S. Rajan,
Professor & Head i/c,
Dept. of Olericulture.

External Examiner

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INTRODUCTION

Vegetables play an important role in balanced human nutrition as these are valuable sources of carbohydrates, proteins, vitamins and minerals. Since both food and nutritional security are important requirements, special efforts on intensification of production and supply of vegetable crops are necessary.

Vegetables belong to about thirteen families, of which tomato, brinjal and chilli belong to the family Solanaceae. Tomato is popular because of the wide variety of products; also because it supplies vitamin C and adds variety of colours and flavours to the food. Brinjal is of much importance in India and other parts of the world. It is highly productive and usually finds its place as the poor mans crop. Chilli forms an indispensable adjunct in every house in the tropical world. It is specially liked for its pungency, spicy taste, besides the appealing colour it adds to the food.

FAO estimates show a world tomato production of 84.6 million tonnes from an area of 31 lakh ha in 1996. In India the annual production of tomato is 48 lakh tonnes from an area of 3.2 lakh ha, of brinjal, it is 58.4 lakh tonnes from an area of 4.47 lakh ha and of chilli it is 7.79 lakh tonnes from 9.17 lakh ha.

Bacterial wilt caused by *Ralstonia solanacearum* is the most important constraint faced by the vegetable growers especially in the cultivation of solanaceous crops like tomato, brinjal and chilli. The disease is prevalent largely in the tropics and subtropics of the developing world. The destructiveness of the pathogen is attributed to its wide spread occurrence, the existence of different strains, its exceptional ability to survive in soil and in the roots of non host plants, and to its broad host range. Losses caused by this disease vary from 20-100 per cent.

International research efforts on bacterial wilt emphasize the magnitude of the problem world wide. Many international conferences/ meetings/ symposia were held on bacterial wilt, the first of its kind was held at North Carolina, USA, in July 1976 and the latest held at Guadeloupe- Antilles Francaises in June 1997, and this showed the global importance of the problem.

A comprehensive listing of hosts of *Ralstonia solanacearum* includes species in 35 plant families, with most genera in the family Solanaceae (Kelman, 1953). Subsequently species susceptible to the pathogen have been observed to occur in more than 50 plant families and the number of new host species continues to increase (Hayward,1994 a).

Despite decades of efforts by many national and international organisations, bacterial wilt has continued to be a perennial problem throughout the world. The variability of both the pathogen and the agroecosystems have undoubtedly hampered progress in controlling the disease.

As with other bacterial diseases, it is very difficult and costly to control bacterial wilt with chemicals. Breeding for host resistance remains the best control strategy. Even this property may fluctuate from breeding to cropping areas, due to extreme variability and adaptation of the pathogen (Persley, 1986).

Despite the variation in cultivar susceptibility and the interaction of environmental factors with strain variation in the pathogen, breeding for resistance is likely to remain the most widespread control measure as well as the core of integrated control strategies. Integrated disease management is the latest strategy for getting better crops with a pathogen like *R. solanacearum* and hence some location specific informations will be of prime value to draw out suitable management practices.

Buddenhagen(1986) stated that disease management and resistance are inextricably intertwined, and

not separate approaches, to control. The combination of host resistance with location specific additional measures for control is probably one of the cheapest strategies available and also one of the most satisfactory from an ecological point of view.

Although widely used, the physiological bases of genetic resistance to bacterial wilt disease are still poorly understood. Whatever the strategy, control of the disease can be achieved only through a better understanding of the complex interactions between *R. solanacearum* , the host genotype and the environment.

Though intensive efforts have been made to understand the basic mechanism of disease resistance, the fundamental biochemical basis is still unknown. With the advances made in the basic genetics of the pathogen and major host plants, it is likely that progress in understanding the basis for resistance will be resolved in the near future and cultivars with high levels of resistance will be developed.

Many approaches to control bacterial wilt through different methods have baffled the purpose and genetic host resistance seems to be the best ideal method to solve the problem. In this context there are only very little studies on the mechanism, bases and pattern of resistance of solanaceous crops against the bacterial wilt

pathogen. The genetic factors may have a role in the basic physiological and biochemical activities of the plant and the pathogen. In view of this the following aspects were taken up for the present study.

Isolation and characterisation of bacterial pathogen from tomato, brinjal and chilli.

Screening of varieties of tomato, brinjal and chilli for resistance / susceptibility against *R.solanacearum*.

Biochemical, biological and nutritional bases of resistance in solanaceous vegetables under healthy condition.

Biochemical, biological and nutritional changes in resistant and susceptible varieties of tomato, brinjal and chilli due to infection by *R.solanacearum*.

Review of literature

REVIEW OF LITERATURE

The bacterial wilt of solanaceous crops by *Pseudomonas solanacearum* was first reported by Burril(1890) in potatoes as an unidentified bacterial pathogen from United States. But it was Smith(1896) who first published the definite description of *Pseudomonas solanacearum* causing bacterial wilt in potato, tomato and egg plant. The disease has been reported in every major continent and most islands from the warm temperate to tropical regions of the world. Kelman(1953) reported that it attacked more than 200 plant species belonging to 33 families and the family Solanaceae has the largest number of hosts. A review of the new records of bacterial wilt since 1950s showed that more than 20 additional families of plants contain hosts of *P. solanacearum* (Hayward, 1994).

In India the occurrence of bacterial wilt of tomato was first reported by Hedayathullah and Saha(1941) from West Bengal.

The first report of a detailed study of bacterial wilt of brinjal in India was made by Das and Chattopadhyay (1955). They estimated that the average reduction in yield due to this disease was 54.6 to 62.3 per cent.

Bacterial wilt of chilli was first reported in India from Madhya Pradesh(ICAR,1969).

In Kerala, Studies on the various aspects of bacterial wilt of solanaceous crops were made by Rahim(1972); George (1973); Devi (1978); Celine (1981); Nayar (1982); Peter *et al.*,(1984); Rajan (1985); Gopalakrishnan and Peter (1991); Jyothi (1992); Markose (1996) and Singh (1996).

2.1 The Pathogen

The shape and size of the bacterium was first delineated by Smith(1896) as nonspore forming, noncapsulate, gram negative small rods with polar flagella. Stanford and Wolf (1917) reported that the colonies of the bacterium on solid media were circular, glistening white, slightly raised with smooth margin and appeared within 36 to 48 hours.

Okabe(1937) had described four colony types, viz., F = wild types which were fluidal, irregular milky colony, readily isolated from the lesions; OP = opalescent, circular, homogenous; C = circular, light brownish, straite and SS = pale, fluorite green with cream coloured centre. The last three were isolated from advance stage of the disease.

Kelman (1954) distinguished colony variants on Tetrazolium medium. These were the normal or wild type which were irregularly round, entire, white or white with light pink centre and the mutant or butyrous type which were round, translucent, smooth, deep red with a narrow light bluish border.

An association between levels of virulence and colony morphology of the pathogen on Triphenyl Tetrazolium Chloride(TZC) medium had been demonstrated (Okabe, 1949; Kelman, 1954; Okabe and Goto, 1954; Husain and Kelman, 1958). They observed that virulent wild type isolates formed irregularly round, fluidal, white colonies with light pink centres while avirulent mutants formed small butyrous colonies with distinct red centres.

Khan *et al.,* (1979) reported that the chilli isolate produced convex, slimy colonies with slight pinkish centre on TZC medium. On the same medium the colonies of tomato isolate were convex to flat, fluidal, slimy with pink centre, while the colonies of brinjal isolate were convex to flat fluidal, less slimy with pinkish centre. Mathew and Nayar(1983) stated that *P. solanacearum* isolated on TZC medium yielded circular, smooth and greyish white colonies with light pink centre. The absence of pigment production by *P.solanacearum* either on Yeast Glucose Chalk Agar or

King's medium had been reported by many workers (Smith, 1914; Hayward, 1964; El-Helaly *et al.*,1969; Devi, 1978; Nayar, 1982; Swanepoel and Young, 1988 and Jyothi, 1992).

The aerobic nature of *P.solanacearum* was well established by many workers (Smith, 1914; Labrousse, 1932; Moraes,1947). Kelman and Jensen (1951) also opined that it could grow anaerobically. While studying the utilization of carbon sources by isolates of *P. solanacearum* Devi (1978) noticed both aerobic and anaerobic growth.

Hayward (1964) studied the characteristics of *P. solanacearum* and reported that on tyrosine medium a diffusible brown pigment was produced the intensity of which might vary between isolates. He further observed that one of the isolates produced a green fluorescent pigment on Kings medium. Catalase and oxidase were produced by the organism and citrate but not melonate was utilized as sole source of carbon. Nitrate reduction and ammonia production were positive. It did not hydrolyse soluble starch or produce indole. An alkaline reaction was produced in litmus milk and growth occurred in o.5 and 1 per cent sodium chloride broth. Slight gelatin liquefaction took place on prolonged incubation. Similar characters with slight variations were observed by many workers while studying the biochemical and physiological

characters of strains of *P. solanacearum* from tomato, brinjal, chilli or ginger (Devi, 1978; He *et al.*, 1983; Psallidas, 1985; Swanepoel and Young, 1988; Prior and Steva , 1990). However, an acidic reaction of the isolates of the pathogen in milk was observed by Samuel (1980) and Nayar (1982). They also observed positive urease activity and levan production.

The existence of variation among the isolates of *P. solanacearum* had been well demonstrated (Smith, 1896; Kelman, 1954; Buddenhagen and Kelman, 1964; Addy *et al.*, 1980).

Starr and Weiss (1943) reported that *P. solanacearum* could utilize asparagine as a sole source of carbon and nitrogen. Palleroni and Duodoroff (1971) considered the inability to hydrolyse arginine as a negative nutritional character of *P. solanacearum.* Nayar (1982) and Jyothi (1992) also observed negative arginine hydrolase activity with brinjal and chilli isolate respectively. Liberation of hydrogen sulphide and negative MR and VP tests by isolates of *P. solanacearum* were observed by many workers (Devi, 1978; He *et al.*, 1983). Nayar (1982) noticed positive MR test and negative reaction for VP test and in the utilization of sodium citrate, with the isolates from brinjal.

A large number of carbon / organic compounds like glucose, ribose, fructose, sucrose, galactose, dextrose, lactose, maltose, mannose, xylose, trehalose, arabinose, cellobiose, mannitol, glycerol, dulcitol, sorbitol, inositol, dextrin, pectin and sodium acetate were reported to be utilized by *P. solanacearum* with or without acid production (Hayward, 1964; He *et al.*, 1983; Prior and Steva, 1990 and Jyothi, 1992).

Cross infectivity of isolates of *P. solanacearum* from different host plants were studied by many workers. Buddenhagen *et al.*, (1962) have reported that *P. solanacearum* from many solanaceous plants like tobacco, tomato and brinjal were capable of cross infecting each other. Devi (1978) observed that the chilli strain of *P. solanacearum* caused high degree of wilting in tomato and eggplant and that the brinjal and tomato isolates were capable of cross infecting each other. Nayar (1982) showed that tomato and brinjal isolates were capable of cross infecting each other and that chilli and ginger isolate caused wilting of their respective hosts only. He *et al.*,(1983) reported that ginger strain caused varying degree of wilting in tomato, eggplant and chilli and the chilli strain caused wilting in eggplant, tomato and chilli. One tomato strain and an eggplant strain caused wilting in tomato and eggplant and no wilting in chilli while, the other strain of tomato caused wilting in tomato, eggplant and chilli. Velupillai and Stall (1984) found that

the strains of *P. solanacearum* from tomato, brinjal, potato and sunflower were all of race 1 and pathogenic to brinjal, chilli, potato and tomato. Some were pathogenic to sunflower and ginger but none affected groundnut. Prior and Steva (1990) showed that chilli isolate caused rapid wilting in tomato and eggplant. The tomato and eggplant isolates also caused wilting in chilli (Jyothi 1992).

Several attempts have been made to group *P.solanacearum* isolate into biotypes, varieties or races on the basis of difference in physiological characteristics (Kelman, 1953; Buddenhagen and Kelman, 1964; Hayward, 1964); and pathogenicity (Kelman and Persoon, 1961).

Buddenhagen *et al.*, (1962) differentiated strains of *P. solanacearum* into three races, race-1 affecting tobacco, tomato, many solanaceous and other weeds and certain diploid bananas; race-2 affecting triploid bananas, heliconia or both; race-3 affecting potato and tomato, but highly virulent on other solanaceous crops. Later, two new races were proposed affecting ginger and mulberry from Philippines and China respectively (Buddenhagen, 1986). According to Persley *et al.*, (1985) the bacterial wilt pathogen could be grouped into five races which differ in host ranges, geographic distribution and ability to survive under different environmental conditions.

1. Solanaceous strain (Race-1) : Wide host range, distributed through-out the lowlands of tropics and subtropics;

2. Musaceous strain (Race-2) : restricted to Musa, and a few perennial hosts initially limited to American tropics, now spreading to Asia;

3. Potato strain (Race-3) : restricted to potato and a few alternative hosts in the tropics and subtropics;

4. Ginger strain (Race-4) : From the Philippines; and

5. Mulberry strain (Race-5) : From China

Hayward (1964) classified a collection of 185 isolates of *P.solanacearum* into 4 biotypes, based on the capacity to oxidise 3 disaccharides (lactose, maltose, cellobiose) and 3 hexose alcohols (mannitol, sorbitol, dulcitol). Isolate of biotype-1 oxidized neither group; biotype-2 only disaccharides; biotype-3 both the groups and biotype-4 only hexose alcohols. Biotype-2 appeared to have a restricted host range and it was solely obtained from two host plants, potato and tomato whereas the other biotypes were obtained from many families in addition to Solanaceae.

It was well established that biovar III is the dominant strain of *P. solanacearum* affecting solanaceous crops (Hayward, 1964; Hayward *et al.*, 1967; He *et al.*,

1983; Prior and Steva, 1990). In Kerala, Devi (1978) compared twenty six different isolates of *P. solanacearum* from tomato, brinjal and chillies and grouped them into 12 pathogroups under race 1 and biotype III. Samuel (1980), Nayar (1982) and Jyothi(1992) characterized isolates of bacterial wilt pathogen of ginger, brinjal and chilli respectively and reported that they belong to biotype III of *P. solanacearum*. *P. solanacearum* has been separated in to biovars on the basis of the ability to utilise and or oxidise three hexose alcohols and three disaccharides (Haywards, 1964; He *et al.*, 1983).

He *et al.*, (1983) obtained a series of isolates from China which oxidised mannitol but not sorbitol or dulcitol, and these were designated as biovar V.

Kumar *et al.*,(1993) differentiated twelve isolates of *P.solanacearum* from solanaceous hosts into biovars following Haywards classification. All the isolates from tomato, potato, aubergine and bell pepper (Capsicum) were identified as biovar 111 or a sub-type in biovar 111. An isolate from chilli (Capsicum) that differed from the others was tentatively identified as biovar V. All the isolates utilized glucose, fructose, sucrose, galactose and glycerol.

Hayward (1994 b) differentiated biovar III of *P.solanacearum* from biovar V of *P.solanacearum* based on its ability to utilise the sugar alcohols, sorbitol and dulcitol.

Yabuuchi *et al.*,(1992) transferred several species of the rRNA homology group II Pseudomonads including *P.solanacearum* to the genus *Burkholderia*. Later work based on sequencing of 16s rRNA genes and polyphasic taxonomy led to the proposal of genus *Ralstonia* and the pathogen has been named as *Ralstonia solanacearum* Yabuuchi *et al.*, 1995.

Aubergine, capsicum and tomato cultivars differing in resistance to *P. solanacearum* were inoculated by root injury with an aggressive strain of the bacterium. Wilted plants of all the host species contained similar bacterial populations at the hypocotyl and midstem. All the plant species exhibited latent infections at lower population level. Resistant tomato and aubergine cultivars showed a decrease in bacterial colonisation between taproot and mid-stem, whereas populations in the capsicum cultivars were both constant and higher than in other plant species. Results suggested that tomatoes and aubergines have similar mechanisms of resistance to *P. solanacearum* and that Capsicum is more tolerant towards high bacterial populations than the other plant species (Grimault and Prior, 1994).

2.2 *In vitro* sensitivity to chemicals

Attempts have been made by many scientists to test the *in vitro* sensitivity of *P. solanacearum* to plant protection chemicals. Hidaka and Murano (1956) found that

Streptomycin at 0.3 /ug per ml. of water inhibited and 5/ug per ml killed the pathogen atonce. Campacci *et al.*, (1962) reported that among various chemicals tested the bacterium was most sensitive to Agristrep, Streptomycin, Penicillin-G-potassic, Penicillin procain, Dihydro streptomycin sulphate and Erythromycin. Streptocycline was found to give good control of *P. solanacearum in vitro* (Chakravarti and Rangarajan, 1966). The inhibitory effects of Streptomycin and Streptocycline on *Pseudomonas* and *Xanthomonas* have been observed by many workers (Rangaswami, 1957; Rangarajan and Chakravarti, 1969; Shivappashetty and Rangaswami, 1971). Several antibiotics like Oxytetracycline, Tetracycline, Penicillin-G, Streptomycin were reported to inhibit the pathogen (Goorani *et al.*, 1978). Mondal and Mukherjee (1978) observed that Ampicillin, Streptomycin at 500 ppm each were of promise against the pathogen *in vitro*. He *et al.*, (1983) reported that all the strains of *P. solanacearum* from China showed susceptibility to Streptomycin, but were resistant to Penicillin, Viomycin and Chloramphenicol.

Farag *et al.*, (1986) also observed that both virulent and avirulent forms of the pathogen were sensitive to Streptomycin and Dihydrostreptomycin. Gunawan (1989) found that optimum concentration for suppression of bacterial multiplication *in vitro* were 175 and 450 ppm of Streptomycin sulphate.

2.3 Toxigenic property

The first report of pathological wilting of plants to the formation of a systemic toxin by a vascular pathogen was made by Hutchinson (1913) and he reported that the wilting by *P. solanacearum* was due to the formation of a systemic toxin that altered cellular permeability.

Husain and Kelman (1958) made detailed studies on the mechanism of wilting by *P. solanacearum.* They observed that culture filtrates of slime forming virulent strains of the bacterium contained a heat-stable polysaccharide that played the primary role in wilting. These culture filtrates were found to contain heat sensitive cellulase as well as pectic enzymes. Heating these filtrates slightly reduced their ability to wilt tomato cuttings.

According to Maine(1960) extracellular hydrolytic enzymes and toxins produced by *P. solanacearum* affected the structural integrity and essential physiological process of host tissues respectively. Gowda *et al.,* (1977) studied the biological properties of a toxic compound isolated from *P. solanacearum.* They could partially purify the toxin on various host plants and found that it was nonspecific. Cuttings of host plants when treated with 0.2 per cent aqueous toxin solution wilted, whereas plants kept in distilled water

as control did not wilt. Samuel (1980) obtained a heat stable viscous substance from the culture filtrate of the *P. solanacearum* of ginger which could produce wilt symptoms on healthy ginger shoots and concluded that it had got role in the pathogenicity of the bacterium and symptom expression of the disease.

2.4 Source of resistance to *R.solanacearum*

2.4.1 Tomato

Grimault *et al.*,(1994) ranked 10 tomato cultivars from highly susceptible to totally resistant and no significant difference was observed in bacterial population in wilting plants, regardless of the cultivar. All symptomless plants were latently infected at the collar level. The percentage of symptomless plants with bacteria at the midstem level was significantly correlated with the degree of resistance, the more resistant, the lower the stem colonization. Restriction of *P. solanacearum* invasiveness in the vascular tissues of the stem is associated with resistance properties in tomato.

The most effective way of control of this organism is the development of resistant varieties (Kelman, 1953). Abeygunawardena and Siriwardena (1963) reported *Lycopersicon pimpinellifolium* as a source of resistance. The resistance was partially dominant at the seedling stage. In mature

plants, resistance was controlled by recessive genes. The expression of the resistant variety is a function of the age of the plant and changes in temperature (Acosta *et al.*, 1964).

Henderson and Jenkins (1972) reported resistance in Venus, Saturn and Beltisville 3814 to bacterial wilt. Rao *et al.*, (1975) tested 23 wilt resistant cultivars and lines from USA and Philippines for their reaction to an Indian isolate of *P. solanacearum* and among them only one line, CRA 66 selection A from Hawaii was resistant.

Mew and Ho (1976) found that the line VC-8-1-2-1 was resistant to *P. solanacearum* regardless of the inoculum density. They also observed that susceptible varieties were not significantly affected by changes in inoculum density but resistant lines became less resistant at high inoculum densities. Hsu (1976) found that varieties A 95-6 and UP 1167 were comparatively resistant following root inoculation, but were susceptible following inoculation of the stem or top leaf. Devi (1978) reported wilt incidence of less than 30 per cent in Venus, Saturn and CRA 66 selection A. Goth *et al.*, (1983) tested selected tomato lines and cultivars against eight isolates of *P. solanacearum* collected from different locations and found that CL 32d-0-1-19 GS was resistant to three isolates viz. K60, 126408-1 and Tifton 80 of race 1.

The sources of resistance in tomato was reported by many workers. The variety TSS 1(highly resistant) by Hoque *et al.*,(1981); Scorpio by Peterson *et al.*,(1983); Redlands Summertaste by Herrington and Saranah (1985); Redlander by Herrington and Brown (1988); Hawaii 7997, Hawaii 7996, GA 1565, GA 1405 and GA 219 by Scott *et al.*,(1993).

Sadhankumar (1995) evaluated 66 tomato genotypes against bacterial wilt for three seasons and revealed that Sakthi and LE 79-5 were consistently resistant to bacterial wilt. He could also locate four additional sources of resistance viz. LE 214, CAV-5, LE 415 and LE 382-1.

2.4.2 Brinjal

Winstead and Kelman (1952) suggested that increased resistance in resistant lines was apparently associated with age rather than plant size. Bell (1981) stated that each plant part changes in its level of resistance with age. Levels of resistance in leaves and fruits frequently declined with age. He also reported that long photoperiods generally result in high levels of resistance. Increasing the concentration of potassium and calcium enhances most often level of resistance while nitrogen decreased resistance.

Goth *et al.,* (1983) observed that bacterial wilt resistance was broken down when root knot nematode larvae were added at the rate of 100/10cm pot at the time of inoculation with bacterial isolates.

A large number of brinjal varieties were found resistant under different agroclimatic condition by many workers. Pusa Purple Round, Vijay hybrid and Banaras Giant Green by Sitaramaiah *et al.*,(1981,1984); SM 1-5, SM 1-10, SM 1-31-2 by Narayanan and Nair (1983); Surya by Gopalakrishnan *et al.*, (1990); SM 141 by KAU (1989,1995); Swetha by KAU (1996); IHR 180, IHR 181 by Sadashiva *et al.*,(1993). Singh (1996) reported that in addition to the already available bacterial wilt (*P. solanacearum*) resistant varieties viz: Annapurna, Composite-2, TGR, SM 71, SM 116 and SM 141 were found resistant after artificial inoculation.

2.4.3 Chilli

Empig *et al.,* (1962) screened varieties and two strains of pepper for bacterial wilt resistance and found that `Pasites', `All big' and `World Wonder' gave the lowest disease index. Out of the nine chilli varieties screened for resistance against *P. solanacearum* Rahim and Samraj (1974) found that the variety khandari was highly resistant and Pungent Pride, Cherry Red, Vatlal, Dark Purple and Long

Red were moderately resistant. Goth *et al.*,(1983) reported KAU cluster as resistant to four race 1 isolates and one race three isolate of *P. solanacearum*.

Peter *et al.*, (1984) evaluated four Indian hot chillies (Pant C-1, KAU cluster, White Khandari and Chuna) along with six US cultivars for reaction to nine isolates of *P. solanacearum*. Valdez (1985) screened 21 accessions of Pepper for resistances to bacterial wilt and found that only three varieties were resistant to both biovars III and IV. When four cultivars of sweet pepper were inoculated with *P.solanacearum*, `cholo' was the most resistant compared with traditional cultivars, `Agronomico 10', `Tacares PL' and '17245'(Jimenez *et al.*,1988).

A study conducted at Kerala Agricultural University, Vellanikkara revealed that *Capsicum annum* accessions CA33 (KAU cluster) and CA 219 were resistant to bacterial wilt disease (KAU, 1988). Matos *et al.*, (1990) evaluated 50 genotypes of *Capsicum sp.* and found that *C. annum* genotype NPH-143, NPH-144 and NPH-145 were highly resistant. Jyothi (1992) screened 29 accessions the varieties of chillies for host resistance against bacterial wilt and revealed that the variety `Manjari' (CA 33) was resistant to the disease. The accessions / varieties CA 205 and CA 207 exhibited moderately resistant reaction.

Matsunaga and Monma (1995) evaluated 23 accessions of *Capsicum chinense*, 14 of *C. frutescens*, 25 of *C. baccatum*, 2 of *C. pubescence*, and 3 of *C. annum* eight weeks after inoculation with bacterial wilt pathogen and found that Ranche Khorsano *(C. chinense)*; Heiser 6240, LS2390 and LS 1840 (*C.frutescens*) and LS 1716, Casali BGH 1761 and Piickers-gill (*C. baccatum*) were resistant.

2.5 Biochemical basis of resistance

2.5.1 Phenolics

A wide range of chemicals possessing an aromatic ring bearing a hydroxyl substituent called phenolic substances show antifungal, antibacterial and antiviral activities. Phenolics in high concentrations are toxic to plant cells themselves (Tepper and Anderson, 1984). Hence phenolics will normally be present in small quantities only in plants and these quantities may not be sufficient to suppress the development of pathogens. But in many plant pathogen interactions, the synthesis of phenolics is activated after infection and the high amount of phenolics synthesized rapidly suppress the pathogen development (Vidhyasekaran, 1990).

Phenolics play a key role in Fusarium wilt resistance in tomato. Tomato plants inoculated with *Fusarium oxysporum* f.sp. *lycopersici* synthesized increased

amounts, both of total and orthodihydroxy phenols. These compounds were synthesized rapidly in resistant than in susceptible plants (Matta *et al.*, 1967). Peroxidase and polyphenol oxidase are capable of oxidising phenolic compounds and oxidised phenolics (quinones) are more toxic to the fungi.

Protective role of phenolics against bacterial wilt disease was reported by many scientists (Patil *et al.*, 1964 and Tapliyal and Nene, 1967 in potato; Rajan, 1985 and Sadhankumar, 1995 in tomato; Gangappa, 1986 and Gopinath and Madalageri, 1986 in brinjal; Markose, 1996 in chilli). Gopinath and Madalageri (1986) and Sadhankumar (1995) indicated a high significant correlation of phenol with resistance and suggested a possible role of phenols in the mechanism of wilt resistance in brinjal and tomato respectively. But Sitaramaiah *et al.*, (1984) and Geetha (1989) were unable to correlate the total phenol content to resistance/susceptibility to bacterial wilt in brinjal. However, Kuc (1964) and Rajan (1985) observed a negative correlation between resistance and total phenol content in tomato and they suggested that the lower levels of phenolics in the roots of the resistant line might be due to the increased rate of oxidation of phenolics. Markose (1996) reported that the resistant variety Ujwala exhibited significant increase in total phenol content in roots.

Among the different phenolics, orthodihydroxy phenolics (OD phenolics) are known to be highly toxic and play a major role in disease resistance (Mahadevan, 1966). They are easily oxidised by polyphenol oxidase and peroxidase to highly reactive quinones which are effective inhibitors of sulphydryl enzymes thereby preventing the metabolic activities of host and parasitic cells (Mahadevan, 1970). Chlorogenic acid and caffeic acid were the most important phenolic compounds involved in disease resistance mechanisms (Bajaj, 1988).

Orthodihydroxy phenolic compounds such as caffeic acid and chlorogenic acid, and orthoquinones and tannins were shown to strongly inhibit the activities of extracellular enzymes produced by microorganisms, in addition to inhibition of its growth (Hunter, 1978). The importance of orthodihydroxy phenolic compounds in conferring disease resistance needed no further emphasis.

There was a positive association between OD phenol content in the roots and bacterial wilt resistance. The resistant lines had higher OD phenol content compared to the susceptible lines in tomato, brinjal and chilli (Rajan, 1985; Gangappa,1986; Geetha, 1989; Sadhankumar, 1995 and Markose, 1996).

Rajan (1985) reported that after artificial inoculation, total phenols were higher in roots and shoots of susceptible variety of tomato, whereas OD phenol content was increased and remained at a higher level in resistant variety. Ahmed *et al.*, (1994) reported that total phenols and OD phenols were found high in the yellow vein mosaic virus resistant varieties of bhindi before inoculation while the phenolic compounds decreased in the resistant lines after inoculation in Okra. Markose (1996) obtained significant increase in OD phenol content in the roots and shoots of Ujwala, the resistant variety of chilli in 45 to 60 days old plants. On artificial inoculation Ujwala had significantly higher OD phenol content compared to Pusa Jwala.

2.5.2 Soluble sugars

A progressive decrease in amounts of total, non-reducing and reducing sugars, amino acids and total and orthodihydroxy phenols was recorded in aubergines following inoculation with *Diaporthe vexans*, corresponding to increases in severity of infection (Sharma et al., 1993).

2.5.3 Total free amino acid

The free amino acid content of tomato fruit was 500.5 mg/100g FW and was highest in the content of lysine

(15.9 mg/100g). Tomato also had the highest glutamic acid (174.0), cysteine (11.1) and histidine (106.0) contents (Sheng *et al.*, 1988).

Phenolic compounds and amino acids were high in tolerant cultivars of tomato followed by susceptible and highly susceptible cultivars. Percentage increase in both phenolics and amino acids were high in tolerant and lowest in highly susceptible cultivars when inoculated with *Rotylenchulous reniformis* (Mahmood and Siddiqui, 1993).

Saxena and Prasad (1995) concluded from their study on pre and post emergence damping off of tomato by *Fusarium solani* that profuse proteolytic enzyme activity, high level total amino acid out put and low protein content can be correlated with the susceptibility of the host.

2.5.4 Proteins

Enhanced protein synthesis appears to be a universal phenomenon in compatible host pathogen interactions. *De novo* synthesis of new proteins was also reported (Tani and Yamamoto, 1979; DeWit and Bakker, 1980). When the protein synthesis is inhibited by introducing inhibitors such as blasticidin S, puromycin and cycloheximide, resistance of the varieties break down. This clearly suggests that the protein synthesis is an

important factor in disease resistance. The synthesized proteins may not be inhibitory to the pathogens. They mostly activate the synthesis of defence chemicals. The preformed existing proteins may not be involved in the disease resistance process (DeWit and Bakkar, 1980; Gabriel and Ellingboe, 1982).

Changes in soluble protein constitution of leaves of near isogenic lines of tomato carrying resistance gene Cf4 or Cf5 to *Cladosporium fulvum* were investigated by Dewit and Bakkar (1980). A protein appeared more rapidly in the two incompatible combinations than in the compatible ones. In healthy uninoculated plants, it was not detectable. However, the protein did not inhibit hyphal growth of the fungus in tomato leaf. The exact role of this protein in disease resistance is not known.

Leach *et al.*, (1983) detected entirely new protein which was different from Pathogenesis Related proteins (PR proteins). This protein could not be detected in healthy tissues. This protein appeared when lipopolysaccharide of *P. solanacearum* was infiltrated into the leaves of tobacco cultivar. The accumulation of new protein as well as the increase in relative content of atleast two other proteins were correlated with the appearance of resistance to bacterial multiplication in tobacco tissues.

Hanudin (1987) reported that tomato plants with high protein levels were more susceptible to infection by *P. solanacearum* than plants with lower levels.

Biochemical properties associated with rust and powdery mildew resistance in pea were studied by Chander (1989) revealing that the healthy leaves of powdery mildew and rust resistant lines of peas had more total nitrogen and protein.

Nasar (1993) reported that mycorrhizal tomato plants had less carbohydrates in the roots than in the leaves. Total protein and phenylalanine contents showed pronounced increases, while proline content decreased.

Valenzuela *et al.*, (1993) conducted a study on physiological indicators of phenological stages in tomato and cucumber and found that leaf concentration decreased over time, as did DW and the concentrations of nitrates, amino acids and total and soluble proteins NH4+ concentrations etc. peaked during the period of greatest metabolic activity, coinciding with flowering and the initial and final phases of fruit ripening.

Chander(1994) indicated that the resistant chilli lines contained less total nitrogen and true protein.

Malhotra and Singh (1994) reported negative correlation between coefficient of disease index of Fusarium wilt in tomato and total protein.

Ganguly (1995) suggested that the *Rhizoctonia solani* resistant rice variety had higher levels of protein than susceptible cultivar tested. Post infectional increase appeared to be associated with disease resistance. Protein content was high after 21 days.

Markose (1996) reported that the resistant variety Ujwala contained higher protein content than the susceptible variety Pusa Jwala and the increase in protein content due to infection was noticed in all plant parts of Ujwala.

2.5.5 Host enzymes

2.5.5.(i) Polyphenol oxidase

Some of the host enzymes play an important role in disease resistance. Peroxidase and polyphenol oxidases are the key enzymes which are responsible for synthesis of quinones from phenolics. Quinones are highly bactericidal and fungitoxic (Rama and Dunleavy, 1975). Hence sometimes the increased activity of these enzymes might be responsible for disease resistance.

Felton *et al.*, (1989) reported that the foliage and fruit of the tomato plant contains polyphenol oxidases (PPO) and peroxidases (POD) that are compartmentally separated from orthodihydroxyphenolic substrates *in situ*. However when leaf tissue is damaged by insect feeding, the enzyme and phenolic substrates come in contact, resulting in rapid oxidation of phenolics to orthoquinones.

Singh and Singh (1989) studied the content of total phenols, O-dihydroxy phenols and flavanols and the activity of peroxidase and ploy phenol (catechol) oxidase in the leaves of 2 resistant and 2 susceptible varieties of chilli pepper (*Capsicum annum* L) after inoculation with cucumber mosaic cucumovirus. The increase in phenols and decrease in flavanols immediately after infection was much less marked in the resistant than in the susceptible material and was associated with increased activity of the enzymes studied, leading to the formation of more quinones and other oxidation products in the resistant varieties, resulting in reduced multiplication and inactivation of the virus.

Action of polyphenol oxidase is similar to that of peroxidase. This enzyme oxidised phenols to quinones and tannins which were highly toxic to microorganisms, resulting a major role in disease resistance. It is also toxic to viruses in certain cases. Maine and Kelman (1961) observed

that polyphenol oxidase activity was much greater in infected than in healthy stem tissues and suggested that polyphenol oxidase activity may be involved directly or indirectly in resistance of host plants to pathogenic microorganisms including *Pseudomonas*.

Retig (1974) conducted studies on the role of polyphenol oxidase in Fusarium wilt resistance in tomato and observed a very high increased activity in both roots and stems of the resistant plants after inoculation. No increase in activity was found in susceptible plants.

Obukowicz and Kennedy (1981) also stressed importance of polyphenol oxidase enzyme in resistance against *P. solanacearum* in tobacco. In relation to resistance against *Pseudomonas syringae* pv. *tomato*, Bashan *et al.*, (1987) also observed higher polyphenol oxidase enzyme activity in inoculated resistant cultivars than in inoculated susceptible ones.

In potato, Karwasra and Parashar (1989) reported higher polyphenol oxidase activity in Kufri Lalima, a potato variety resistant to bacterial soft rot, compared to Kufri Badshah, a susceptible potato variety. Ahmed *et al.*,(1994) reported higher polyphenol oxidase activity in yellow vein mosaic resistant okra varieties than

susceptible ones. However, Chander (1994) detected lower polyphenol oxidase activity in powdery mildew resistant chilly line compared to that in susceptible one.

Duan *et al.*, (1994) studied correlation between bacterial wilt resistance and polyphenol oxidase activity in groundnut and reported that no significant difference was observed between resistant and susceptible genotypes before inoculation. But after inoculation, differences were significant. Maximum enzyme activity was observed after six days of inoculation in resistant lines, while in susceptible ones, it took 10 days. Liao *et al.*, (1994) also reported similar results in groundnut.

Markose (1996) reported that polyphenoloxidase activity was higher in bacterial wilt resistant variety of chilli in all the plant parts at various growth stages. The enzyme activity increased upon infection, to a greater extent in the resistant genotype.

2.5.5.(ii) **Peroxidase**

Peroxidase is a host enzyme which is frequently correlated with disease resistance. It is an important enzyme in the synthesis of lignins and it catalyses the oxidation of phenolics into more toxic quinones. The

enzyme itself is inhibitory to some microorganisms (Rama and Dunleavy, 1975).

In French bean Rudolph and Stahmann (1964) reported increased peroxidase activity in the halo blight *(Pseudomonas phaseolicola)* resistant variety than in susceptible variety. Tissues of *Nicotiana tabacum* having high peroxidase activity were more resistant to the wild fire disease (*Pseudomonas tabaci*) (Lovrekovich *et al.*, 1968). Commercial peroxidase injection resulted in induced resistance. They also detected a positive correlation between the level of peroxidase activity in tobacco leaves and resistance to *P. tabaci*.

Retig (1974) made detailed studies on the role of peroxidase in Fusarium wilt resistance in tomato. In the resistant plants, peroxidase activity in the roots increased significantly at 24 hours after inoculation, whereas in the susceptible plants, a similar increase was observed only 24 hours later. In the resistant plants alone the stem tissues showed high peroxidase activity, three days after inoculation.

Hammerschmidt *et al.*,(1982) reported that resistance to *Pseudomonas lachrymans* and *Colletotrichum lagenarium* was correlated with increased peroxidase

lagenarium was correlated with increased peroxidase activity in cucumber. Higher peroxidase activity was detected in potato varieties resistant to bacterial soft rot when compared to the susceptible variety based on the studies of Karwasra and Parashar (1989).

Ahmed *et al.*, (1994) reported higher peroxidase activity in yellow vein mosaic resistant okra varieties. The activity of peroxidase was found to be high in powdery mildew resistant chilly variety IIHR 517 A (Chander, 1994).

Investigations on groundnut bacterial wilt resistance revealed that peroxidase activity was higher in resistant genotypes before and after inoculation (Kang and He, 1994; Liao *et al.*, 1994). Shan and Tan (1994) also reported that roots were the most appropriate plant part for studying biochemical changes that occur after invasion by the wilt pathogen *P. solanacearum*.

Markose (1996) reported higher peroxidase activity in the bacterial wilt resistant variety of chilli, Ujwala before and after inoculation and the rate of increase was also highest in Ujwala compared to Pusa Jwala, the susceptible variety.

2.5.6 **Alkaloids**

Tomatine is a steroidal glycoalkaloid found in tissues of *Lycopersicon* genus which have antibiotic activity against a wide range of micro organisms (Irwing, 1947). A high content of tomatine in the wilt resistant tomato plants made it to survive even if affected by the pathogen. Kuhn *et al.*, (1952) observed differences in tomatine content in different species of *Lycopersicon*. Tukalo (1958) found 0.86 to 1.9 per cent tomatine in the leaves of tomato, 0.3 per cent to 0.6 per cent in stems and roots and 0.93 per cent to 2.2 per cent in fully expanded flowers.

Sander (1956) found that shoot is the main site of tomatine synthesis. The main site of tomatine biosynthesis in the root is the actively growing region. The content of tomatine in the host plant appears to be variable and it is influenced by environment. Mohanakumaran *et al.*, (1969) found that tomatine levels are high in roots of *Lycopersicon pimpinellefolium* resistant to *P. solanacearum* than in susceptible cultivars. Tomatine disappearance during fruit ripening is due to actual degradation of the alkaloid (Roddick, 1974). He also reported that impure tomatine inhibited growth of number of bacteria and plant and animal pathogenic fungi. Gram positive bacteria are more sensitive to tomatine than gram negative.

Levin (1976) reported that specific resistance is conferred by a compound or compounds extremely toxic to a small groups of specialised pathogen of herbivores. Such compounds are signigrin, gossypol, juglone, phlorizidin, tomatine and solanine.

Devi (1978) found higher content of tomatine in shoots and roots of venus than in the susceptible line Marglobe. Rajan (1985) reported that in root the total content of tomatine was higher in LE 79 three days after inoculation. The content decreased in both the lines seven days after inoculation, but a higher level of tomatine was maintained in LE 79.

Matsuda *et al.*,(1991) reported that roots of several solanaceous plants produce the anticholinergic alkaloids hyoscyamine and scopalamine.

2.6. Biological basis of resistance

2.6.1 Actinomycete

Devi(1978) reported a definite increase in population of fungi and bacteria as influenced by the presence of tomato plants even after the addition of soil amendments. But such an influence was not seen in the case of actinomycetes.

Yao *et al.*, (1994) suggested a soil amendment similar to S-H mixture which can be effectively used against *P. solanacearum*. Heat treatment reduced the suppressive effect, suggesting that the mixture may have suppressed the pathogen through stimulating growth of saprophytic microorganisms, especially Actinomyces and *Bacillus* spp.

2.6.2 **Virulent Pseudomonas**

Devi and Menon (1980) reported that the wilt incidence was positively correlated with soil populations of *P. solanacearum* and with the combined influence of population and grassland minimum temperature.

Population of *P. solanacearum* biovar 3 were monitored in a clay loam soil by Moffett and Wood (1984) and found that the numbers in soil increased during symptom development and declined with the death of infected plants. A 1000-fold increase in pathogen population was noticed in the root zone soil of susceptible tomato cultivar Floradel compared with the root zone of a resistant line.

Prior and Beramis(1990) reported that induced resistance was not accompanied by a rapid decline of *P.solanacearum* in the soil, nor by lasting breakdown of its

pathogenicity. Tolerance of *P.solanacearum* in stem vessels resulted in necrosis. Induced resistance (necrotic response) was compared with intrinsic resistance (systemic response) of improved tomatoes to explain the mechanisms of resistance to *P.solanacearum.*

Hartman *et al.*, (1991) reported that within the same field the population density of *P. solanacearum* was 34 times higher in the soil associated with roots of wilted plants of tomato than from non wilted plants.

2.6.3 Mycorrhiza

Garcia *et al.*, (1988 a) reported that protection of tomato against the pathogen and reduction in the number of c.f.u. of *Erwinia carotovora* in the rhizosphere of mycorrhizal plants were independent of concentration of P in the plant and the timing of incubation with the two microorganism.

When tomato plants were inoculated with *Glomus mosseae* and *Pseudomonas syringae*, the percentage of mycorrhizal root length infection was unaffected by *P. syringae*. However the population of *P. syringae* in the rhizosphere decreased in the presence of *G. mosseae* (Garcia *et al.*, 1988 b).

Singh *et al.*, (1990) reported that preoccupation of the roots with *Glomus fasiculatum* coupled with biochemical changes such as increases in lignins and phenols make Pusa Ruby resistant to root knot nematodes caused by *Meloidogyne javanica.*

Mittal *et al.*, (1991) reported that tomato root tissue forming galls following inoculation with the nematode *Meloidogyne incognita* had no VA mycorrhizal fungi, while vesicles and arbuscules of *Glomus fasciculatum* were present on roots lacking nematode galls. It was concluded that the presence of VAM fungi in the roots was inhibitory to the formation of nematode galls.

Sreenivasa (1994) reported that the rate of application of P fertilisers in chilli could be reduced through the efficient use of suitable mycorrhizal fungi.

2.6.4 **Azospirillum**

Hadas and Okon (1987) reported that the Azospirillum colonisation increased root dry weight, protein content and respiration rate per root in tomato seedlings.

Inoculation of crop plants like tomato, egg plants, sweet pepper and cotton plants by *Azospirillum*

brasilense resulted in early maturation and increase in yield. The level of root colonisation by *A. brasilense* was similar in all four plant species., i.e root population size of $5x10^5$ cfu/g fresh weight root. It was suggested that inoculation of non cereal crop plants by the cereal-root originate *A. brasilense* was non specific with inconsistency in plant response to inoculation (Bashan *et al.*, 1989).

Sanhita *et al.*,(1995) reported that inoculation of roots of tomato plants with *Azospirillum* sp., *Azotobacter chroococcum* and *P. fluorescens* significantly reduced disease incidence and severity of damping off of tomato seedlings.

2.6.5 **Nematodes**

Jenkins (1974) reported that nematodes had no apparent effect on wilt development.

Reddy *et al.*, (1979) reported that the highly resistant egg plant cv. Pusa Purple Cluster when inoculated with a combination of *P. solanacearum* and *Meloidogyne inocognita*, 20 to 40 per cent plants were wilted. Similar results were obtained by Sellam *et al.*, (1980) in tomato; Sitaramaiah and Sinha (1984), Swain *et al.*, (1987); Nayar *et al.*, (1988) and Ravichandra *et al.*, (1990) in highly resistant cv. Gulla of brinjal.

Sellam *et al.*, (1980) observed no wilting symptoms on tomato plants inoculated with either *P. solanacearum* or *Meloidogyne incognita* separately. The presence of *P.solanacearum* in soil infested with *M. incognita* had no effect on root galling. Combined inoculations caused greatest wilting.

According to Granada and Sequeira (1983) long term survival of *P. solanacearum* appeared to be correlated with its ability to infect plant roots. Brown and Smart (1985) reported that *Bacillus penetrans* inhibited penetration by *Meloidogyne incognita* juveniles into tomato roots in the laboratory and green house.

Routaray *et al.*, (1986) reported that no wilting was observed in resistant tomato plants when *Meloidogyne incognita* and *P. solanacearum* were inoculated separately.

Haider *et al.*, (1987) recorded wilt symptoms 30 days after bacterial inoculation in treatments were *M.incognita* was inoculated either simultaneously or 15 days prior to *P.solanacearum*. Inoculation of the nematode 15 days after bacterial inoculation, did not affect wilt incidence in comparison with bacterium alone. At 60 days, inoculation of *M.incognita* prior to inoculation of *P.solanacearum* produced maximum wilt (100 per cent) followed by that obtained with simultaneous inoculation of

both the pathogen (80 per cent).Minimum wilt was noticed with bacterium alone which was at par with the inoculation of bacterium before nematode inoculation. The root knot index and larval development of *M.incognita* in soil were significantly less in treatments where the bacterium was present.

Zavaleta *et al.*, (1987) reported that out of the 28 actinomycetes and 326 bacterial isolates which were inoculated in roots of tomato cv. Tropic, a decrease in root galling and an increase in shoot weight of atleast 10 per cent was assessed for 31 per cent of the bacterial isolates and for 14 per cent of the actinomycetes.

Peer and Schippers (1989) hypothesised that plant growth promotion is due to the suppression of a deleterious rhizosphere microflora, especially deleterious endorhizophere bacteria by the plant growth promoting *Pseudomonas* strains.

Aubergine plants were inoculated with a suspension of *Fusarium solani* spores, a suspension of *P. solanacearum* and *Rotylenchus reniformis.* The bacterium alone led to a slight inhibition of nematode activity but the combination of the bacteria and the fungus led to a sharp decline in nematode numbers in aubergine roots. (Kermarrec *et al.*, 1994).

2.7 Nutritional basis of resistance

An inverse relationship of nitrogen and phosphorus was reported by Kenaga (1974) on tomato affected by wilt disease. It has also been reported that phosphorus was essential for many diverse functions in the plant metabolism affecting its growth (Chaboussou,1987 and Malavolta,1980).

Power and Frankel (1983) conducted studies with tomato plants planted on sandy soil and sea shell soils which reduce and increase resistance respectively to *P. solanacearum*. The rate of increase of wilting on sandy soil was highest from the second to the fifth week after transplanting, when the tissue calcium level was low, and subsequently declined with rising Ca and Mg levels.

Soil amendment study was conducted by Araki *et al.*, (1985) using woody materials (sawdust, bark) or rice straw for 10 years in greenhouse soil. The K content of soils treated with woody materials was lower than the rice straw plot and resulted in higher Ca: K and Mg:K ratios. The number of fungal organisms was particularly increased by the application of woody materials (sawdust and bark) whereas the numbers of bacteria were highest in the rice straw plot.

Locascio *et al.*, (1988) reported that leaf tissue concentration of Ca and Mg were higher in tomato variety, Capitan which was intermediate in its expression to bacterial wilt (42 per cent) and giving highest yield among the 6 cultivars tested. Leaf and soil Ca concentration were increased by application of $CaCo_3$.

Kishore *et al.*, (1990)reported a decrease in nitrogen and other minerals due to loss as root exudate in mustard seedlings raised from the seeds stored with *Aspergillus flavus*. Similar observations in nitrogen content was also made by Prasad *et al.*,(1997) in *Lathyrus sativus* infected with *Peronospora lathyri-palustris*. According to him no change was noticed in phosphorus, potassium and calcium content between healthy and diseased leaflets.

According to Zhang (1991) zinc deficiency increased root exudation of amino acids, sugar and phenolic compounds in sunflower, *Phaseolus vulgaris*, tomato, apple and cotton grown in nutrient solutions under controlled environmental conditions. The release of these substances decreased with increasing zinc concentrations. Root exudates of Zn-deficient sunflower and tomato plants mobilised 1.6-2.1 and 2.7-3.5 times more Fe and Mn from calcareous soil than those of Zn - sufficient plants, the root exudates didn't mobilise zinc.

Gupta *et al.*,(1992) reported an increase in nitrogen and phosphorus content in groundnut leaflets infected with leafspot pathogens.

Franco *et al.*, (1994) reported that the blossom end rot of tomato can be lowered by the application of gypsum and protein hydrolysate. Applying gypsum increased leaf calcium concentration. Applying the protein hydrolysate increased the contents of histidine (by 17 per cent), proline by (15 per cent) and alanine by (11 per cent) in ripe fruits.

Cavalcante *et al.*, (1995) reported that disease severity was reduced when nutrient concentration increased from 1H to 2H. Analysis of shoot tissues for macronutrients revealed that *P. solanacearum* inoculated plants showed higher element contents than noninoculated plants except for Mg, and K in Yoshanmatsu and Ca and K in Santa Cruz in tomato.

Yamazaki and Hoshina (1995) studied the relationship between Ca nutrition and bacterial wilt development in seedlings of 3 tomato cultivars with varying resistance levels. Disease development was rapid in the susceptible cv.Ponderosa at all Ca concentration. Increased Ca concentration in the nutrient solution reduced

disease severity in Zuiei (moderately resistant). Resistance was negated at low concentration in Hawai 7991 (highly resistant). Pathogen population in stems decreased with increasing Ca concentration.

Twenty three tomato cultivars were classified into 3 groups based on the degree of disease resistance. Differences in nutrient uptake among cultivars were observed for all the elements tested, and highly resistant cultivars were characterized by a high calcium uptake. (Yamazaki *et al.*, 1996).

Prasad *et al.*, (1997) conducted studies on change in mineral content in *Lathyrus sativus* infected with *Peronospora lathyri- palustris* and found that the quantity of P, K and Ca remains unchanged in healthy and diseased leaflets. But a gradual decrease in Zn and Mn was noticed. Fe was found to be gradually accumulated in diseased leaflets.

Materials and methods

MATERIALS AND METHODS

The present study was undertaken during 1993-96 at the college of Horticulture, Vellanikkara, Trichur. The details of the present studies are elaborated under the following headings.

3.1 Isolation and characterisation of *R.solanacearum* from tomato, brinjal and chilli.

3.1.1 Isolation of the bacterium from tomato, brinjal and chilli

Isolation of the bacterial isolates from wilted tomato, brinjal and chilli was done on Triphenyl Tetrazolium Chloride medium (TZC) containing 0.005 per cent 2,4,5 triphenyl tetrazolium chloride by following the standard methods.

Triphenyl Tetrazolium Chloride medium (TZC)

Peptone	10.0 g
Casamino acid	1.0 g
Glucose	5.0 g
Agar agar	20.0 g
Distilled water	1000 ml
p^H	6.8

Irregularly round, fluidal, slimy, white colonies with light pink centres which characterise virulent colonies of *R. solanacearum* were selected after incubation at 30 ± 2^{0}C for 24 to 48 hours and were then purified by 2 to 3 cycles of purification on the same medium (Kelman, 1954). Stock suspensions were maintained by keeping 2 or 3 loopful of bacteria from the pure isolate in test tubes containing 5 ml of sterile distilled water. The suspensions were stored at 5^0 C under refrigeration. The stock cultures were also maintained in Peptone Casamino acid agar slants and stored at 5^{0}C under refrigeration. The cultures were tested periodically for virulence and purity by streaking on TZC medium. A total of three isolates were maintained one each from each host. The isolates were collected from the crops in the campus of College of Horticulture, Vellanikkara.

3.1.2 Pathogenicity tests

Pathogenicity of the bacterial isolates was tested on the respective hosts, using suspensions prepared from the bacterial growth of 24 to 48 h old Peptone Casamino acid slant cultures of the bacterium in sterile distilled water. The optical density (OD)of the solution was adjusted to 0.5 which is equivalent to 10^7 cfu per ml.

Thirty days old vigorously growing tomato, brinjal and chilli plants were used for inoculation of the bacterial isolates. The seedlings were inoculated by root dip method (Winstead and Kelman, 1952) and then transplanted in pots. The pathogen was reisolated from the artificially inoculated host plants and compared and identified with the original isolate of the pathogen. The pure culture of the isolates were maintained in PCA slants at 5^0 C in refrigerated condition. Cultures were tested periodically for virulence and purity by streaking on TZC medium.

3.2 Characterisation of the Pathogen

Characterisation of the different isolates of the pathogen was done according to the methods recommended in the Manual of Microbiological Methods published by the Society of American Bacteriology and Laboratory Methods in Microbiology (Harrigan and Mc Cance,1966). The cultural and physiological characteristics of the three bacterial isolates were studied using the following methods. Before each test a loopful of the bacterial suspension from the stock culture was transferred to TZC agar slants and incubated at room temperature for 24 to 48 h and the resulting bacterial growth was used for each study. Tests were conducted in triplicates and incubated at 30 ± 2^0 C.

3.2.1 Cultural characters

3.2.1.(i) Colony morphology

The colony morphology was studied using 24 h old culture of the bacterium .

Hucker's modification of gram staining was employed to study the gram reaction of the bacterial isolates (Hucker and Conn, 1923).

3.2.1.(ii) Colony characteristics of the different bacterial isolates on Peptone Casamino acid medium.

A sterile loop charged with dilute suspension of each bacterial isolate was streaked on Peptone Casamino acid medium. The colony characteristics were studied after 48 to 72 h of incubation.

3.2.1.(iii) Pigment production

Production of water insoluble pigment by the three isolates was tested after incubation for 48 h on Yeast Glucose Chalk Agar medium.

Yeast Glucose Chalk Agar medium

Yeast extract	-	10.0 g
Glucose	-	10.0 g
Chalk	-	20.0 g
Agar agar	-	20.0 g
Distilled water	-	1000.0 ml
P^H	-	7.2

Production of water soluble pigment was studied using King's medium (King *et al* ., 1954)

King's medium

Peptone	-	20.0 g
Glycerine	-	10.0 ml
K_2HPO_4	-	1.5 g
$MgSO_4$ $7H_2O$	-	1.5 g
Agar agar	-	20.0 g
Distilled water	-	1000.0 ml
P^H	-	7.0

The test cultures were spot inoculated on the sterilised medium in petri plates, incubated for 48 h and examined for pigmentation around the colonies.

3.2.1.(iv) **Potato soft rot test.**

Fresh, 7-8 mm thick slices of washed, peeled and alcohol flamed potato tubers were kept half immersed in sterile distilled water in sterilised petri plates. A loopful of 48 h growth of the bacterial isolates was placed in a nitch made at the centre of each slice. Rotting of the slices was watched after 3-5 days. Uninoculated slices were kept as control.

3.2.1.(v) **Oxygen requirements**

Nutrient Glucose Agar (containing 0.005 per cent Bromocresol purple) columns in test tubes were inoculated with each bacterial isolate by stabbing with a sterile inoculation needle. The agar surface of one set of tubes was covered with sterile liquid paraffin to a depth of 1 cm. The tubes were incubated and observations on colour change of the medium were recorded at 48 h intervals for 7 days.

3.2.1.(vi) **Production of levan**

Peptone beef extract medium containing 5 per cent sucrose was used for this test.

Peptone	-	10.0 g
Beef extract	-	5.0 g
Sucrose	-	50.0 g
Agar agar	-	20.0 g
Distilled water	-	1000.0 ml
p^H	-	7.0

Dilute suspension of the bacterial isolates were streaked over the sterilised medium in petriplates and growth characters were observed after 48 h. Presence of large, white, domed and mucoid colonies characterised the production of levan from sucrose.

3.2.2 Physiological characters

3.2.2.(i) Starch hydrolysis

Nutrient agar containing 0.2 per cent soluble starch was employed for this test .

Peptone	-	10.0 g
Beef extract	-	5.0 g
Starch (soluble)	-	2.0 g
Agar agar	-	20.0 g
Distilled water	-	1000.0 ml
P^H	-	7.0

The test isolates were spot inoculated on the medium poured in sterilised petriplates. Starch hydrolysis was tested after 4 days of incubation, by flooding the agar surface with Lugol's iodine solution. A colourless Zone around the bacterial growth in contrast to the blue back ground of the medium, indicated positive starch hydrolysis.

3.2.2(ii) Tyrosinase activity

Dyes medium (Dye, 1962) was used for detection of tyrosinase.

$NH_4H_2PO_4$	-	0.5 g
K_2HPO_4	-	0.5 g
$Mg\ SO_4\ 7H_2O$	-	0.2 g
NaCl	-	5.0 g
Yeast extract	-	5.0 g

Tyrosine	-	0.5 g
Agar agar	-	20.0 g
Distilled water	-	1000.0 ml
p^H	-	6.8 to 7.0

The medium was dispensed in test tubes, autoclaved and slants were prepared. They were inoculated with the different isolates and incubated. Melanin production was estimated as high, medium or low based on the intensity of brown discolouration developed in the medium after 48 to 72 h of growth of the cultures.

3.2.2.(iii) **Production of indole.**

Tryptophan broth medium was employed for this test.

Tryptophan (Casein digest)	-	10.0 g
NaCl	-	5.0 g
Distilled water	-	1000.0 ml
p^H	-	7.0

The medium was dispensed in test tubes and autoclaved. Whatman No.1 filter paper strips, (5 X 50 mm) soaked in warm saturated solution of oxalic acid, cooled and were used as indicator paper. The strips became covered with oxalic acid crystals, dried at room temperature and used without sterilising.

The tubes were inoculated with the test isolates and an oxalic acid strip was inserted into each tube by the side of the plug. They were incubated for 14 days. A change in colour of the oxalic acid crystals to pink or red denoted the production of indole.

3.2.2.(iv) **Methyl red and Voges - Proskaeur tests.**

Methyl red broth was used as the basal medium for both MR and VP tests .

Proteose peptone	-	5.0 g
Glucose	-	5.0 g
K_2HPO_4	-	5.0 g
Distilled water	-	1000.0 ml
p^H	-	7.0

The medium was dispensed in test tubes in 5ml aliquots and sterilized by tyndalisation. Two sets of tubes were inoculated with 48 h old culture of the isolates for MR and VP tests respectively. The tubes were incubated for 7 days.

For MR test, a few drops of 0.02 per cent methyl red in 50 per cent alcohol was added to the culture tubes. A distinct red colour indicated positive methyl red reduction.

For VP test 0.6ml of alpha naphthol solution (5 per cent in 95 per cent alcohol) and 0.2 ml of 40 per cent aqueous solution of KOH was added to one ml of the culture. The mixture was shaken for few minutes and allowed to stand for 2 h. A crimson or ruby colour indicated positive VP test.

3.2.2.(v) **Production of ammonia.**

Peptone water medium was used for this test.

Peptone	-	10.0 g
NaCl	-	5.0 g
Distilled water	-	1000.0 ml
p^H	-	7.0

The bacterial cultures were inoculated in tubes containing sterilised peptone water medium and incubated for 48 h. The accumulation of ammonia was detected using Nessler's reagent which gave a brown to yellow precipitate with ammonia.

3.2.2.(vi) **Action on milk**

The bacterial isolates can cause changes in milk and the changes can best be detected in bromocresol purple milk. Both skimmed and unskimmed milk were used. A 1:3 dilution of skimmed milk was prepared in water and bromocresol purple was added to give a final concentration

of 0.002 per cent when a light blue colour was obtained (Clark and Lubs, 1917). Unskimmed milk (containing approximately 3 per cent fat) was also diluted with water and the indicator was added as above. The milk medium was then dispensed in 5 ml aliquots in test tubes and sterilised by tyndalization. The medium was inoculated with a loopful of 48 h old growth of each bacterial isolate and incubated. Observations were recorded periodically for 30 days, for acidic or alkaline reaction, curdling and peptonization. The milk changed from light blue to yellow in acidic reaction and to violet in alkaline reaction. Curdling was indicated by the heterogenous clumps due to precipitation of casein. Peptonization was indicated by the partial clearing of milk.

3.2.2.(vii) **Gelatin liquefaction**

Nutrient gelatin medium was used in this test.

Peptone	-	10.0 g
Beef extract	-	5.0 g
Gelatin	-	4.0 g
Agar agar	-	20.0 g
Distilled water	-	1000.0 ml
p^H	-	7.0

The medium was dispensed in test tubes to a depth of four cm and autoclaved. Forty eight hour old cultures of each isolate was stab inoculated into the sterilised gelatin columns. The tubes were incubated and observed for the liquefaction of the gelatin column at regular intervals for 30 days.

3.2.2.(viii) **Sodium chloride tolerance test**

Peptone water with different concentrations of sodium chloride namely 1 per cent, 2 per cent, 3 per cent and 5 per cent were used for this test. The isolates were inoculated into the tube containing different concentrations of sodium chloride and observed for growth for 48 to 72 h of incubation.

3.2.2.(ix) **Catalase test**

Smears of 24 h old bacterial isolates were prepared on clean glass slides and covered with a few drops of 20 volume hydrogen peroxide. Effervescence indicates the presence of catalase in the culture.

3.2.2.(x) **Production of hydrogen sulphide**

Peptone water containing 1 per cent Casamino acid was used for testing the ability of the bacterial isolates to produce hydrogen sulphide.

Peptone	-	10.0 g
NaCl	-	5.0 g
Casamino acid	-	10.0 g
Distilled water	-	1000.0 ml
p^H	-	7.0

The medium was dispensed in five ml quantities in test tubes and autoclaved. The indicator papers were prepared by cutting strips of Whatman No. 1 filter paper. These strips were soaked in warm saturated solution of lead acetate, dried, sterilised and then again dried. The bacterial isolates were inoculated into the test tubes and the indicator papers were inserted aseptically into the tubes between the plug and the glass with the lower end of the strip just above the broth. The tubes were incubated and observations were recorded at regular intervals upto 14 days. Liberation of hydrogen sulphide caused blackening of the lead acetate paper strip.

3.2.2.(xi) **Arginine hydrolase test**

Thornley's semi solid Arginine medium (Thornley, 1960) was utilised for this test.

Peptone	-	1.0 g
K_2HPO_4	-	0.3 g
NaCl	-	5.0 g
Agar agar	-	3.0 g
Phenol red	-	0.01g

L- arginine mono hydrochloride	-	10.0 g
Distilled water	-	1000.0 ml
p^H	-	7.2

Five ml aliquot of each of the semi solid medium was dispensed in test tubes, autoclaved, cooled and stab inoculated with the test isolates. The surface of the medium was sealed with sterile paraffin oil to a depth of 1 cm. The tubes were incubated and observations recorded for 7 days at regular intervals. Hydrolysis of arginine was indicated by a change in colour of the medium to red.

3.2.2.(xii) **Lipolytic activity**

The medium of sierra (Sierra, 1957) was employed in this test.

Peptone	-	10.0 g
NaCl	-	5.0 g
$CaCl_2.\ 1H_2o$	-	0.1 g
Agar agar	-	20.0 g
Distilled water	-	1000.0 ml
p^H	-	7.0

Ninetynine ml aliquots of the medium was dispensed in flasks, autoclaved and one ml of Tween -

80(Oleic acid ester) was added to each flask and mixed thoroughly. Then the medium was poured into sterile petridishes, spot inoculated with the test bacteria, and incubated for 15 days. Observations were taken at regular intervals during incubation. Opaque zones produced around the bacterial growth was indicative of lipase production.

3.2.2.(xiii) **Urease test**

Christensen's urea agar (Christensen, 1946) was used in this test.

Peptone	-	1.0 g
NaCl	-	5.0 g
$KH_2 PO_4$	-	2.0 g
Glucose	-	1.0 g
Phenol red	-	6.0 ml
(0.2 per cent solution)		
Distilled water	-	1000.0 ml
p^H	-	6.8

Ninety ml aliquots of the medium was dispensed in 250 ml conical flasks and autoclaved. To each flask 10 ml of 20 per cent sterilised urea solution was added and dispensed in sterilised test tubes in 5 ml quantities and slants were prepared. The tubes were inoculated as for

slant culture and observations recorded periodically. A change in colour of the medium from yellow to pink or red indicated urease production.

3.2.2.(xiv) **Utilisation of asparagine as sole source of carbon and nitrogen**

This test was performed using Dye's medium (Dye, 1966)

Solution - 1

K_2HPO_4	-	8.0 g
KH_2PO_4	-	2.0 g
Distilled water	-	1000.0 ml

Solution - 2

Mg $SO_4.7H_2O$	-	2.0 g
Fe SO_4	-	0.5 g
NaCl	-	1.0 g
Mn SO_4	-	0.2 g
H_2 SO_4	-	1 drop
Distilled water	-	1000.0 ml

Solution - 3

Na Mo O_4	-	0.02 g
Distilled water	-	1000.00 ml

Solution - 4

Copper sulphate - saturated solution in distilled water.

Ten ml of each solution was mixed in the order of 3,4,2 and 1 and filtered. 960 ml of distilled water and 2.0 g of L-asparagine was added, dispensed in 5ml aliquots in test tubes and sterilized by autoclaving. The bacterial isolates were inoculated into the medium, incubated and examined for growth. Positive growth meant that asparagine was utilised as sole source of carbon and nitrogen.

3.2.2.(xv) **Utilisation of carbohydrates**

The following carbohydrates were employed for this test.

Monosaccharides	Pentoses	Ribose, Arabinose
	Hexoses	Glucose, Fructose, Mannose, Galactose
Disaccharides		Sucrose , Lactose, Cellobiose, Maltose
Sugar alcohols		Glycerol, inositol, sorbitol, dulcitol

The basal medium used in this test was Hayward's semi solid medium (Hayward, 1964).

Peptone	-	1.0 g
NH_4H_2 PO_4	-	1.0 g
KCl	-	0.2 g
Mg So_4. $7H_2O$	-	0.2 g
Bromothymol blue	-	0.03g
Agar agar	-	3.0 g
Distilled water	-	1000.0 ml
p^H	-	7.2

An aliquot of 90 ml each of the basal medium was dispensed in 250 ml flasks and sterilised by autoclaving. Ten per cent solutions of the sugars and sugar alcohols were prepared in sterile distilled water and sterilised by tyndalisation. Ten ml each of the sterile solution was added to 90 ml aliquots of the melted medium to obtain a carbohydrate concentration of one per cent and dispensed in sterile test tubes to a depth of four centimetres. The medium was stab inoculated with the bacterial isolates and the tests were done in duplicate. In one set of tubes the medium was sealed with sterilised liquid paraffin to a depth of one cm. The inoculated tubes were incubated and observations recorded at regular intervals upto a period of 30 days. Change in colour of the medium to yellow indicated positive utilisation of the carbon compounds with the production of acids and gas.

3.2.2.(xvi) Utilisation of organic acids

Hayward's semi solid medium was employed in this test also. Sodium salts of organic acids namely acetate, citrate and benzoate were added to the medium to obtain a concentration of one per cent. The medium was dispensed in test tubes and autoclaved. A loopful of each test isolate was inoculated into the medium and observations were recorded for 30 days.

3.2.3 Cross inoculation studies using isolates of *R.solanacearum* from tomato, brinjal, and chilli.

The bacterial isolate from each host plant (tomato, brinjal, and chilli) was made into a suspension in sterile distilled water and cross inoculated with the other host plants used in this study by root dip method. Twenty inoculated plants and a control for each crop were maintained for each isolate.

3.2.4 Sensitivity to antibiotics

Sensitivity of the three isolates of the bacterium obtained from tomato, brinjal and chilli to four antibiotics were determined by the paper disc assay method. The antibiotics used were Ambistryn - S, Oxytetracycline, Penicillin G Potassium, and Streptocycline each at 10 ppm, 100 ppm, 250 ppm and 500 ppm concentrations.

Sterilised filter paper discs of 10mm diameter soaked in the antibiotic solution were placed aseptically on Peptone Casamino acid medium seeded with 24 h old culture of the bacterial isolate. Sterilized filter paper discs dipped in sterile water were kept as control. The tests were performed in triplicates. After incubation for 48 h, diameter of the zones of inhibition of growth around the discs were measured in the different plates.

3.2.5 Toxigenic property of the bacterial isolates

Toxigenic property of the bacterial isolates of tomato, brinjal and chilli were studied by following the methods of Alouf and Raynard (1970), Otto *et al* ., (1971) and Patil *et al.*,(1972) with slight modifications.

The bacterium was grown in Peptone Casamino acid broth. The broth was inoculated by a loopful of the bacterial isolates separately and incubated for 5 days. Mechanical shaking of the inoculated broth was also given. The bacterial broth was then autoclaved after 5 days at 15 lbs pressure for 20 minutes, and then filtered. This extract was then tested for toxin precipitation by adding acetone. The extract was mixed with acetone three times the volume of the precipitate. The precipitate was then allowed to settle for over night and separated by centrifuging at 5600 rpm for 20 minutes. The supernatant was discarded and the precipitate was then washed with acetone and kept for

evaporation. The toxin metabolite was then dissolved in distilled water to get a concentration of 0.2 per cent. Ten centimetres long twigs of tomato, brinjal, and chilli which started flowering were kept in these toxin preparation of each bacterial isolate and checked for its toxigenicity. Thirty days old seedlings of tomato, brinjal and chilli were also used for testing the toxigenic property of the isolates by dipping them in the toxin metabolite solution for 24 h and then transferred to distilled water.

3.3 Screening varieties / lines of tomato, brinjal and chilli for host resistance/susceptibility against *R.solanacearum*

Forty three varieties / lines each of tomato, brinjal and chilli obtained from the Department of Olericulture, College of Horticulture, Vellanikkara were evaluated for their relative resistance / tolerance to bacterial wilt in a wilt sick field during October, 1994 - January, 1995. Thirty seedlings were planted for each variety/line in three rows of ten each.

The crop was raised as per the Package of Practices Recommendations for Crops (KAU, 1993). Wilt incidence was recorded at weekly intervals and wilt percentage of each variety/line was calculated. The percentage of wilt incidence were scored according to Mew and Ho (1976) as follows:

R - Resistant < 20 per cent plants wilted

MR- Moderately resistant > 20 < 40 per cent plants wilted

MS- Moderately susceptible > 40 < 60 per cent plants wilted

S - Susceptible > 60 per cent plants wilted

3.4 Biochemical basis of bacterial wilt resistance

From the screening trial conducted for host resistance one variety / line from each category (Resistant, Moderately resistant, Moderately susceptible, Susceptible) of tomato, brinjal and chilli were selected and used for further studies to know the biochemical factors which determine the defence reactions. Altogether 12 varieties/ lines were utilized for the study at the flowering stage. The biochemical and nutritional factors in root, stem and leaf, and biological factors were estimated separately for each variety / line under healthy condition as well as in the diseased condition at the flowering stage. In order to assure disease occurrence the plants were raised in a wilt sick plot and samples were collected immediately on symptom expression. Four replications were maintained for each of the experiments. The laboratory studies were carried out at the Biochemistry unit of College of Horticulture, Vellanikkara as well as at the Analytical laboratory, KHDP, Vellanikkara.

The Biochemical factors studied were

1. Estimation of total phenols
2. Estimation of OD phenols
3. Estimation of soluble sugars
4. Estimation of total free amino acids and number of amino acids
5. Estimation of soluble protein
6. Enzyme activities.
    a. Polyphenol oxidase activity
    b. Peroxidase activity
7. Estimation of alkaloid content.

3.4.1 Estimation of total phenols, OD phenols and soluble sugars

Alcoholic extracts of root, stem and leaf were used for estimation. The root, stem and leaf of four varieties each of tomato, brinjal and chilli at flowering stage were used for the study both under healthy and diseased condition.

Two grams of plant tissue were homogenised in a mortar and pestle with methyl alcohol and volume made up to 10 ml. The homogenised material was centrifuged at 3000 rpm for 10 minutes.

3.4.1.(i) Total phenol

Total phenols were estimated by Folin ciocalteu method (Mahadevan and Sridhar, 1982). The intensity of colour developed was read at 650 nm in a spectrophotometer. The total phenol content was calculated from a standard curve of tannic acid and was expressed as mg g^{-1} of fresh weight of sample.

3.4.1.(ii) Ortho - dihydric phenol

Arnow's method was followed for the estimation or Ortho-dihydric phenols (Mahadevan and Sridhar, 1982) The absorbance of the pink solution was read in a spectrophotometer at 515 nm. Catechol was used as the standard and OD phenol content was expressed as mg g^{-1} fresh weight of sample.

3.4.2 Soluble sugars

Soluble sugar content was estimated by following the Phenol - Sulphuric acid method (Sadasivam and Manickam,1992). The intensity of colour developed was read at 490 nm in a spectrophotometer. Glucose was used as the standard and soluble sugar content was expressed as mg g^{-1} fresh weight of sample.

3.4.3. Estimation of total free amino acids

The total free amino acid and the number of amino acid content was estimated by the method suggested by Sadasivam and Manickam (1992) using 10 per cent isopropanol as extractant. Leucine was used as the standard and total free amino acid content was expressed as mg g^{-1} fresh weight of sample.

3.4.4 Estimation of soluble protein

The soluble protein content of enzyme extract was determined by Lowry's method (Sadasivam and Manickam, 1992).

The composition of the extraction buffer used is as follows.

Tris (hydroxymethyl) Aminomethane	- 21.1995 g (35 µ molar)
Citric acid	- 2.62675 g (2.5 µ molar)
Vitamin C (L-Ascorbic acid)	- 0.52839 g (6 µ molar)
Cystein Hcl	- 0.52689 g (6 µ molar)
2 mercaptoethanol	- 39 mg (1 m µ)
Water	- 500 ml
p^H	- 7

Enzyme Extract

Two gram of fresh plant tissue was macerated in 5 ml of extraction (buffer p^H 7) in a precooled mortar and pestle. The homogenised material was centrifuged at 18000 rpm for 15 minutes at 5^0C. The supernatant was used as enzyme source.

The protein in the enzyme extract was precipitated with Trichloro Acetic Acid(TCA). To one ml of the prepared enzyme extract, added two ml of 10 per cent TCA, kept for one minute for precipitation of protein in the sample. Centrifuged at 10,000 rpm for 10 minutes. The supernatant was discarded and the residue or precipitate left was dissolved in one ml of 0.1N NaOH. This was used for the estimation of soluble protein.

The soluble protein content was measured by the intensity of blue colour developed and was read at 660 nm in a spectrophotometer. Bovine serum albumin dissolved in 0.1N, NaOH was used as the standard. The soluble protein content expressed in mg g^{-1} of fresh weight of sample.

3.4.5 **Enzyme activities**

3.4.5.(i) **Polyphenol oxidase activity**

Polyphenol oxidase activity was assayed by the method suggested by Malik and Singh (1980).

Extraction buffer

Same as for estimation of soluble protein.

Phosphate Buffer for assay (0.1 M)

Monobasic sodium phosphate solution 0.2 M - 87.7 ml
Dibasic sodium phosphate solution 0.2 M - 12.3 ml.
Water to - 200 ml
p^H - 6.

Substrate

Buffer (0.1 M) - 100 ml
Catechol - 0.01 µg (0.11g/ 100 ml)

Enzyme Extract

The same method as that used for estimation of soluble protein.

Pipetted out one ml of enzyme extract and 5.5 ml phosphate buffer in the cuvette and noted the reading at 495nm. One ml of enzyme extract, 5.4 ml of phosphate buffer and 0.1 ml of catechol were pipetted into a cuvette, mixed immediately and recorded the changes in absorbance immediately at an interval of 15 seconds for a period of five minutes.

Plotted the increasing absorbance values and read the changes in absorbance per minute from the linear

phase of the curve. Enzyme activity was expressed in terms of rate of increased absorbance at the first minute and as specific activity (unit per mg protein at 30^{0} C per minute).

3.4.5.(ii) Peroxidase

Peroxidase activity of the plant samples was studied by the method suggested by Sadasivam and Manickam, (1992).

Enzyme Extract

One gram of fresh plant tissue was macerated in three ml of phosphate buffer (P^{H} 7) in presence of 0.04g of insoluble Polyvinyl Pyrrolidine (PVP) in a pre cooled mortar and pestle. All operations were carried out at 4^{0} C. The homogenised material was centrifuged at 18000 rpm for 15 minutes in a refrigerated centrifuge at 5^{0} C. The supernatant used as enzyme source with in 2-4 h .The peroxidase activity was expressed as units per litre.

3.4.6. Total alkaloids

The root, stem and leaf samples were dried in the hot air oven at 70^{0} C and powdered and used for the estimation of total alkaloids using the Soxhlet extraction method (Harborne, 1973). Five gram sample and 100 ml methanol were used for each sample. The total alkaloid content was expressed in percentage.

3.5 Biological basis of bacterial wilt resistance

3.5.1 Estimation of microbial population

To understand the possible role of biological factors in imparting bacterial wilt resistance in solanaceous plants. The rhizosphere microflora like fungi, bacteria, actinomycetes, virulent *Ralstonia*, *Avirulent Pseudomonas*, Azospirillum were estimated both in the healthy plants as well as in the diseased plants for each category using serial dilution plate technique. The dilutions used were 10^{-3} for fungal and Pseudomonads colonies, for Azospirillum 10^{-4} and 10^{-5} for bacteria and actinomycets. The media used were Martin's Rose Bengal Streptomycine Agar for fungus (Martin, 1950), Thornton's standardisation medium for bacteria (Thornton, 1922), TZC medium for Pseudomonads (Kelman, 1954), Kenknight's medium for actinomycetes (Rangaswami and Bagyaraj, 1993), and Okon's medium for Azospirillum (Okon *et al*, 1977 as modified by Kumari *et al*, 1980).

3.5.2 Estimation of V.A. Mycorrhizal infection.

Root samples of healthy and diseased plants of selected varieties / lines of tomato, brinjal and chilli were stained for V.A. mycorrhizal infection by the method of Philips and Hayman(1970) and the percentage of infection was estimated.

3.5.3. Estimation of nematode population

Nematode population was estimated using modified Baermann's Funnel method (Christie and Perry, 1951). The rhizosphere soil of healthy and diseased plants of selected varieties / lines were used for this study.

3.6 Nutritional factors for bacterial wilt resistance.

Samples for the plant chemical analysis were taken from the same lot used for the determination of total alkaloids. The various macro and micro elements in the plant samples studied were Nitrogen, Phosphorus, Potassium, Calcium, Magnesium, Iron, Zinc and Manganese. Five hundred mg of sample was used and the content was expressed in percentage except in zinc and Manganese, which were expressed in µg g^{-1} sample.

Chemical analysis of plant sample

Sl. No.	Nutrient	Method
1.	Nitrogen	Microkjeldahl method
2.	Phosphorus	Diacid extract estimated colorimetrically in a spectronic- 20 spectrophotometer by Vanadomolybdophosphoric yellow colour method

3.	Potassium	Diacid extract method using a EEL Flame Photometer
4.	Calcium	Diacid extract method using atomic absorption spectrophotometer (Perkin Elmer model)
5.	Magnesium	Diacid extract method using atomic absorption spectrophotometer (Perkin Elmer model)
6.	Iron	Diacid extract method using atomic absorption spectrophotometer (Perkin Elmer model)
7.	Zinc	Diacid extract method using atomic absorption spectrophotometer (Perkin Elmer model)
8.	Manganese	Diacid extract method using atomic absorption spectrophotometer (Perkin Elmer model)

3.7. Statistical analysis

Data were subjected to analysis of variance [2 X 4 experiment in CRD] using MSTATC package.

Results

RESULTS

4.1. Isolation and characterisation of isolates of *Ralstonia solanacearum* and pathogenicity tests

Three isolates of bacterial wilt pathogen *Ralstonia solanacearum* were isolated from newly wilted plants of tomato, brinjal and chilli on Triphenyl Tetrazolium Chloride Agar medium (TZC). The cultures were purified by repeated cycles of purification by streaking on TZC media. Koch's postulates were proved with each isolate on their respective host plant. The inoculated plants produced wilt symptoms within a period of 7 to 15 days.

4.2. Characterisation of the pathogen

Cultural, morphological, biochemical and physiological characters of the three isolates of *R. solanacearum* were studied and the results are presented in Tables.1 and 2.

4.2.1. Cultural characters

4.2.1.(i) Morphology

The three isolates of the bacterium *R.solanacearum* from tomato brinjal and chilli were gram negative motile short rods.

4.2.1.(ii) Colony characteristics of the different isolates of the bacterium on Triphenyl Tetrazolium chloride (TZC) medium.

The colony characteristics of the three isolates of the pathogen on TZC medium were compared (Table.1). All the isolates produced circular, smooth, raised, creamish white colonies with pink centre with entire margin within a period of 24 h. The brinjal and tomato isolates produced more slime in the medium when compared to the chilli isolate. The fluidity was highest with brinjal isolate followed by tomato and lowest in chilli isolate.

4.2.1.(iii) Pigment production

All the three isolates failed to produce water insoluble pigment on Glucose Chalk Agar medium and water soluble pigments on King's medium (Table.2).

Table : I Comparison of colony characters, growth, slime production and fluidity of the isolates of *R. solanacearum.* on TZC medium

Isolates from	Nature and colour of colony	Growth, slime and fluidity	
Tomato	Circular, smooth creamish white colony with a light pink centre, convex with entire margin	GR	+++
		Sl	+++
		Fl	++
Brinjal	Circular, smooth creamish white colony with a light pink centre, convex with entire margin	GR	+++
		Sl	+++
		Fl	+++
Chilli	Circular, smooth creamish white colony with a light pink centre, convex with entrire margin	GR	+++
		Sl	++
		Fl	+

GR - Growth +++ Good
Sl - Slime ++ Moderate
Fl - Fluidity + Slight

4.2.1.(iv) **Potato soft rot test**

The bacterial isolates caused blackening and rotting of the potato slices within 48 h after inoculation Table.2.

4.2.1.(v) **Oxygen requirement**

The colour of the Nutrient Dextrose Agar medium changed from blue to yellow in all test tubes inoculated with the bacterial isolates indicating the aerobic nature of the bacteria (Table. 2).

4.2.2. **Physiological characters**

The results of the physiological characters were given in Table. 2.

4.2.2.(i) **Production of levan**

Large, white domed and mucoid colonies were produced by the bacterial isolates indicating high levan production on Peptone Beef extract medium containing 5 per cent sucrose. Largest colonies were produced with brinjal isolate, followed by tomato isolate and smallest in chilli isolate.

4.2.2.(ii) **Starch hydrolysis**

The ability of all the three bacterial isolates to hydrolyse starch was evidenced by the appearance of a colourless zone in contrast to the blue background of the medium around the growth of the bacterial isolates upon addition of iodine solution.

4.2.2.(iii) **Tyrosinase activity**

The bacterial isolates developed a slight brown discolouration in the medium which indicated that they possessed low tyrosinase activity.

4.2.2.(iv) **Production of indole**

The colour of the oxalic acid crystals on the test strips did not change to pink or red which showed the absence of indole production by the three isolates of the pathogen.

4.2.2.(v) **MR and VP test**

The three bacterial isolate developed a dark yellow colour in the methyl red broth instead of distinct red colour by the addition of 0.2 per cent methyl red in 50 per cent alcohol which indicated a positive methyl red reaction.

For VP test, the crimson or ruby colour developed 2h after the addition of 0.6 ml of alpha - naphthol solution (5 per cent in 95 per cent alcohol) and 0.2ml of 40 per cent aqueous solution of KOH to 1 ml of the culture indicated positive VP reaction. However the chilli isolate developed a ruby red colour with a brownish tinge which was not seen with the other isolates.

4.2.2.(vi) **Production of ammonia**

A dark yellow precipitate was produced upon addition of Nessler's reagent in the Peptone Water medium inoculated with the bacterial isolates, indicating that the isolates were capable of producing ammonia. The precipitate was lowest with chilli isolate.

4.2.2.(vii) **Action on milk**

Acidic reaction, indicated the change of blue colour to yellow in both skimmed and unskimmed milk, was noticed in all the bacterial isolates. Curdling was noticed in the case of unskimmed milk with all the isolates.

4.2.2.(viii) **Gelatin liquefaction.**

The bacterial isolates failed to liquefy gelatin even after one month.

4.2.2.(ix) **Sodium chloride tolerance**

The isolates tolerated sodium chloride concentration upto two per cent. Above this concentration there was no growth at all.

4.2.2.(x) **Catalase test**

Positive catalase activity was shown by all the bacterial isolates by the production of effervescence upon addition of a few drops of 20 volume hydrogen peroxide solution to the culture smeared on a clean glass slide. The effervescence was highest in chilli isolate, followed by tomato isolate and lastly in brinjal isolate.

4.2.2.(xi) **Production of Hydrogen sulphide**

The three bacterial isolates produced traces of hydrogen sulphide as evidenced by a slight black discolouration on the lead acetate strips. The colour intensity was highest in brinjal, followed by chilli and tomato isolates.

4.2.2.(xii) **Arginine hydrolase test**

The three bacterial isolates turned the Thornley's semisolid Arginine medium to pink indicating their ability to hydrolyse arginine. The intensity of pink colour was highest in brinjal and tomato isolates when compared to the chilli isolate.

4.2.2.(xiii) **Lipolytic activity**

The three bacterial isolates are not showing any lipolytic activity.

4.2.2.(xiv) **Urease test**

The urease test was positive with the three bacterial isolates, indicated by the colour change of Christensen's Urea Agar from yellow to pink within two days after inoculation. The pink colour was deepest in tomato isolate, followed by chilli isolate and very light in brinjal isolate.

4.2.2.(xv) **Utilisation of asparagine as sole source of carbon and nitrogen**

None of the bacterial isolates tested was capable of utilising asparagine as sole source of carbon and nitrogen.

4.2.2.(xvi) **Utilization of carbon compounds**

The three bacterial isolates gave highly acidic reaction with gas production (within 15 days after inoculation) in most of the sugars tested both under aerobic and anaerobic condition. In all the monosaccharides (ribose, glucose, fructose, mannose, galactose) tested the colour of the medium changed to yellow within 72 h after

Table : 2 Biochemical and physiological characters of the three isolates of *R. solanacearum* from tomato, brinjal and chilli

Sl. No.	Characters studied	Tomato isolate	Brinjal isolate	Chilli isolate
1.	Gram reaction	- ve	- ve	- ve
2.	Pigment production			
	a) Water Insoluble	--	--	--
	b) Water soluble	--	--	--
3.	Potato soft rot test	+	+	+
4.	Oxygen requirement aerobic	+	+	+
	anaerobic	+	+	+
5.	Production of levan	+	+	+
6.	Starch hydrolysis	+	+	+
7.	Tyrosinase activity	+	+	+
8.	Production of indole	-	-	-
9.	a) MR test	+	+	+
	b) VP test	+	+	+
10.	Production of ammonia	+	+	+
11.	Action on milk			
	a) skimmed	+	+	+
	b) unskimmed	+	+	+
12.	Gelatin liquefaction	--	--	--
13.	Sodium chloride tolerance			
	1 per cent	+	+	+
	2 per cent	+	+	+
	3 per cent	--	--	--
	5 per cent	--	--	--
14.	Catalase test	+	+	+
15.	Production of hydrogen sulphide	+	+	+
16.	Arginine hydrolase test	+	+	+
17.	Lipolytic activity	-	-	-
18.	Urease test	+	+	
19.	Utilisation of asparagine as sole source of carbon and nitrogen	-	-	-

Sl. No.	Characters studied	Tomato isolate		Brinjal isolate		Chilli isolate	
		a	b	a	b	a	
20.	Utlization of carbon source with acid production						
Monosaccharides							
	a. Arabinose	+	D	D	D	D	D
	b. Ribose	++*	++*	++*	++*	++*	++*
	c. Glucose	++*	++*	++	++	++*	++*
	d. Fructose	++*	++	++*	++*	++*	++*
	e. Mannose	++*	++*	++*	++*	++*	++*
	f. Galactose	++*	++*	++*	++*	++*	++*
Disaccharides							
	a. Sucrose	++*	++*	++*	++*	++*	++
	b. Lactose	+	+	+	+	+	+
	c. Cellobiose	++*	++*	++*	++*	++*	++*
	d. Maltose	++*	++	++*	++	++*	++*
Sugar alcohols							
	a. Glycerol	+	+	+	+	+	+
	b. Inositol	+	+	+	+	+	+
	c. Sorbitol	++*	++	--	--	++*	++*
	d. Dulcitol	+	+	--	--	++*	++*
	e. Mannitol	++*	++*	++*	++*	++*	++*
21.	Utilisation of organic acid						
	a. Sodium acetate	Al	Al	Al	Al	Al	Al
	b. Sodium citrate	Al(y)	Al(y)	Al(y)	Al(y)	Al(y)	Al(y)
	c. Sodium benzoate	--	--	--	--	--	--

a- aerobic without paraffin oil
b- anaerobic with paraffin oil
++* Highly acidic with gas production (after 24 h.)
++ Acidic without gas production
+* Slightly acidic with gas production(after 72 h / 12 days)
+ Slightly acidic
-- No Change
D Doubtful (almost no change)
Al Alkaline (green colour to bule colour)
Al(y) Initially acidic after 24 h and then to blue

inoculation except in the case of arabinose. In arabinose the tomato isolate produced yellow colour under aerobic condition and an yellowish tinge was seen in brinjal and chilli isolates in the media after 21 days. With glucose, the brinjal isolate showed acidic reaction without gas production.

The three bacterial isolates also utilised the disaccharides (sucrose, cellobiose, maltose) with highly acidic reaction. In the case of lactose, all the isolates gave slight acidic reaction both under aerobic and anaerobic condition without any gas production. The chilli isolate failed to produce gas with sucrose and tomato and brinjal isolates failed to produce gas with maltose under anaerobic condition.

In the utilization of sugar alcohols, slightly acidic reaction was shown by all the isolates with glycerol and inositol. The brinjal isolate failed to utilise sorbitol, whereas the tomato and chilli isolates showed highly acidic reaction in sorbitol with gas production. The gas production was absent in the case of tomato isolate under anaerobic condition. The chilli isolate showed highly acidic reaction with gas production with dulcitol, whereas brinjal isolate failed to utilize dulcitol and tomato isolate gave slightly acidic reaction both under aerobic and anaerobic condition without any gas production. The isolates also utilized mannitol both under aerobic and anaerobic condition with gas production. The above observations form the basis for the distinction into biovars of the pathogen.

4.2.2.(xvii) **Utilisation of organic acids.**

Alkaline reaction as indicated by the change in colour of the medium from green to blue was shown by all the isolates with sodium acetate after 6 days. With sodium citrate the change in colour was almost yellow in all the bacterial isolates after 48 h, but by the 6th day after inoculation there was a change to blue colour in all the isolates. No change in colour was noticed in sodium benzoate.

4.2.3. Cross inoculation studies using isolates of *R. solanacearum* from tomato, brinjal and chilli

Cross inoculation studies were carried out as described in the Materials and Methods and the results are presented in Table. 3. All the isolates produced symptoms in all the three hosts tried, but the intensity of symptom expression varied. The wilting of the plants started within ten days in each host plant by their respective pathogen isolates. The tomato isolate wilted brinjal and chilli plants after ten days. But brinjal isolate wilted tomato plants in five days and chilli plants after ten days. The chilli isolates wilted tomato and brinjal plants ten days after inoculation.

Table : 3 Cross inoculation studies using isolates of *R. solanacearum.* from tomato, brinjal and chilli

Isolate	Relative virulence on different hosts		
	Tomato	Brinjal	Chilli
Tomato isolate	95 H	100 H	55 M
Brinjal isolate	90 H	100 H	50 M
Chilli isolate	65 H	100 H	65 H

H - High (> 65 per cent wilt incidence).
M- Moderate (> 40 < 65 per cent wilt incidence).
L - Low (< 40 per cent wilt incidence)

All the three isolates of the pathogen were highly virulent on brinjal and tomato with more than 65 per cent wilt incidence. Among these two hosts, the isolates were highly virulent on brinjal with 100 per cent wilt. The chilli isolates exhibited high virulence on chilli plants, whereas the other two isolates were moderate in their virulence in chilli.

4.2.4. Sensitivity to antibiotics

Data on the *in vitro* sensitivity of the bacterial isolates to four common antibiotics at different concentrations are given in Table.4. Among the concentrations tried 10 and 100 ppm of all antibiotics were found insufficient to inhibit the growth of the pathogen. Also the antibiotic Penicillin G could not give any inhibition to any of the bacterial isolates at the different concentrations tried.

A comparison of the mean diameter of zone of inhibition of the antibiotics indicated that Ambistryn S at 250 and 500 ppm caused maximum inhibition of growth of tomato isolate. This was followed by Streptocycline 250 and 500 ppm. For brinjal isolate, the maximum inhibition of growth was shown by Streptocycline. In the case of chilli isolate also maximum inhibition was recorded with the Streptocycline at 500 ppm.

Table : 4 Relative sensitivity of the different isolates of *R. Solanacearum* to antibiotics.

Treatments	Zone of inhibition (mm)		
	Tomato isolate	Brinjal isolates	Chilli isolates
Penicillin G 10 ppm	0	0	0
Penicillin G 100 ppm	0	0	0
Penicillin G 250 ppm	0	0	0
Penicillin G 500 ppm	0	0	0
Ambistryn S 10 ppm	0	0	0
Ambistryn S 100 ppm	0	0	0
Ambistryn S 250 ppm	35	30	25
Ambistryn S 500 ppm	43	40	30
Oxytetracycline 10 ppm	0	0	0
Oxytetracycline 100 ppm	0	0	0
Oxytetracycline 250 ppm	23	30	30
Oxytetracycline 500 ppm	25	40	30
Streptocycline 10 ppm	0	0	0
Streptocycline 100 ppm	0	0	0
Streptocycline 250 ppm	25	48	28
Streptocycline 500 ppm	30	60	35

4.2.5. Toxigenic property of the bacterial isolates

Studies were conducted on the production of toxic metabolite by the pathogen in *in vitro*. It was observed that the maximum dry weight of toxic metabolite was with tomato isolate (0.165g / 250 ml) followed by chilli isolate (0.104g / 250 ml) and lastly brinjal isolate (0.079g / 250 ml).

The *in vivo* studies conducted with toxic metabolites from isolates of the pathogen from tomato, brinjal and chilli using detached twigs and seedlings have given the following results. None of the wilted twigs / seedling recovered from wilting when they were transferred to distilled water. The twigs of chilli were showing earlier wilt symptoms by the three toxic metabolites followed by tomato and brinjal.

When the study was conducted with the seedling the tomato seedlings were most sensitive followed by brinjal and chilli seedlings.

4.3 Screening varieties/ lines of tomato, brinjal and chilli for resistance / susceptibility against *R.solanacerum*.

The results of the study on the screening of varieties/lines of tomato, brinjal and chilli for resistance / susceptibility to *R.solanacearum* are presented in Tables

5,6 and 7. Out of the 43 varieties/lines of tomato screened against the pathogen six were rated as resistant, four moderately resistant, seven moderately susceptible and 26 as susceptible. In brinjal eight entries were grouped as resistant, 13 as moderately resistant, nine as moderately susceptible and 13 as susceptible. In chilli eight lines were categorized as resistant, 16 as moderately resistant, 12 as moderately susceptible and seven as susceptible. The following varieties/ lines were selected from each crop under each category for further studies based on their reaction to *R. solanacearum*.

Reaction	Tomato	Brinjal	Chilli
Resistant	LE 79-5	Swetha	Ujwala
Moderately resistant	BT-10	Composite-2	Manjari
Moderately susceptible	LE 470	BB-7	Jwalasakhi
Susceptible	Pusa Ruby	Pusa Purple Long	Pusa Jwala

4.4 Biochemical constituents of resistant and susceptible varieties/lines of healthy tomato, brinjal and chilli.

This study was carried out to know the biochemical constituents of healthy solanaceous vegetables. The biochemical studies were carried out with root, stem and leaf of the selected four varieties of each crop plant namely LE 79-5 (R), BT-10 (MR), LE-470 (MS) and Pusa Ruby (S) for tomato; Swetha (R), Composite-2 (MR), BB-7 (MS) and Pusa Purple Long (S) for brinjal and Ujwala (R), Manjari(MR), Jwalasakhi (MS) and Pusa Jwala (S) for chilli.

Table.5 Reaction of varieties / lines of tomato for resistance / susceptibility to *R.solanacearum* .

Sl. No.	Varieties / lines	Wilt Percentage	Reaction
1.	EC 164666	91.67	S
2.	P.M.D	90.00	S
3.	BT-10	33.30	MR
4.	EC 164656	100.00	S
5.	Pusa Ruby	90.00	S
6.	EC 164642	83.30	S
7.	EC 164668	100.00	S
8.	EC 164670	100.00	S
9.	BT 18	10.00	R
10.	EC 164660	80.00	S
11.	CO1	53.84	MS
12	BT-2	7.69	R
13.	BT-1	70.00	S
14.	LE 79-5	5.88	R
15.	EC 165393	100.00	S
16.	EC 164661	100.00	S
17.	LE 296	15.00	R
18.	Sakthi	11.10	R
19.	EC 164665	88.24	S
20.	EC 164663	71.43	S
21.	LE 457	57.14	MS
22.	LE 455	57.14	MS
23.	LE 435	60.00	MS
24.	LE 434	20.00	MR
25	LE 453	5.00	R
26	LE 458	58.30	MS
27	LE 459	50.00	MS

Sl. No.	Varieties / lines	Wilt Percentage	Reaction
28.	LE 470	58.00	MS
29.	LE 518	23.00	MR
30.	LE 508	25.00	MR
31.	LE 447	90.00	S
32.	LE 462	100.00	S
33.	LE 463	100.00	S
34.	LE 464	100.00	S
35.	LE 465	100.00	S
36.	LE 466	100.00	S
37.	LE 467	100.00	S
38.	LE 468	100.00	S
39.	LE 469	100.00	S
40.	LE 471	100.00	S
41	LE 450	100.00	S
42.	LE 451	100.00	S
43	LE 452	100.00	S

R - Resistant, MR - Moderately resistant
S - Susceptible MS - Moderately susceptible

Table.6. Reaction of varieties/lines of brinjal for resistance / susceptibility to *R. solanacearum*.

Sl. No.	Varieties / lines	Wilt Percentage	Reaction
1.	IC 112712	50.00	MS
2.	IC 112359	63.64	S
3.	334 B/170 - 2	20.34	MR
4..	NL / 500 - 3	20.38	MR
5.	502 / 491 - 1,3,5	12.50	R
6.	409 - A / 25 - 1	78.57	S
7	235 - 402 - 5	33.33	MR
8.	IC 112358	84.61	S
9.	268 / 47 - 4	20.28	MR
10.	NL / 497 - 4	46.15	MS
11.	BB-7	57.78	MS
12.	BB 44	14.29	R
13.	BB 13 - 1	23.18	MR
14.	IC 112347	91..66	S
15.	296 - A /431 - 5	60.56	S
16.	242 - A/409 - 2	20.00	MR
17.	243 / 410 - 1	42.86	MS
18.	268 / 48 - 3	80.00	S
19.	IC 112714	100.00	S
20..	563 / 492 - 2	43.46	MS
21..	Surya	8.00	R
22..	CO2	92..31	S
23.	406 / 657 - 3,4,5	100.00	S
24.	376 - A /199 - 4,5	30..00	MR
25.	NL / 501 - 3	50.00	MS
26.	268 / 47 - 4	80.00	S
27	468 - A/ 709 - 5	20.00	MR

Sl. No.	Varieties / lines	Wilt Percentage	Reaction
28	409 / 252 /4	66.70	S
29.	361 / B /463 - 3,4	23.10	MR
30.	NL / 498 , 2,3, 4,5	60.00	MS
31..	NL / 2	42.50	MS
32.	NL / 502 - 3	84.62	S
33.	Pant - Samrat	80.29	S
34.	503 / 492 - 1	5.00	R
35.	Arka - Keshav	20.29	MR
36.	IC 112357	43.50	MS
37.	296 A/731-3	20.20	MR
38.	238/ 602 - 2,3	8.19	R
39.	408 /A/247 - 3	4.23	R
40.	Swetha	5.10	R
41.	Pusa Purple Long	80.00	S
42.	Composite - 2	30.00	MR
43.	SM 141	8.89	R

R - Resistant, MR - Moderately resistant
S - Susceptible MS - Moderately susceptible

Table.7. Reaction of varieties / lines of chilli for resistance / susceptibility to *R. solanacearum.*

Sl. No.	Varieties / lines	Wilt Percentage	Reaction
1.	JBT -- 12 /10	46.36	MS
2.	CO2	26.67	MR
3.	JBT - 12 /1	25.38	MR
4.	AKC 86 - 39	22.50	MR
5.	Ujwala	10.00	R
6	CO3	28.75	MR
7.	IC 119704	35.00	MR
8.	D - 1742	30.00	MR
9.	SA 2575	30.11	MR
10.	IC 119797	21.11	MR
11.	Arka Lohit	42.00	MS
12.	Manjari	30.22	MR
13.	JCA - 283	55.00	MS
14.	LCA - 204	45.71	MS
15	PKM - 1	41.25	MS
16.	LCA - 206	21.76	MR
17.	AS - 68	18.09	R
18.	PK - 1	40.80	MS
19.	JBT - 12 / 83	40.77	MS
20.	VKP - 455	26.67	MR
21.	IC 119752	67.14	S
22.	Kokan Keerthi	25..05	MR
23.	NKG - 88/34	80.78	S
24.	CO 1	12.14	R
25.	NIC 17737	30.67	MR
26.	LCA - 305	47.86	MS
27.	IC 119575	24.29	MR

Sl. No.	Varieties / lines	Wilt Percentage	Reaction
28.	JBT 12/39	18.00	R
29.	IC 119705	80.00	S
30.	MR 90/181	100.00	S
31.	SA 2224	12.00	R
32.	IC 119695	43.33	MS
33.	IC 119642	40.21	MS
34.	Pusa Jwala	85.71	S
35.	NC 65934	65.14	S
36.	IC 119639	15.14	R
37.	PBC 122	19.09	R
38.	Surakta	100.00	S
39.	IC 119710	23.67	MR
40.	SA3209	26.18	MR
41.	JBT 12/93	14.29	R
42.	SA 2308	23.19	MR
43.	Jwala Sakhi	50.67	MS

R - Resistant, MR - Moderately resistant
S - Susceptible MS - Moderately susceptible

The results of the biochemical constituents in the healthy solanaceous vegetables are given in Tables. 8,9 and 10.

4.4.1 Total phenol

The total phenol content in the healthy root varied considerably depending on the crops (Table. 8). In tomato the total phenol content was highest in LE 470 (MS) and lowest in the variety LE 79-5 (R). In brinjal significantly higher total phenol content was observed by Composite-2 (MR) and lower in BB-7 (MS). The chilli variety Ujwala (R) had the highest content of phenol and lowest in Manjari (MR).

There was significant difference between the varieties/lines in their total phenol content in the stem. It was highest in BT-10 (MR) of tomato and lowest in LE 79-5 (R). In brinjal it was maximum in BB-7 (MS) and minimum in Composite-2 (MR). In chilli Manjari (MR) recorded the maximum total phenol content. Lowest phenol content was obtained in Pusa Jwala (S).

Compared to root and stem, the leaf recorded a higher total phenol content. The results are presented in Table.10. in tomato leaf the total phenol content was

significantly higher in Pusa Ruby (S) and was lower in LE 470 (MS). Whereas in brinjal the total phenol content was significantly highest in Swetha (R) and lowest in Pusa Purple Long (S). In chilli the highest total phenol content was obtained in Ujwala (R) and lowest in Manjari (MR).

4.4.2 OD Phenol

In tomato root the variety LE 79-5 (R) recorded significantly higher content of OD phenol,when compared to the other varieties/ lines (Table 8). The OD phenol content was lowest in BT-10 (MR). The same trend was observed for brinjal also. It was highest in Swetha (R), lowest in Composite-2 (MR). In chilli, Manjari (MR) gave the maximum OD phenol content and Jwalasakhi (MS) gave the minimum.

In tomato stem the OD phenol content was maximum in Pusa Ruby (S) and minimum in LE 79-5 (R) (Table. 9). The difference between the varieties/ lines in their OD phenol content was not so significant in the case of brinjal and chilli. However in brinjal also the OD phenol content was highest in Pusa Purple Long (S) and lowest in Composite-2 (MR), in chilli it was in Manjari (MR) and Jwalasakhi (MS) respectively.

There were significant differences between the varieties of different crops in their OD phenol content in the leaf (Table. 10). In tomato the OD phenol content was highest in Pusa Ruby (S) and lowest in LE 79-5 (R). In brinjal, Swetha (R) was significantly superior in its OD phenol content than the rest of the varieties/lines. The lowest OD phenol content was noticed in Composite-2 (MR). In chilli also, the Ujwala (R) has got maximum OD phenol content and minimum in Pusa Jwala (S).

4.4.3. Soluble sugars

The soluble sugar content was significantly highest in Pusa Ruby (S) and lowest in LE 79-5 (R) in the case of tomato root (Table. 8). In brinjal the soluble sugar content was maximum in Swetha (R) and minimum in Pusa Purple Long (S). In chilli also the soluble sugar content was higher in the variety Ujwala (R) and lower in Jwalasakhi (MS).

In the stem the soluble sugar content was highest in Pusa Ruby (S) in tomato and lowest in LE 79-5 (R) (Table. 9). In brinjal also maximum soluble sugar content was noticed in Pusa Purple Long (S) and minimum in Composite-2 (MR), while in chilli the soluble sugar content was highest in Ujwala (R) and lowest in Manjari (MR).

Table. 9 Biochemical constituents in the healthy stem of bacterial wilt resistant and susceptible varieties / lines of tomato, brinjal and chilli

Sl. No.	Varieties / lines	Disease reaction	Total phenol (mg g^{-1})	OD phenol (mg g^{-1})	Soluble sugars (mg g^{-1})	Total free amino acids (mg g^{-1})	No. of amino acids	Soluble protein (mg g^{-1})	Poly phenol oxidase activity *	Specific actiivity **	Peroxidase activity ***	Alkaloids (%)
	Tomato											
1.	LE 79-5	R	0.505	0.001	0.459	4.19	5	2.561	0.036	0.132	500.00	16.00
2	BT 10	MR	1.013	0.001	0.823	2.40	6	3.403	0.048	0.115	1041.67	14.00
3	LE 470	MS	0.692	0.015	0.596	2.690	7	3.961	0.056	0.079	588.24	16.00
4.	Pusa Ruby	S	0.790	0.057	0.838	2.540	8	0.765	0.011	0..090	312.50	16.75
	CD (0.05)		0.194	0.012	0.094	0.755		0.165	0.010		24.82	NS
	Brinjal											
5.	Swetha	R	1.350	0.004	1.224	7.000	1	2.429	0.115	0.199	1315.79	6.00
6.	Composite-2	MR	1.102	0.002	0.429	5.000	5	4.489	0.132	0.131	1515.15	8.00
7.	BB 7	MS	1.736	0.002	0.881	2.000	5	3.270	0.057	0.136	1470.59	6.50
8	Pusa Purple Long	S	1.142	0.008	1.296	12.920	6	3.592	0.062	0.095	2272.73	16.00
	CD (0.05)		0.171	0.016	0.090	8.405		0.327	0.015		7.28	NS
	Chilli											
9.	Ujwala	R	2.434	0.014	1.063	3.630	4	1.749	0.069	0.300	934.40	10.0
10.	Manjari	MR	2.472	0.026	0.264	5.930	3	2.864	0.088	0..130	462.96	10.00
11.	Jwalasakhi	MS	1.629	0.009	0.349	4.410	8	3.044	0.120	0.179	510.20	14.00
12.	Pusa Jwala	S	1.384	0.024	0.336	5.630	5	3.563	0.072	0.113	735.29	18.00
	CD (0.05)		0.428	0.012	0.092	4.744		0.182	0.014		3.340	3.18

Mean of four replications

* - OD values ** - Unit mg^{-1} protein at 30°C for one minute, *** - Units per litre

R - Resistant MR - Moderately resistant

S - Susceptible MS - Moderately susceptible NS - Not significant

Table. 10 Biochemical constituents in the healthy leaf of bacterial wilt resistant and susceptible varieties / lines of tomato, brinjal and chilli

Sl. No.	Varieties / lines	Disease reaction	Total phenol (mg g^{-1})	OD phenol (mg g^{-1})	Soluble sugars (mg g^{-1})	Total free amino acids (mg g^{-1})	No. of amino acids	Soluble protein (mg g^{-1})	Poly phenol oxidase activity *	Specific activity **	Peroxidase activity ***	Alkaloids (%)
	Tomato											
1.	LE 79-5	R	2.164	0.002	0.846	4.930	6	5.643	0.112	0.278	240.380	24.00
2.	BT-10	MR	3.178	0.084	0.804	5.660	10	7.826	0.104	0..149	166.670	16.00
3.	LE 470	MS	1.613	0.030	0.645	7.270	7	7.902	0.061	0.089	384.620	25.00
4.	Pusa Ruby	S	3.380	0.167	0.999	4.270	6	3.081	0.020	0.124	490.200	16.00
	CD (0.05)		0.259	0.009	NS	0.807		0.349	0.034		78.370	7.22
	Brinjal											
5.	Swetha	R	8.011	0.159	0.911	10.00	9	1.408	0.166	0.972	847.460	22.00
6	Composite 2	MR	1.889	0.034	0.437	3.500	9	5.615	0.130	0.151	2083.330	20.00
7.	BB 7	MS	3.116	0.097	0.493	7.000	3	5.567	0.081	0.143	137.740	22.00
8..	Pusa Purple Long	S	1.169	0.067	0.366	7.000	6	8.961	0.103	0.132	375.940	22.00
	CD (0.05)		0.599	0.026	0.079	1.872		0.101	0.009		8.220	3.71
	Chilli											
9.	Ujwala	R	5.333	0.066	1.618	9.340	8	3.573	0.044	0.165	980.390	24.00
10.	Manjari	MR	2.721	0.050	0.581	5.460	6	4.764	0.034	0.256	151.520	30.00
11.	Jwalasakhi	MS	3.094	0.029	0.895	6.320	8	9.754	0.064	0.114	176.450	34.00
12.	Pusa Jwala	S	3.070	0.020	0.673	8.40	5	8.081	0.008	0..096	231.480	30.00
	CD (0.05)		1.432	0.010	0.172	1.270		0.187	0.041		7.910	6.09

Mean of four replications

* - OD values ** - Unit mg^{-1} protein at 30°C for one minute, *** - Units per litre

R - Resistant MR - Moderately resistant

S - Susceptible MS - Moderately susceptible NS - Not significant

Significant differences were not obtained in soluble sugar content between the leaf of different varieties/lines of tomato, the highest content was obtained in Pusa Ruby (S) and lowest in LE 470 (MS). In brinjal the soluble sugar content was significantly highest in Swetha(R) and lowest in Pusa Purple Long (S). In chilli also, Ujwala(R) was significantly superior in soluble sugar content than the other varieties/lines and Manjari (MR) recorded the lowest.

4.4.4 Amino acid

In the root the total free amino acid content was highest in BT-10 (MR) and lowest in LE 470 (MS), but the number of amino acid was maximum in the variety Pusa Ruby (S) and was minimum in BT-10 (MR) and LE 79-5 (R) in tomato. In brinjal the total free amino acid content was significantly higher in Pusa Purple Long (S) compared to other varieties/lines (Table. 8). The variety BB-7 (MS) gave the lowest total free amino acid content. Pusa Purple Long (S) also recorded the maximum number of amino acids and minimum by Swetha (R) and Composite-2 (MR). In chilli the total free amino acid content and number of amino acids were highest in Pusa Jwala (S) and lowest in resistant genotypes, Manjari (MR) and Ujwala (R).

The total free amino acid content was significantly highest in the stem of LE 79-5 (R) and lowest in BT-10 (MR) whereas the number of amino acids were highest in Pusa Ruby (S) and lowest in LE 79-5 (R) in tomato (Table. 9). In brinjal the total free amino acid and number of amino acids were highest in Pusa Purple Long (S). But it was lowest in BB-7 (MS) and Swetha (R) respectively. In chilli the total free amino acid was maximum in Manjari (MR) and minimum in Ujwala (R). The number of amino acids was highest in Jwalasakhi (MS) and lowest in Manjari (MR).

Total free amino acid was highest in the leaf of LE-470 (MS) and lowest in Pusa Ruby (S) (Table.10). The number of amino acids was highest in BT-10 (MR) in tomato and lowest in LE 79-5 (R) and Pusa Ruby (S). In brinjal leaf, Swetha (R) has got significantly highest total free amino acids and lowest in Composite-2 (MR). The number of amino acids was highest in the variety, Swetha (R) and Composite-2 (MR) and lowest in BB-7 (MS). Ujwala (R) had the highest total free amino acid and lowest in Manjari (MR). The number of amino acids were maximum in Ujwala (R) and Jwalasakhi (MS) in chilli and minimum in Pusa Jwala (S).

4.4.5. Soluble protein

In tomato root the soluble protein content was significantly superior in LE 470 (MS) and lower in LE 79-5 (R) (Table. 8). In brinjal there was significant difference between the varieties in soluble protein content, the maximum was given by Composite-2 (MR) and minimum in BB-7 (MS). In chilli also significant difference was observed, with the highest in Pusa Jwala (S) and lowest in Ujwala (R).

In the stem of tomato, the soluble protein content was maximum in LE 470 (MS), and minimum in Pusa Ruby (S) (Table. 9). In brinjal the highest soluble protein content was obtained in Composite-2 (MR) and lowest in Swetha(R). In chilli Pusa Jwala (S) was significantly superior in soluble protein content and lower in Ujwala (R).

The soluble protein content was highest in the leaf of LE 470 (MS) and lowest in Pusa Ruby (S) in tomato (Table. 10). In brinjal and chilli the highest soluble protein content was obtained in susceptible varieties Pusa Purple Long (S) and Pusa Jwala (S) and lowest in resistant varieties Swetha (R) and Ujwala (R) respectively.

4.4.6 Polyphenol oxidase activity

In tomato root the polyphenol oxidase activity was significantly superior in the variety LE 79-5 (R) and lower in Pusa Ruby (S) (Table.8). In brinjal also the same trend was noticed, the highest activity in Swetha (R) and lowest in Pusa Purple Long (S). In chilli maximum enzyme activity was noticed in Jwalasakhi (MS) and minimum in Ujwala (R).

Polyphenol oxidase activity was highest in the stem of LE 470 (MS) and lowest in Pusa Ruby (S) for tomato (Table. 9). In brinjal the maximum activity was noticed in Composite-2 (MR) and minimum in BB-7 (MS). In chilli the highest activity was noticed in Jwalasakhi (MS) and lowest in Ujwala (R).

In tomato leaf the polyphenol oxidase activity was highest in LE 79-5 (R) and lowest in Pusa Ruby (S) (Table. 10). In brinjal also, the same trend was noticed with more activity in Swetha (R), which was significantly superior to others. A lesser activity was observed in BB-7 (MS). In chilli the maximum activity was noticed in Jwalasakhi (MS) and minimum in Pusa Jwala (S).

4.4.7 Specific activity

The root of resistant genotype of tomato recorded a higher specific activity with regard to polyphenol oxidase activity, the maximum in BT-10 (MR) and minimum in LE-470 (MS) (Table 8). In brinjal the specific activity was highest in BB-7 (MS) and lowest in Pusa Purple Long (S). The same trend was noticed in chilli also, the highest in Jwalasakhi (MS) and lowest in Pusa Jwala (S).

The resistant genotypes recorded a higher specific activity in the stem of all the three crops (Table.9). In tomato, brinjal and chilli the specific activity was highest in LE 79-5 (R), Swetha (R) and Ujwala(R) and lowest in Pusa Ruby (S), Pusa Purple Long (S) and Pusa Jwala (S) respectively.

In leaf of tomato, brinjal and chilli the specific activity was higher in resistant genotypes compared to the susceptible ones. The highest specific activity was noticed in LE 79-5 (R) of tomato, Swetha (R) of brinjal and Manjari (MR) of chilli. The lowest activity was recorded in Pusa Ruby (S), Pusa Purple Long (S) and Pusa Jwala (S) of tomato, brinjal and chilli respectively.

4.4.8 Peroxidase activity

There were significant differences in peroxidase activity between the varieties/lines in the root of different crops. In tomato the peroxidase activity was highest in BT-10 (MR) and lowest in LE 79-5 (R). In brinjal the maximum activity was recorded in Swetha (R) and minimum in Pusa Purple Long (S). In chilli, the peroxidase activity was highest in Jwalasakhi (MS) and lowest in Ujwala (R).

There were significant differences between the varieties/lines in their peroxidase activity in the stem of three crops (Table. 9). The peroxidase activity was highest in BT-10 (MR) and lowest in Pusa Ruby (S) of tomato. In brinjal the activity was maximum in Pusa Purple Long (S) and minimum in Swetha (R). In chilli the activity was highest in Ujwala (R) and lowest in Manjari (MR).

In tomato leaf, the peroxidase activity was significantly highest in Pusa Ruby (S) and lowest in BT - 10 (MR) whereas in brinjal it was significantly highest in resistant varieties/lines, the highest in Composite-2 (MR) and lowest in BB-7 (MS) (Table.10). In chilli also the maximum activity was recorded in Ujwala (R) and minimum in Manjari (MR).

4.4.9 Alkaloid Content

The alkaloid content was more in LE 79-5 (R) and less in Pusa Ruby (S) in tomato root (Table. 8). In brinjal significant difference was obtained between varieties/lines in their alkaloid content. The highest alkaloid content was recorded in BB-7 (MS) and lowest in Swetha (R). In chilli the maximum alkaloid content was recorded in Manjari (MR) and lowest in Ujwala (R).

Significant differences were not obtained between the varieties/lines in their alkaloid content in the stem (Table. 9). In tomato, brinjal and chilli the alkaloid content was highest in susceptible genotypes viz. Pusa Ruby (S), Pusa Purple Long (S) and Pusa Jwala (S) and lowest in BT-10 (MR), Swetha (R) and Ujwala (R) respectively.

In tomato the alkaloid content in leaf was highest in LE 470 (MS) and lowest in BT-10 (MR) and Pusa Ruby (S). In brinjal and chilli there was not much difference in alkaloid content of leaf in the different varieties/lines. However in brinjal more alkaloid content was noticed in Swetha (R) and less in Composite-2 (MR). In chilli the maximum content was recorded in Jwalasakhi (MS) and minimum in Ujwala (R).

4.5 Biological factors in the rhizosphere soil of resistant and susceptible varieties/lines of healthy tomato, brinjal and chilli.

The counts of total microflora (fungi, bacteria, actinomycetes) pseudomonads (virulent *Ralstonia*, and avirulent *Pseudomonas)*, beneficial microbes (mycorrhiza and Azospirillum) and nematodes (parasitic and saprophytic) populations in the rhizosphere soil of different varieties/ lines of tomato, brinjal and chilli under healthy condition given in Table. 11.

4.5.1 Total Microflora

The fungal population was significantly higher in the susceptible tomato, namely Pusa Ruby (S) and was lower in BT-10 (MR). In brinjal the fungal population was maximum in the variety Swetha (R) and minimum in Composite-2 (MR). In chilli significant difference was not seen between varieties/lines in their fungal flora, the highest in Pusa Jwala (S) and lowest in Manjari (MR).

The bacterial population was significantly higher in the susceptible varieties of tomato, the highest in LE 470 (MS) and lowest in LE 79-5 (R). In brinjal the population of bacteria was highest in Composite-2 (MR) and lowest in BB-7 (MS). In chilli also, the maximum population was recorded in Manjari (MR) and minimum in Ujwala (R), although significant difference was not obtained between the varieties/lines.

Table. 11 Biological factors in the rhizosphere soil of healthy plants of bacterial wilt resistant and susceptible varieties / lines of tomato, brinjal and chilli

Sl. no.	Varieties / lines	Disease reaction	Fungi (c.f.u.)	Bacteria (c.f.u.)	Actino-mycets (c.f.u.)	Virulent *Ralstonia* (c.f.u.)	Avirulent *Psedomonas* (c.f.u.)	Mycorr-hiza **	Azospi-rillum (c.f.u.)	Saprophytic Nematodes *	Parasitic Nematodes *
	Tomato										
1.	LE 79-5	R	2.035	2.780	2.060	1.387	1.000	39.00	2.850	303.00	25.00
2.	BT-10	MR	1.785	3.337	2.870	1.662	3.425	33.00	1.993	179.00	14.00
3.	LE 470	MS	1.898	8.060	2.525	1.387	2.803	48.00	1.993	391.00	15.00
4.	Pusa Ruby	S	2.998	5.782	6.105	5.332	7.080	41.00	5.430	178.00	23.00
	CD (0.05)		0.692	0.634	0.725	1.055	1.516	NS	0.971	85.77	7.823
	Brinjal										
5.	Swetha	R	4.873	5.520	3.960	5.558	4.590	57.00	2.787	1026.0	67.00
6	Composite-2	MR	1.958	8.007	5.822	5.655	5.520	57.00	6.215	319.00	34.00
7.	BB7	MS	3.730	4.412	2.630	4.335	4.237	30.00	3.450	150.00	25.00
8.	Pusa Purple Long	S	3.965	6.178	6.975	10.525	4.287	38.00	4.905	756.00	72.00
	CD (0.05)		0.676	1.045	0.989	0.945	0.629	NS	1.414	50.05	3.12
	Chilli										
9	Ujwala	R	3.033	5.242	2.543	4.110	3.152	35.00	4.448	786.00	126.00
10.	Manjari	MR	2.783	6.983	4.829	4.685	7.170	34.00	3.885	251.00	35.00
11.	Jwalasakhi	MS	2.815	6.918	6.218	6.102	5.805	50.00	9.263	35.00	29.00
12.	Pusa Jwala	S	3.953	6.620	3.168	3.413	2.730	24.00	5.978	221.00	37.00
	CD (0.05)		NS	NS	1.445	2.331	NS	NS	3.045	12.51	5.40

Mean of four replications

R - Resistant MR - Moderately resistant

S - Susceptible MS - Moderately susceptible NS - Not significant

* Counts. (No transformation)

** Percentage of infection.

The actinomycete population was significantly higher in Pusa Ruby (S) and Pusa Purple Long (S) of tomato and brinjal varieties respectively. The population was lowest in LE 79-5 (R) in tomato and in brinjal BB-7 (MS). In chilli the maximum population was recorded in Jwalasakhi (MS) and minimum in Ujwala (R).

4.5.2. Pseudomonads

Virulent *Ralstonia* population was significantly highest in Pusa Ruby (S) of tomato. In the other three varieties/lines significant difference was not obtained. In brinjal also it was significantly highest in Pusa Purple Long(S) and lowest in BB-7 (MS). In chilli, significant difference was not obtained between the varieties/lines in virulent *Ralstonia* population, the maximum obtained in Jwalasakhi (MS) and minimum in Pusa Jwala (S).

In tomato the avirulent *Pseudomonas* population was significantly highest in Pusa Ruby (S) and lowest in LE 79-5 (R). In brinjal maximum population was obtained in Composite-2 (MR) and minimum in BB-7 (MS). In chilli also the avirulent *Pseudomonas* population was highest in Manjari (MR) and lowest in Pusa Jwala (S).

4.5.3. Beneficial microbes

In tomato and brinjal the varieties/lines do not differ significantly in their mycorrhizal association, the highest noted in LE 470 (MS) of tomato and Swetha (R) and Composite-2 (MR) of brinjal. The lowest population was recorded in BT-10 (MR) of tomato and BB-7 (MS) of brinjal. In chilli the population was maximum in Jwalasakhi (MS) and minimum in Pusa Jwala (S).

The Azospirillum population was highest in Pusa Ruby (S) and lowest in LE 470 (MS) and BT-10 (MR) of tomato. In brinjal the maximum population was recorded in Composite-2 (MR) and minimum in Swetha (R). In chilli, the Azospirillum population was more in susceptible varieties/ lines when compared to the resistant ones, the highest in Jwalasakhi (MS) lowest in Manjari (MR).

4.5.4. Nematodes

The saprophytic nematode population was maximum in LE 470 (MS) and minimum in Pusa Ruby (S) of tomato. Its population was significantly highest in the rhizosphere soil of the resistant varieties/lines of brinjal and chilli, Swetha (R) and Ujwala (R) respectively. The lowest population recorded in moderately susceptible

varieties/lines of brinjal and chilli viz. BB-7 (MS) and Jwalasakhi (MS) respectively. In tomato Pusa Ruby (S) recorded the lowest saprophytic nematode population.

In tomato the highest parasitic nematode population was seen in rhizosphere soil of LE 79-5 (R). The lowest population was recorded in BT-10 (MR). In brinjal the variety Pusa Purple Long (S) recorded the highest parasitic nematode population and BB-7 (MS) the lowest. In chilli the maximum population was recorded in Ujwala (R), and minimum in Jwalasakhi (MS).

The common parasitic nematode genera noticed in the samples during the study were *Radopholus sp, Rotylenchus sp., Hoplolaimus sp.* and *Helicotylenchus sp.*

4.6. Nutritional factors in the resistant and susceptible varieties/ lines of healthy tomato, brinjal and chilli

The root, stem and leaf of tomato, brinjal and chilli were analysed for the contents of the major nutrients like nitrogen, phosphorus and potassium and minor nutrients like calcium, magnesium, iron, zinc and manganese. The results are presented in Tables 12,13 and 14.

Table. 12. Nutritional factors in the healthy roots of bacterial wilt resistant and susceptible varieties / lines of tomato, brinjal and chilli

Sl. no.	Varieties / lines	Disease reaction	Nitrogen (%)	Phos-phorus (%)	Potassium (%)	Calcium (%)	Magne-sium (%)	Iron (%)	Zinc ($\mu g\ g^{-1}$)	Man-ganese ($\mu g\ g^{-1}$)
	Tomato									
1.	LE 79-5	R	2.430	0.237	1.640	0.225	0.064	0.226	66.500	75.900
2.	BT-10	MR	1.650	0.157	1.200	0.495	0.073	0.115	82.900	165.750
3.	LE 470	MS	2.330	0.150	1.070	0.391	0.071	0.358	83.500	507.900
4.	Pusa Ruby	S	1.630	0.271	1.320	0.388	0.080	0.558	80.200	170.100
	CD (0.05)		NS	0.007	0.094	NS	NS	0.012	5.110	39.914
	Brinjal									
5.	Swetha	R	1.720	0.140	1.080	0.870	0.073	0.059	113.700	177.900
7.	Composite-2	MR	1.870	0.126	1.030	0.535	0.070	0.259	65.800	385.700
8.	BB7	MS	1.540	0.055	0.320	0.374	0.052	0.092	77.200	134.400
9.	Pusa Purple Long	S	1.210	0.270	1.505	0.600	0.067	0.172	82.000	305.300
	CD (0.05)		0.575	0.018	NS	0.029	0.001	0.019	NS	12.270
	Chilli									
10.	Ujwala	R	0.990	0.133	0.830	0.286	0.062	0.199	28.200	444.200
11.	Manjari	MR	2.120	0.126	1.263	0.894	0.069	0.435	33.600	556.100
12.	Jwalasakhi	MS	1.390	0.267	1.170	0.308	0.067	0.183	26.800	490.500
13.	Pusa Jwala	S	1.400	0.171	2.380	0.699	0.085	0.078	64.100	258.900
	CD (0.05)		0.677	0.042	0.292	0.059	0.002	0.016	6.076	13.996

Mean of four replications

R - Resistant MR - Moderately resistant

S - Susceptible MS - Moderately susceptible NS - Not significant

4.6.1. Nitrogen content

When the nitrogen content in the different varieties/lines of tomato, brinjal and chilli were compared, significant difference was not obtained between them. In tomato root, the nitrogen content was highest in the variety LE 79-5 (R) and lowest in Pusa Ruby (S) (Table 12). Similarly in brinjal the nitrogen content was higher in resistant varieties/lines, the highest in Composite-2 (MR) and lowest in Pusa Purple Long (S). In chilli, the nitrogen content was maximum in Manjari (MR), and minimum in Ujwala(R).

The nitrogen content in the stem of different varieties of tomato, brinjal and chilli did not differ significantly (Table 13). In tomato the nitrogen content was highest in Pusa Ruby (S) and lowest in LE 79-5 (R). In brinjal the highest nitrogen content was noticed in Composite-2 (MR) and lowest in Pusa Purple Long (S). In chilli Ujwala (R) contained the maximum nitrogen and Pusa Jwala (S) and Manjari (MR) the minimum.

The nitrogen content in the leaf of different varieties/lines of tomato, brinjal and chilli differ significantly except in tomato. Here the leaf of Pusa Ruby

Table.13 Nutritional factors in the healthy stem of bacterial wilt resistant and susceptible varieties / lines of tomato, brinjal and chilli

Sl. no.	Varieties / lines	Disease reaction	Nitrogen (%)	Phos-phorus (%)	Potassium (%)	Calcium (%)	Magne-sium (%)	Iron (%)	Zinc ($\mu g\ g^{-1}$)	Man-ganese ($\mu g\ g^{-1}$)
	Tomato									
1.	LE 79-5	R	1.990	0.124	1.540	0.906	0.062	0.113	58.800	332.900
2.	BT-10	MR	2.280	0.134	1.410	0.715	0.083	0.085	68.400	183.700
3.	LE 470	MS	2.040	0.229	1.730	0.388	0.086	0.144	81.700	417.700
4.	Pusa Ruby	S	2.370	0.315	0.970	0.491	0.077	0.320	51.200	411.000
	CD (0.05)		0.534	0.025	NS	0.038	0.004	0.010	9.500	13.172
	Brinjal									
5.	Swetha	R	2.140	0.161	1.630	0.843	0.080	0.046	80.330	305.800
6.	Composite-2	MR	2.320	0.135	1.670	0.975	0.084	0.218	52.600	750.300
7.	BB7	MS	2.170	0.181	1.760	0.877	0.082	0.072	65.400	436.300
8.	Pusa Purple Long	S	1.840	0.274	1.130	0.812	0.079	0.064	64.600	697.700
	CD (0.05)		NS	0.015	NS	0.030	0.002	0.005	3.978	16.940
	Chilli									
9.	Ujwala	R	2.590	0.173	1.520	0.239	0.081	0.069	41.200	117.900
10.	Manjari	MR	1.640	0.104	1.150	0.449	0.068	0.093	37.000	642.000
11.	Jwalasakhi	MS	1.850	0.278	1.370	0.215	0.071	0.096	32.600	737.800
12.	Pusa Jwala	S	2.300	0.120	1.420	0.174	0.073	0.056	37.300	148.100
	CD (0.05)		NS	0.127	0.235	0.020	0.001	NS	3.340	13.968

Mean of four replications

R - Resistant MR - Moderately resistant

S - Susceptible MS - Moderately susceptible NS - Not significant

(S) recorded the highest and was superior to other varieties/lines (Table. 14). The lowest nitrogen content was recorded in LE 79-5 (R). In brinjal, the content was higher in BB-7 (MS) and lower in Composite-2 (MR). In chilli, the leaf of the variety Ujwala (R) contained the highest nitrogen percentage and lowest in Jwalasakhi (MS).

4.6.2. Phosphorus

The phosphorus content in the root was significantly higher in the susceptible genotypes compared to the resistant ones (Table. 12). In tomato, Pusa Ruby (S) gave the maximum content and LE 470 (MS) gave the minimum. The same trend was observed in the case of brinjal also. The phosphorus content was highest in Pusa Purple Long (S) and lowest in BB-7 (MS). In chilli the content was more in Jwalasakhi (MS) and less in Manjari (MR).

As in the case of root, in stem also the phosphorus content was higher in the susceptible varieties/lines of tomato and brinjal, Pusa Ruby (S) and Pusa Purple Long(S) respectively (Table. 13). The phosphorus content was low in LE 79-5 (R) of tomato and in Composite -2 (MR) of brinjal. In chilli, highest content was noticed in Jwalaskhi (MS) and lowest in Manjari (MR).

The leaf of susceptible genotypes of tomato, brinjal and chilli were significantly superior in phosphorus content (Table. 14). The varieties of tomato and brinjal Pusa Ruby (S) and Pusa Purple Long (S) recorded the highest phosphorus content in their leaf when compared to the resistant genotypes. In tomato LE 79-5 (R) and in brinjal Swetha (R) contained the lowest phosphorus content. In chilli it was highest in Jwalasakhi (MS) and lowest in Manjari (MR).

4.6.3. Potassium

In tomato the potassium content in root was significantly the highest in the variety LE 79-5 (R) and lowest in LE 470 (MS) (Table.12). In brinjal it was maximum in Pusa Purple Long (S) and minimum in BB-7 (MS). In chilli also the variety Pusa Jwala (S) was significantly superior in potassium content and it was lowest in Ujwala (R).

The potassium content in the stem of different varieties/lines of tomato, brinjal and chilli did not differ significantly. However the LE 470 (MS) of tomato, BB-7 (MS) of brinjal and Ujwala (R) of chilli recorded the highest potassium content. The lowest potassium content was recorded in Pusa Ruby (S) of tomato, Pusa Purple Long(S) of brinjal, and in Manjari(MR) of chilli.

In tomato leaf the potassium content was highest in the variety LE 79-5 (R) and lowest in BT-10 (MR) (Table. 14). In brinjal the maximum content was noticed in BB-7(MS) and minimum in Pusa Purple Long (S). In chilli Manjari (MR) gave the highest content and the lowest in Pusa Jwala (S).

4.6.4. Calcium

In tomato and chilli the same trend was noticed in calcium content in their root (Table. 12). In tomato the calcium content was significantly highest in BT-10 (MR) and lowest in LE 79-5 (R). In brinjal it was significantly highest in Swetha (R), and lowest in BB-7 (MS). In chilli, as in tomato the higher calcium content was in Manjari (MR) and lower in Ujwala (R).

There were significant differences between the genotypes in their calcium content in the stem of tomato, brinjal and chilli (Table. 13). In all the three crops the resistant genotypes gave the highest calcium content, LE 79-5 (R) of tomato, Composite-2 (MR) of brinjal and Manjari (MR) of Chilli. The lowest calcium content was recorded in the susceptible genotypes LE 470 (MS), Pusa Purple Long (S) and Pusa Jwala (S) of tomato, brinjal and chilli respectively.

Table.14 Nutritional factors in the healthy leaf of bacterial wilt resistant and susceptible varieties / lines of tomato, brinjal and chilli

Sl. No.	Varieties / lines	Disease reaction	Nitrogen (%)	Phos-phorus (%)	Potassium (%)	Calcium (%)	Magne-sium (%)	Iron (%)	Zinc ($\mu g\ g^{-1}$)	Man-ganese ($\mu g\ g^{-1}$)
	Tomato									
1.	LE 79-5	R	3.630	0.157	1.400	2.594	0.086	0.463	37.400	632.300
2.	BT-10	MR	4.080	0.191	1.120	1.839	0.084	0.366	37.000	400.300
3.	LE 470	MS	3.920	0.243	1.190	2.400	0.086	0.344	33.900	1024.90
4.	Pusa Ruby	S	4.600	0.312	1.180	1.156	0.085	0.245	30.600	1108.20
	CD (0.05)		NS	0.041	0.237	0.144	0.001	0.011	2.472	44.329
	Brinjal									
5.	Swetha	R	4.050	0.183	1.780	0.994	0.077	0.388	38.400	372.30
6.	Composite-2	MR	3.400	0.188	1.510	1.062	0.082	0.285	28.800	917.80
7.	BB7	MS	4.340	0.276	2.540	2.139	0.084	0.190	32.100	793.20
8.	Pusa Purple Long	S	3.930	0.292	0.880	1.202	0.080	0.139	22.300	680.90
	CD (0.05)		0.902	NS	0.495	0.056	0.002	0.011	3.394	6.156
	Chilli									
9.	Ujwala	R	5.480	0.215	1.570	0.685	0.084	0.114	56.900	177.00
10.	Manjari	MR	4.480	0.182	2.240	0.872	0.083	0.122	70.200	888.30
11.	Jwalasakhi	MS	4.290	0.295	1.580	0.691	0.081	0.085	45.300	1021.10
12.	Pusa Jwala	S	4.380	0.197	1.500	0.405	0.079	0.114	66.900	1206.20
	CD (0.05)		0.413	0.027	0.198	0.031	NS	0.029	2.891	24.631

Mean of four replications

R - Resistant MR - Moderately resistant

S - Susceptible MS - Moderately susceptible NS - Not significant

The calcium content was highest in the leaf of resistant genotypes of tomato and chilli while it was lowest in brinjal (Table. 14). In tomato it was significantly highest in LE 79-5 (R) and lowest in Pusa Ruby (S). In brinjal the maximum calcium content was recorded in BB-7 (MS) and minimum in Swetha (R). In chilli it was higher in Manjari (MR) and lower in Pusa Jwala (S).

4.6.5. **Magnesium**

In tomato and chilli the highest magnesium content was recorded in their susceptible varieties, viz. Pusa Ruby (S) and Pusa Jwala (S) and lowest in their resistant varieties, LE 79-5 (R) and Ujwala (R) respectively (Table. 12). In brinjal it was higher in resistant genotypes, the highest in Swetha (R) and lowest in BB-7 (MS).

In tomato the magnesium content was maximum in the stem of LE 470 (MS) and minimum in LE 79-5 (R) (Table.13). In brinjal Composite-2 (MR) recorded the highest content and Pusa Purple Long (S) the lowest. In chilli, the magnesium content was significantly highest in Ujwala (R) and lowest in Manjari (MR).

The magnesium content was maximum in the leaf of tomato variety LE 79-5 (R) and minimum in BT-10 (MR) (Table. 14). In brinjal, it was highest in BB-7 (MS) and lowest in Swetha (R). In chilli the higher magnesium percentage was obtained in Ujwala (R) and lower in Pusa Jwala (S).

4.6.6. Iron

In tomato the iron content was more in the susceptible varieties/lines, the highest in Pusa Ruby (S) and lowest in BT-10 (MR) (Table. 12). In brinjal it was significantly superior in the variety / line, Composite-2(MR) and lower in Swetha (R). In chilli also, the variety, Manjari (MR) recorded the maximum iron content and minimum in Pusa Jwala (S).

When the iron content of stem was compared, in tomato, the variety Pusa Ruby (S) gave the highest reading and BT-10 (MR) recorded the lowest (Table. 13). In brinjal, it was highest in Composite-2 (MR) and lowest in Swetha (R). In chilli, maximum iron content was observed in Jwalasakhi (MS) and minimum in Pusa Jwala (S).

The iron content was superior in the leaf of resistant genotypes of tomato, brinjal and chilli (Table. 14). In tomato and brinjal it was significantly superior in the leaf of LE 79-5 (R) and Swetha (R) and lowest in Pusa Ruby (S) and Pusa Purple Long (S) respectively. In chilli no significant difference was noticed in iron content in their leaf, the highest in Manjari (MR) and lowest in Jwalasakhi (MS).

4.6.7. Zinc

In tomato the zinc content was highest in root of LE 470 (MS) and lowest in LE 79-5 (R)(Table. 12). But in brinjal its content was more in Swetha (R) and less in Composite-2 (MR). In chilli, the variety Pusa Jwala (S) gave the maximum zinc content and minimum by Jwalasakhi (MS).

In stem, the zinc content was highest in LE 470 (MS) and lowest in Pusa Ruby (S) of tomato (Table. 13). Swetha (R) of brinjal and Ujwala (R) of chilli were significantly superior in zinc content compared to other varieties/lines. The lowest content was noticed in Composite-2 (MR) and Jwalasakhi (MS) of brinjal and chilli respectively.

The resistant genotypes of tomato, brinjal and chilli gave the highest zinc content in their leaf (Table.14). In tomato and brinjal it was maximum in LE 79-5 (R) and swetha (R) and minimum in Pusa Ruby (S) and Pusa Purple Long (S) respectively. In chilli the highest zinc content was noticed in Manjari (MR) and lowest in Jwalasakhi (MS).

4.6.8. Manganese

In tomato root the manganese content was highest in LE 470 (MS) and lowest in LE 79-5 (R), whereas in brinjal it was more in Composite-2 (MR) and less in BB-7 (MS) (Table. 12). In chilli, Manjari (MR) gave the maximum content and Pusa Jwala (S) recorded the minimum .

Manganese content was more in the stem of LE 470 (MS) in tomato and lesser in BT -10 (MR) (Table. 13). In brinjal the highest manganese content was recorded in Composite-2 (MR) and lowest in Swetha (R). In chilli the variety, Jwalasakhi (MS) gave the maximum content and minimum by Ujwala (R).

The susceptible genotypes of tomato and chilli recorded a higher manganese content in their leaf (Table. 14). In tomato significantly higher content of manganese was recorded in Pusa Ruby (S) and lower in BT-10 (MR). In

brinjal, the maximum manganese content was noticed in Composite- 2 (MR) and minimum in Swetha (R). In chilli also the highest manganese content was noticed in Pusa Jwala (S) and lowest in Ujwala (R).

The studies on the biochemical, biological and nutritional parameters of the healthy tomato, brinjal and chilli plants with differential reaction to bacterial wilt were carried out to find out some common factors present in the plants which will contribute to the resistance against *R. solanacearum.* In general the study revealed that there is no common trend in the biochemical constituents in the different plants and plant parts even though they belong to the same family. Among the plant parts, the leaf contained more of biochemical constituents. In the case of biological factors, the resistant genotypes sustained a higher population of total microflora, mycorrhiza and nematodes; and the susceptible genotypes maintained a higher population of virulent *Ralstonia.* The nutritional factors studied here also did not show a common pattern or trend under healthy condition.

4.7 Changes in biochemical constituents in different varieties/lines of tomato, brinjal and chilli upon infection by *R. solanacearum.*

The various biochemical changes occurring due to the infection by *R. solanacearum* on different

varieties/lines of tomato, brinjal and chilli were studied. The parameters observed were changes in total phenol, OD phenol, soluble sugars, total free amino acid, number of amino acid soluble protein, polyphenol oxidase, specific activity, peroxidase activity and alkaloid content.

4.7.1. Total Phenol

The results are presented in Table. 15 and in Fig. 1. In tomato root the total phenol content increased due to infection in all varieties/lines of tomato except in BT-10 (MR). Even though total phenol was lowest in LE 79-5 (R) in healthy plant significant increase (10 fold) in total phenol content was observed after infection. The total phenol content was highest in LE-470 (MS) under healthy condition and in LE 79-5 (R) under diseased condition. In stem the phenol content increased in LE 79-5 (R) and LE 470 (MS) and decreased in BT-10 (MR) and Pusa Ruby (S) upon infection. The rate of increase was highest (4 fold) in LE 470 (MS), followed by LE 79-5 (R)(2 fold). The phenol content was highest in BT-10 (MR) under healthy condition and in LE 470 (MS) under diseased condition. In the leaf the total phenol content increased in all varieties/lines due to infection. The phenol content was highest in Pusa Ruby(S) under healthy condition and in LE 79-5 (R) under diseased condition.

Table: 15 Comparison of total phenol content in bacterial wilt resistant and susceptible varieties / lines of tomato, brinjal and chilli under healthy and diseased condition (mgg^{-1} of sample)

Varieties / lines	Disease reaction	Root		Stem		Leaf	
		Healthy	Diseased	Healthy	Diseased	Healthy	Diseased
Tomato							
T1 LE 79-5	R	0.119	1.325	0.505	1.895	2.164	5.155
T2 BT-10	MR	1.053	0.983	1.013	0.704	3.178	3.786
T3 LE 470	MS	1.203	1.218	0.692	3.554	1.613	3.162
T4 Pusa Ruby	S	0.551	0.695	0.790	0.750	3.380	3.865
CD (0.05)		0.235		0.194		0.259	
Brinjal							
B1 Swetha	R	1.938	1.745	1.350	1.873	8.011	2.822
B2 Composite-2	MR	2.451	1.754	1.102	4.145	1.889	2.574
B3 BB7	MS	1.313	1.393	1.736	1.427	3.116	2.186
B4 Pusa purple long	S	1.971	2.327	1.142	2.428	1.169	1.185
CD (0.05)		0.345		0.171		0.599	
Chilli							
C1 Ujwala	R	1.999	3.220	2.434	5.115	5.333	10.778
C2 Manjari	MR	1.543	1.510	2.472	2.841	2..721	8.126
C3 Jwalasakhi	MS	1.607	1.922	1.629	2.447	3.094	3.110
C4 Pusa Jwala	S	1.895	2.437	1.384	1.081	3.070	3.514
CD (0.05)		0.265		0428		1.432	

Mean of four replications

R - Resistant MR - Moderately resistant

S - Susceptible MS - Moderately susceptible

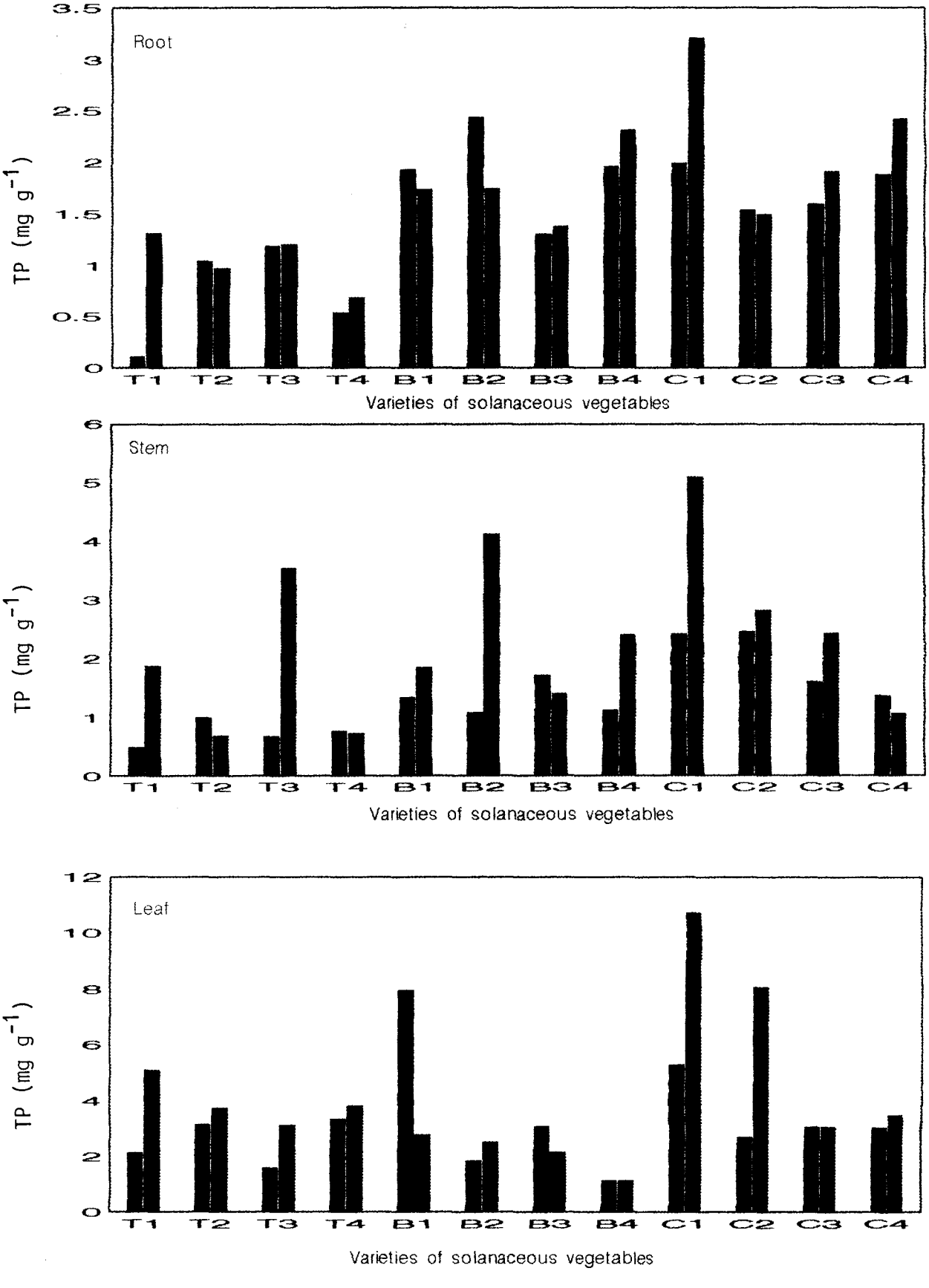


Fig.1. Total Phenol (TP) content of healthy / diseased solanaceous vegetables

In brinjal root the phenol content decreased in the resistant genotypes, whereas it increased in the susceptible genotypes due to infection. The phenol content was highest in the root of Composite-2 (MR) among the healthy plants and was highest in Pusa Purple Long (S) among diseased plants. The rate of decrease was maximum in Composite-2 (MR) and minimum in Pusa Purple Long (S). In the stem , the total phenol content increased in all varieties/lines except in BB-7 (MS). The phenol content was highest in BB-7 (MS) under healthy condition and in Composite-2 (MR) under diseased condition. In leaf the phenol content decreased in Swetha(R), and in BB-7 (MS) due to infection. The phenol content was maximum in Swetha (R) and minimum in Pusa Purple Long (S) both under healthy and diseased condition.

In chilli root the phenol content increased significantly in all varieties/lines except in Manjari (MR) due to infection. In Manjari (MR) it decreased due to infection. The phenol content was highest in Ujwala (R) and lowest in Manjari (MR) both under healthy and diseased condition. In stem the phenol content increased in all the varieties/lines except in Pusa Jwala (S) upon infection. The resistant genotypes showed a higher phenol content both under healthy and diseased condition. The phenol content was highest in Manjari (MR) among healthy plants and in

Ujwala (R) among diseased plants. In the leaf also the phenol content increased in all varieties/lines due to infection. The rate of increase was significantly highest in the resistant genotypes the maximum in Manjari (MR). The phenol content was highest in Ujwala (R) both under healthy and diseased condition.

4.7.2. OD phenol

The results are given in Table. 16 and in Fig.2. In tomato root the OD phenol content increased in all varieties/lines due to infection. The OD phenol content was highest in LE 79-5 (R) both under healthy and diseased condition. The rate of increase was highest in BT-10 (MR) (17 fold). In stem the resistant genotypes showed an increase in OD phenol content and the susceptible genotypes showed a decrease due to infection. The OD phenol content was highest in Pusa Ruby (S) under healthy condition in LE 79-5 (R) under diseased condition. The rate of increase in OD phenol content was highest (19 fold) in LE 79-5 (R).

In the leaf also the OD phenol content increased in all the varieties/lines due to infection. The OD phenol content was highest in Pusa Ruby (S) both under healthy and diseased condition. But the rate of increase was highest (27 fold) in the LE 79-5 (R).

Table. 16 Comparison of OD phenol content in bacterial wilt resistant and susceptible varieties / lines of tomato, brinjal and chilli under healthy and diseased condition (mgg^{-1} of sample)

Varieties / lines	Disease reaction	Root		Stem		Leaf	
		Healthy	Diseased	Healthy	Diseased	Healthy	Diseased
Tomato							
T1 LE 79-5	R	0.032	0.034	0.001	0.020	0.002	0.056
T2 BT-10	MR	0.001	0.018	0.00	0.002	0.084	0.093
T3 LE 470	MS	0.007	0.018	0.015	0.006	0.030	0.097
T4 Pusa Ruby	S	0.006	0.023	0.057	0.005	0.167	0.198
CD (0.05)		NS		0.012		0.009	
Brinjal							
B1 Swetha	R	0.024	0.001	0.004	0.005	0.159	0.097
B2 Composite-2	MR	0.004	0.004	0.002	0.050	0.034	0.080
B3 BB7	MS	0.005	0.002	0.002	0.016	0.097	0.089
B4 Pusa Purple Long	S	0.014	0.005	0.008	0.059	0.067	0.185
CD (0.05)		0.005		0.016		0.026	
Chilli							
C1 Ujwala	R	0.008	0.029	0.014	0.049	0.066	0.197
C2 Manjari	MR	0.018	0.014	0.026	0.018	0.050	0.071
C3 Jwalasakhi	MS	0.002	0.007	0.009	0.009	0.029	0.037
C4 Pusa Jwala	S	0.007	0.011	0.024	0.002	0.020	0.094
CD (0.05)		0.007		0.012		0.010	

Mena of four replications
R - Resistant MR - Moderately resistant
S - Susceptible MS - Moderately susceptible NS - Not Significant

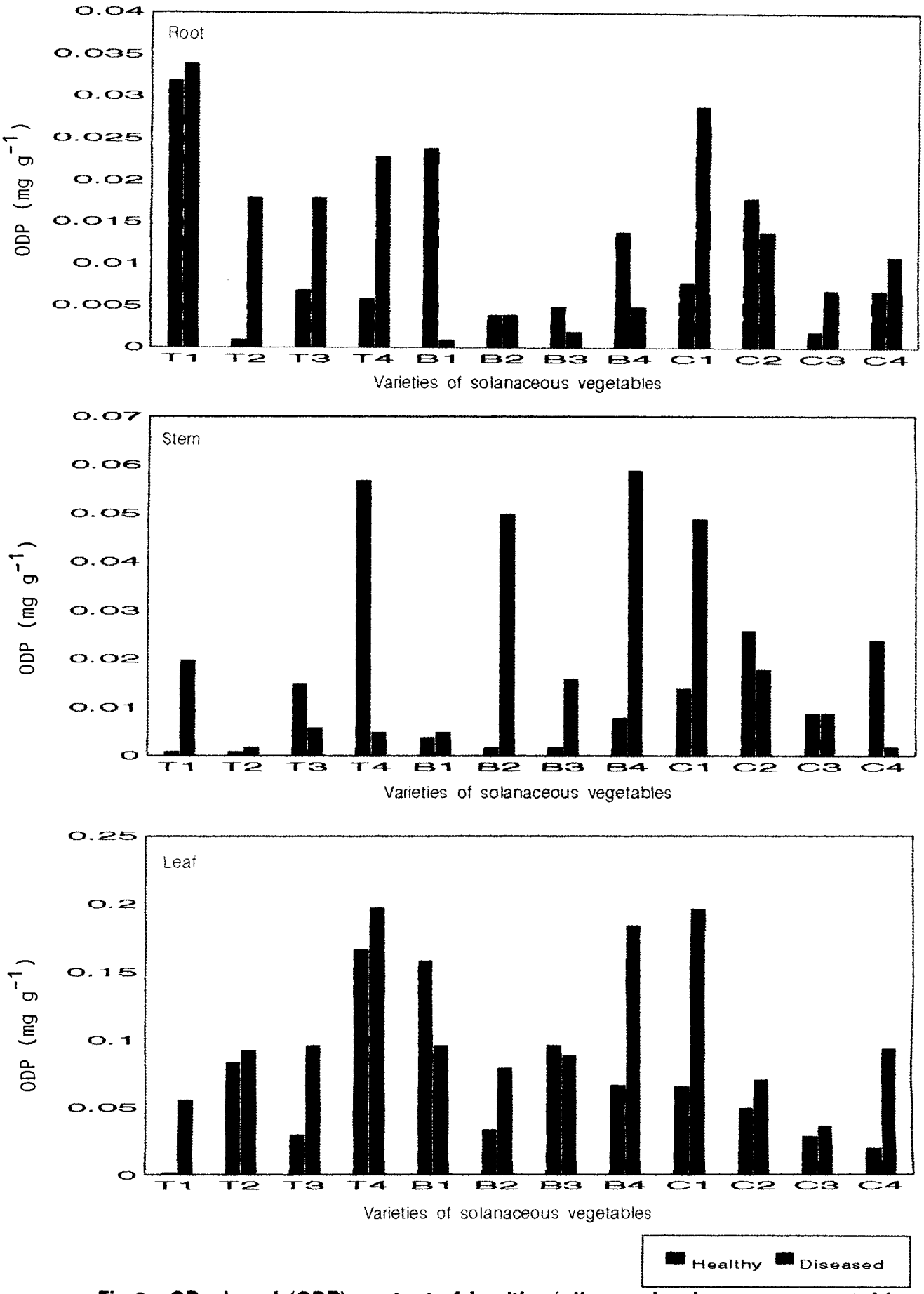


Fig.2. OD phenol (ODP) content of healthy / diseased solanaceous vegetables

In brinjal root, the OD phenol content decreased upon infection in all the varieties/lines. It was highest in Swetha (R) among healthy plants and in Pusa Purple Long (S) among diseased plants. The rate of decrease was significantly highest in Swetha (R). In stem, the OD phenol content increased in all the varieties/lines due to infection. The OD phenol content was maximum in Pusa Purple Long (S) both under healthy and diseased condition. But the rate of increase was significantly highest (24 fold) in Composite- 2 (MR). In the leaf the OD phenol content decreased in Swetha (R) and BB-7 (MS) and increased in Composite -2 (MR) and Pusa Purple Long (S).

In chilli root, the OD phenol content increased in all varieties/lines except Manjari (MR), where a decrease was noticed due to infection. It was highest in Manjari (MR) among healthy plants and was highest in Ujwala (R) among diseased plants. In stem, the OD phenol content increased in Ujwala (R) and decreased in all other varieties/lines due to infection. The OD phenol content was maximum in Manjari (MR) under healthy condition and in Ujwala (R) under diseased condition. A two fold increase in OD phenol content was recorded in the root and stem of the variety, Ujwala (R) due to infection and the rate of decrease was maximum in Pusa Jwala (S). In leaf the OD phenol content increased due to infection. The OD phenol content was highest in Ujwala (R) both under healthy and diseased condition.

4.7.3. Soluble Sugars

The resistant genotypes showed a decrease in the soluble sugar content than the susceptible ones (Table.17 and Fig. 3.). In tomato root the soluble sugar content decreased in all varieties/lines except in LE 79-5 (R), upon infection. The soluble sugar content was highest in Pusa Ruby(S) both under healthy and diseased condition. The decrease in soluble sugar content was highest in BT-10 (MR). In stem the soluble sugar content increased after infection in the varieties/lines LE 79-5 (R) and LE 470 (MS) and decreased in BT-10 (MR) and Pusa Ruby (S). The soluble sugar content was highest in Pusa Ruby (S) among healthy plants and in LE 470 (MS) among diseased plants. In the leaf the soluble sugar content increased due to infection in all the varieties/lines except BT-10 (MR). It was maximum in Pusa Ruby (S) under healthy condition and in LE 79-5 (R) under diseased condition.

In brinjal root, the soluble sugar content decreased in all the varieties/lines after infection. The resistant genotypes possessed a higher soluble sugar content than the susceptible ones. The soluble sugar content was highest in Swetha (R) under healthy condition and in Composite-2 (MR) under diseased condition. The decrease in soluble sugar content after infection was observed in all varieties/lines in stem also. The soluble sugar content was maximum in Pusa Purple Long (S) both

Table.17 Comparison of soluble sugar content in bacterial wilt resistant and susceptible varieties / lines of tomato, brinjal and chilli under healthy and diseased condition (mgg^{-1} of sample)

Varieties / lines	Disease reaction	Root		Stem		Leaf	
		Healthy	Diseased	Healthy	Diseased	Healthy	Diseased
Tomato							
T1 LE 79-5	R	0.349	0.495	0.459	0.889	0.846	1.425
T2 BT-10	MR	0.527	0.336	0.823	0.345	0.804	0.651
T3 LE 470	MS	0.594	0.564	0.596	1.063	0.645	1.331
T4 Pusa Ruby	S	0.756	0.587	0.838	0.681	0.999	1.359
CD (0.05)		0.065		0.094		NS	
Brinjal							
B1 Swetha	R	0.842	0.375	1.224	0.334	0.911	0.626
B2 Composite-2	MR	0.840	0.506	0.429	0.386	0.437	0.441
B3 BB7	MS	0.756	0.221	0.881	0.514	0.493	0.186
B4 Pusa Purple Long	S	0.748	0.424	1.296	1.059	0.366	0.435
CD (0.05)		0.072		0.090		0.079	
Chilli							
C1 Ujwala	R	1.001	0.234	1.063	0.988	1.618	1.986
C2 Manjari	MR	0.407	0.088	0.264	0.624	0.581	1.755
C3 Jwalasakhi	MS	0.369	0.251	0.349	0.414	0.895	1.273
C4 Pusa Jwala	S	0.439	0.289	0.336	0.049	0.673	1.487
CD (0.05)		0.104		0.092		0.172	

Mean of four replications
R - Resistant MR - Moderately resistant
S - Susceptible MS - Moderately susceptible NS - Not Significant

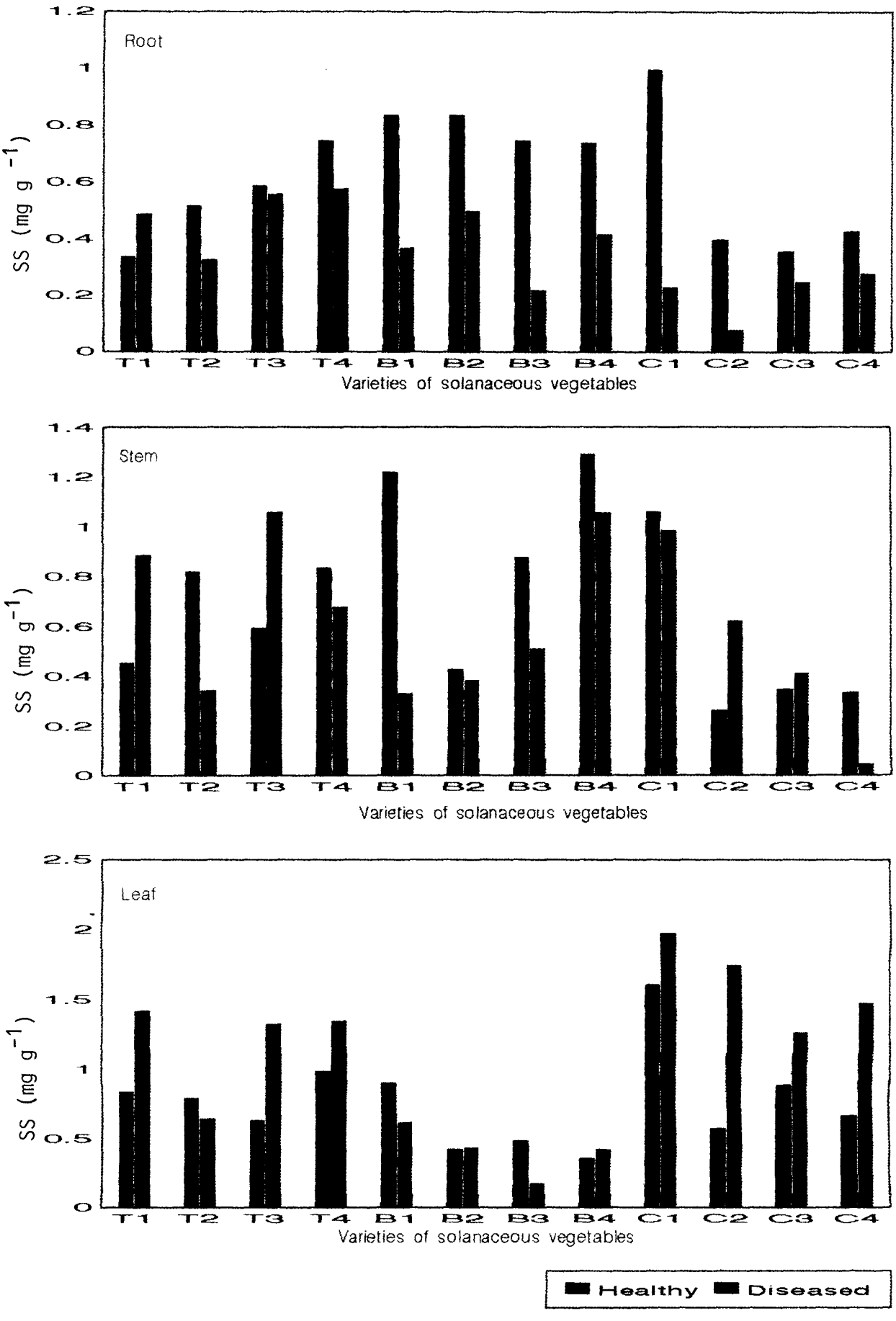


Fig.3. Soluble sugar (SS) content of healthy/diseased solanaceous vegetables

under healthy and diseased condition. But the rate of decrease was highest in Swetha (R). In leaf the decrease in soluble sugar content after infection was noticed in Swetha (R) and BB-7 (MS), and in Composite-2 (MR) and Pusa Purple Long (S) slight increase was noticed. The soluble sugar content was highest in Swetha (R) both under healthy and diseased condition.

In chilli root the soluble sugar content decreased in all the varieties/lines after infection. The soluble sugar content was highest in Ujwala (R), under healthy condition and under diseased condition it was highest in Pusa Jwala (S). In stem the soluble sugar content decreased in the varieties Ujwala (R) and Pusa Jwala (S). It was highest in Ujwala (R) both under healthy and diseased condition. Unlike in others the leaf of chilli showed an increase in soluble sugar content after infection. The soluble sugar was highest in Ujwala (R) both under healthy and diseased condition.

4.7.4 Total free amino acid

The total free amino acid increased in all varieties/lines of tomato, brinjal and chilli after infection (Table. 18 and Fig. 4). In tomato root, the total free amino acid was highest in BT-10 (MR) among healthy plants and in Pusa Ruby (S), among diseased plants. The rate of increase after infection was highest in Pusa

Table. 18 Comparison of total free amino acid content in bacterial wilt resistant and susceptible varieties / lines of tomato, brinjal and chilli under healthy and diseased condition (mgg^{-1} of sample)

Varieties / lines	Disease reaction	Root		Stem		Leaf	
		Healthy	Diseased	Healthy	Diseased	Healthy	Diseased
Tomato							
T1 LE 79-5	R	6.290	5.340	4.190	9.860	4.930	5.170
T2 BT-10	MR	7.000	8.800	2.400	19.370	5.660	19.920
T3 LE 470	MS	3.610	5.200	2.690	10.590	7.270	14.710
T4 Pusa Ruby	S	6.600	12.600	2.540	11.720	4.270	26.000
CD (0.05)		0.589		0.755		0.807	
Brinjal							
B1 Swetha	R	3.335	9.410	7.000	12.280	10.000	11.580
B2 Composite-2	MR	3.000	4.500	5.000	25.545	3.500	8.580
B3 BB7	MS	1.250	15.000	2.000	13.500	7.000	11.500
B4 Pusa Purple Long	S	8.900	10.800	12.920	16.280	7.000	9.110
CD (0..05)		1.383		3.405		1.873	
Chilli							
C1 Ujwala	R	5.010	6.250	3.630	5.600	9.340	13.430
C2 Manjari	MR	2.570	9.420	5.930	7.000	5.460	11.335
C3 Jwalasakhi	MS	3.100	9.507	4.410	11.150	6.320	11.010
C4 Pusa Jwala	S	6.100	7.100	5.360	6.360	8.400	10.180
CD (0.05)		1.159		0.744		1.267	

Mean of four replications

R - Resistant MR - Moderately resistant

S - Susceptible MS - Moderately susceptible

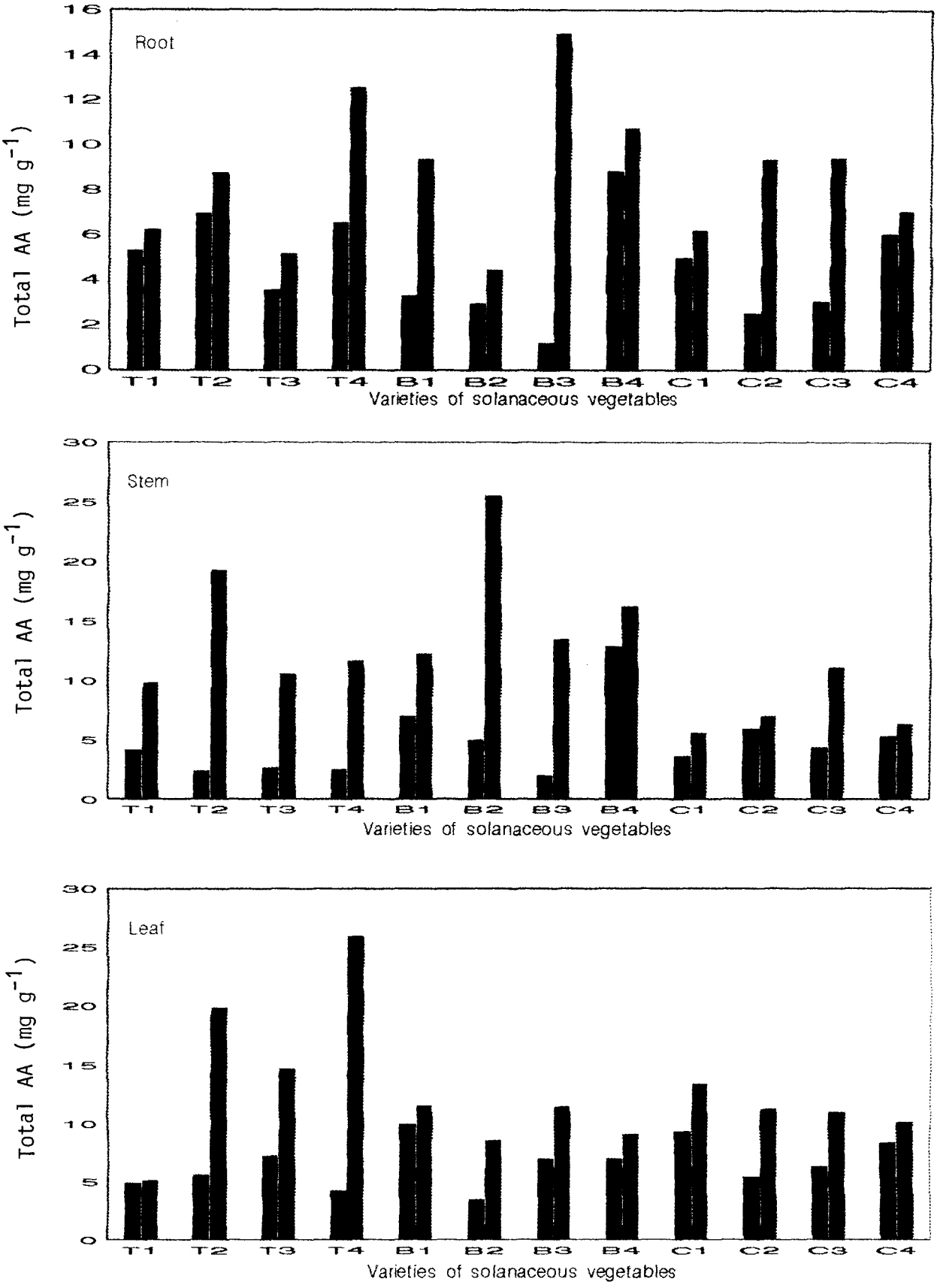


Fig.4. Total free amino acid (AA) content of healthy / diseased solanaceous vegetables

Ruby (S) and was lowest in LE 79-5 (R). In tomato stem, an increase in total free amino acid content noticed in all varieties/lines, but the rate of increase was maximum (7 fold) in BT-10 (MR). The amino acid content was highest in LE 79-5 (R) under healthy condition but it was lowest after infection when compared to other susceptible genotypes. The rate of increase was lowest in LE 79-5 (R). In the leaf also, an increase in total free amino acid after infection was noticed. The amino acid content was lowest in Pusa Ruby (S) under healthy condition, but highest after infection, the rate of increase was also highest in Pusa Ruby (S) and lowest in LE 79-5 (R).

In brinjal root the total free amino acid content increased after infection in all the varieties/lines. The amino acid content was highest in Pusa Purple Long (S) under healthy condition and in BB-7 (MS) under diseased condition. The rate of increase in amino acid content was highest in BB-7 (MS) (11 fold). In stem the amino acid content was highest in Pusa Purple Long (S) under healthy condition, and in Composite-2 (MR) under diseased condition. The rate of increase was maximum in Composite-2 (MR) and minimum in Pusa Purple Long (S). In leaf the amino acid content was highest in the variety Swetha (R) both under healthy and diseased condition, but the rate of increase due to infection was lowest.

In chilli root the total free amino acid content was highest in Pusa Jwala (S) under healthy condition and in Jwalasakhi (MS) under diseased condition. The rate of increase in amino acid content after infection was maximum in Manjari (MR) (2 fold) and minimum in Pusa Jwala (S). In stem the amino acid content was highest in Manjari (MR) and lowest in Ujwala (R) under healthy condition. Under diseased condition it was maximum in Jwalasakhi (MS) and minimum in Ujwala (R). But compared to Pusa Jwala (S), Ujwala (R) gave a higher increase in amino acid after infection. In leaf, the total free amino acid was highest in Ujwala (R) both under healthy and diseased condition. The rate of increase was highest in Manjari (MR).

4.7.5. **Number of Amino acids**

The number of amino acids increased upon infection in tomato, brinjal and chilli (Table. 19 and Fig.5). In tomato root, the number of amino acid was highest in Pusa Ruby (S) under healthy condition and in LE 470 (MS) under diseased condition. The number of amino acids increased in all varieties/lines except in Pusa Ruby (S) due to infection. In stem the number of amino acids increased in the variety LE 79-5 (R) only and decreased in Pusa Ruby (S). It remained the same in the other two varieties/lines. The number of amino acids was highest in Pusa Ruby (S) under

Table. 19 Comparison of number of aminoacids in bacterial wilt resistant and susceptible varieties / lines of tomato, brinjal and chilli under healthy and diseased condition.

Varieties / lines	Disease Reaction	Root		Stem		Leaf	
		Healthy	Diseased	Healthy	Diseased	Healthy	Diseased
Tomato							
T1 LE 79-1	R	2	4	5	7	6	10
T2 BT -10	MR	2	6	6	6	10	6
T3 LE 470	MS	4	8	7	7	7	7
T4 Pusa Ruby	S	8	4	8	5	6	6
Brinjal							
B1 Swetha	R	2	10	1	7	9	9
B2 Composite-2	MR	2	7	5	8	9	8
B3 BB-7	MS	4	10	5	9	3	13
B4 Pusa Purple Long	S	6	7	6	7	6	8
Chilli							
C1 Ujwala	R	4	6	4	6	8	9
C2 Manjari	MR	4	7	3	4	6	6
C3 Jwalasakhi	MS	6	7	8	6	8	8
C4 Pusa Jwala	S	9	6	5	7	5	7

R - Resistant MR - Moderately resistant
S - Susceptible MS - Moderately susceptible

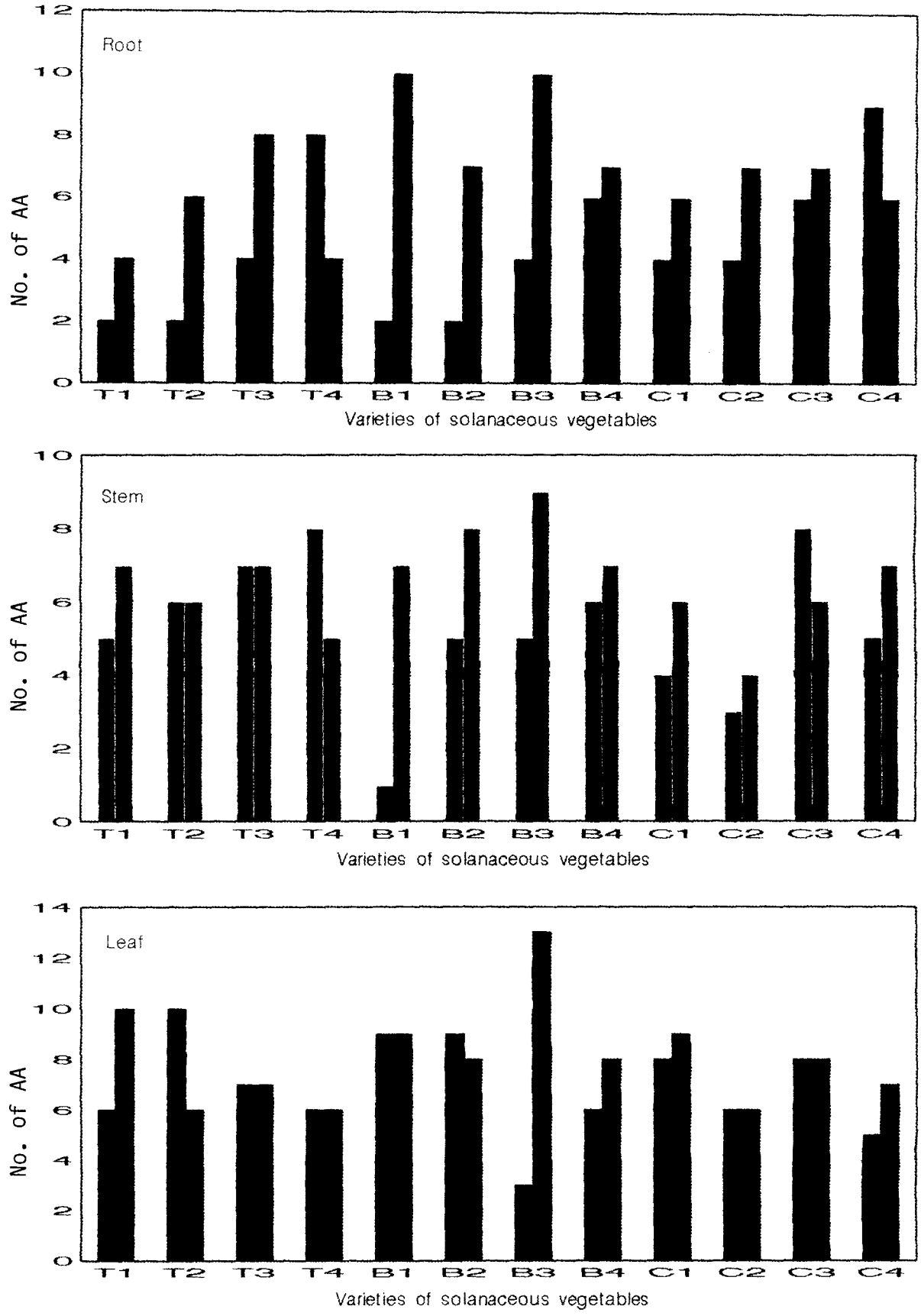


Fig.5. Number of amino acids (AA) in healthy / diseased solanaceous vegetables

healthy condition and in LE 79-5 (R) and LE 470 (MS) under diseased condition. In leaf the number of amino acids increased only in LE 79-5 (R) due to infection. It decreased in BT-10 (MR) and remained the same in susceptible genotypes after infection. The number of amino acids was highest in BT-10 (MR) under healthy condition and in LE 79-5 (R) under diseased condition.

In brinjal root, the number of amino acids was highest in Pusa Purple Long (S) under healthy condition and in Swetha (R) and BB-7 (MS) under diseased condition. A four fold increase in number of amino acids was noticed in Swetha (R). In stem the number of amino acids was highest in Pusa Purple Long (S) under healthy condition and the rate of increase was maximum in Swetha (R) and minimum in Pusa Purple Long (S). In leaf the number of amino acids increased only in the susceptible genotypes after infection. The rate of increase was highest in BB-7 (MS) (3 fold) after infection. The number of amino acids was highest in Swetha (R) and Composite-2 (MR) under healthy condition and in BB-7 (MS) under diseased condition.

In chilli root the number of amino acids increased in all the varieties/lines, except in Pusa Jwala (S) where it decreased. It was highest in Pusa Jwala (S) under healthy condition and in Manjari (MR) and Jwalasakhi

(MS) under diseased condition. The rate of increase was maximum in Manjari (MR) and minimum in Jwalasakhi (MS). In stem, the number of amino acids increased in all varieties/lines except in Jwalasakhi (MS). The number of amino acids was highest in Jwalasakhi (MS) under healthy condition and in Pusa Jwala (S) under diseased condition. The rate of increase was maximum in Ujwala (R). In leaf the number of amino acids increased in Ujwala (R) and Pusa Ruby (S). It was highest in Ujwala (R) and Jwalasakhi (MS) under healthy condition and in Ujwala (R) under diseased condition.

4.7.6 Soluble Protein

The soluble protein content increased after infection in the root of resistant genotypes of tomato (Table. 20 and Fig. 6). Under healthy condition the root of LE 79-5 (R) recorded the lowest soluble protein content which gave the highest increase of protein after infection. The soluble protein content was highest in LE 470 (MS) under healthy condition and was in LE 79-5 (R) under diseased condition. In the stem the soluble protein content increased in all varieties/lines except in LE 470 (MS), where maximum soluble protein content was observed under healthy condition. Under diseased condition the BT-10 (MR) gave maximum soluble protein, but the rate of increase was minimum. The rate of increase in soluble

Table. 20 Comparison of soluble protein content in bacterial wilt resistant and susceptible varieties / lines of tomato, brinjal and chilli under healthy and diseased condition (mgg^{-1} of sample)

Varieties / lines	Disease reaction	Root		Stem		Leaf	
		Healthy	Diseased	Healthy	Diseased	Healthy	Diseased
Tomato							
T1 LE 79-5	R	1.777	4.310	2.561	3.270	5.643	8.856
T2 BT-10	MR	1.957	2.259	3.403	3.951	7.826	3.441
T3 LE 470	MS	4.112	3.592	3.961	2.448	7.902	11.210
T4 Pusa Ruby	S	2.013	2.562	0.765	1.097	3.081	3.573
CD (0.05)		0.069		0.165		0.349	
Brinjal							
B1 Swetha	R	3.866	0.917	2.429	3.875	1.408	8.809
B2 Composite-2	MR	4.622	3.592	4.489	3.752	5.615	4.244
B3 BB7	MS	2.373	2.080	3.270	3.866	5.567	3.800
B4 Pusa Purple Long	S	2.789	2.987	3.592	6.428	8.961	7.401
CD (0.05)		0.126		0.327		0.101	
Chilli							
C1 Ujwala	R	1.285	2.410	1.749	2.722	3.573	3.592
C2 Manjari	MR	1.853	3.100	2.864	5.492	4.764	5.463
C3 Jwalasakhi	MS	2.618	2.807	3.044	3.223	9.754	7.212
C4 Pusa Jwala	S	3.204	2.978	3.563	4.064	8.081	7.231
CD (0.05)		0.169		0.182		0.187	

Mean of four replications

R - Resistant MR - Moderately resistant

S - Susceptible MS - Moderately susceptible

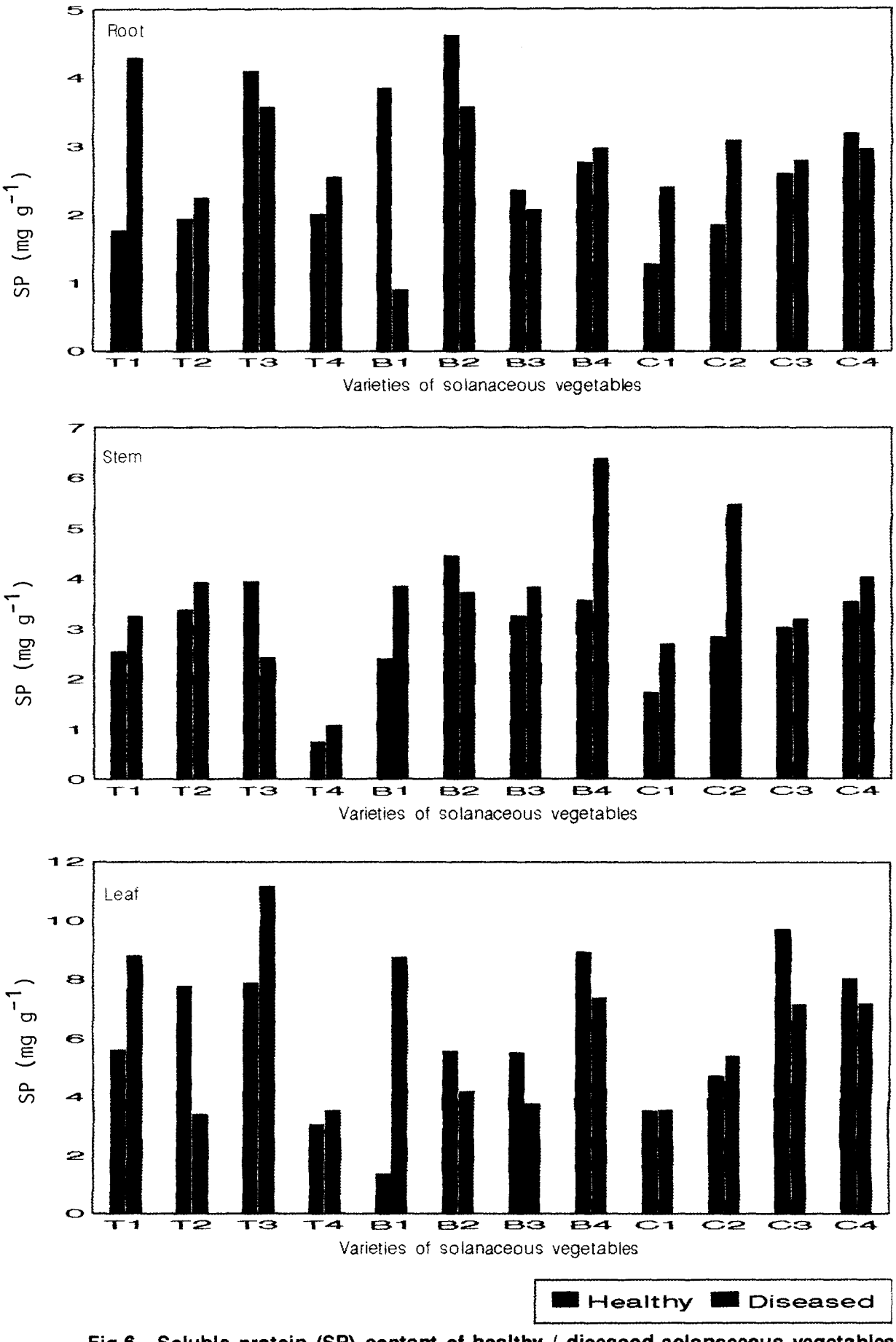


Fig.6. Soluble protein (SP) content of healthy / diseased solanaceous vegetables

protein was maximum in Pusa Ruby (S). In the leaf also the increase in soluble protein was observed in all except BT-10 (MR) where a decrease was observed. The soluble protein was highest in LE 470 (MS) both under healthy and diseased condition.

In brinjal the soluble protein content of root decreased after infection in all the varieties/lines except in the susceptible variety, Pusa Purple Long (S). The rate of decrease was highest in Swetha (R) and lowest in BB-7 (MS). It was highest in Composite-2 (MR) both under healthy and diseased condition. In the stem the soluble protein content increased in all the varieties/lines except in Composite-2 (MR). The maximum protein content was recorded in Composite - 2 (MR) among healthy plants and in Pusa Purple Long (S) among diseased plants. The rate of increase was highest in Pusa Purple Long (S). In leaf also the soluble protein content decreased after infection in all varieties/lines except in Swetha (R). The soluble protein content was highest in Pusa Purple Long (S) and lowest in Swetha (R) under healthy condition. Swetha (R) recorded maximum content of soluble protein with a five fold increase after infection.

In chilli, the soluble protein content in root increased after infection in all the varieties/lines except Pusa Jwala (S). The highest rate of increase was recorded in Ujwala (R) and lowest in Jwalasakhi (MS). The soluble

protein content in the stem also increased in all the varieties/lines after infection. The rate of increase was more prominent in the resistant genotypes, the highest in Manjari (MR). The soluble protein content was highest in Pusa Jwala (S) under healthy condition and in Manjari (MR) under diseased condition. In the leaf the resistant genotypes showed an increase, while the susceptible ones showed a decrease in soluble protein content upon infection. The maximum increase was recorded in Manjari (MR). The protein content was maximum in Jwalasakhi (MS) under healthy condition and in Pusa Jwala (S) under diseased condition.

4.7.7 Polyphenol oxidase activity

The polyphenol oxidase activity in the root of tomato increased in the susceptible genotypes and decreased in resistant ones after infection (Table. 21 and Fig. 7). Its activity was highest in LE 79-5 (R) under healthy condition and in LE 470 (MS) under diseased condition. The rate of decrease was highest in LE 79-5 (R) and the rate of increase was highest in LE 470 (MS). In stem the polyphenol oxidase activity increased in all varieties/lines after infection. The enzyme activity was maximum in LE 470 (MS) among healthy plants, but it didn't show any change after infection. The highest enzyme activity was shown by LE 79-5 (R) under diseased condition. The rate of increase in enzyme

Table. 21 Comparison of polyphenol oxidase activity in bacterial wilt resistant and susceptible varieties / lines of tomato, brinjal and chilli under healthy and diseased conditions (OD values after one minute)

Varieties / lines	Disease reaction	Root		Stem		Leaf	
		Healthy	Diseased	Healthy	Diseased	Healthy	Diseased
Tomato							
T1 LE 79-5	R	0.108	0.059	0.036	0.104	0.112	0.045
T2 BT-10	MR	0.056	0.051	0.048	0.095	0.104	0.097
T3 LE 470	MS	0.052	0.088	0.056	0.056	0.061	0.024
T4 Pusa Ruby	S	0.047	0.065	0.011	0.043	0.020	0.041
CD (0.05)		0.011		0.010		0.034	
Brinjal							
B1 Swetha	R	0.116	0.270	0.115	0.163	0.166	0.360
B2 Composite-2	MR	0.109	0.066	0.132	0.140	0.130	0.130
B3 BB7	MS	0.054	0.057	0.057	0.122	.081	0.169
B4 Pusa Purple Long	S	0.052	0.105	0.062	0.142	0.103	0.100
CD (0.05)		0.028		0.015		0.009	
Chilli							
C1 Ujwala	R	0.053	0.041	0.069	0.045	0.044	0.049
C2 Manjari	MR	0.063	0.073	0.088	0.073	0.034	0.083
C3 Jwalasakhi	MS	0.129	0.075	0.120	0.053	0.064	0.180
C4 Pusa Jwala	S	0.088	0.107	0.072	0.103	0.008	0.012
CD (0.05)		NS		0.014		0.041	

Mean of four replications
R - Resistant MR - Moderately resistant
S - Susceptible MS - Moderately susceptible NS - Not significant

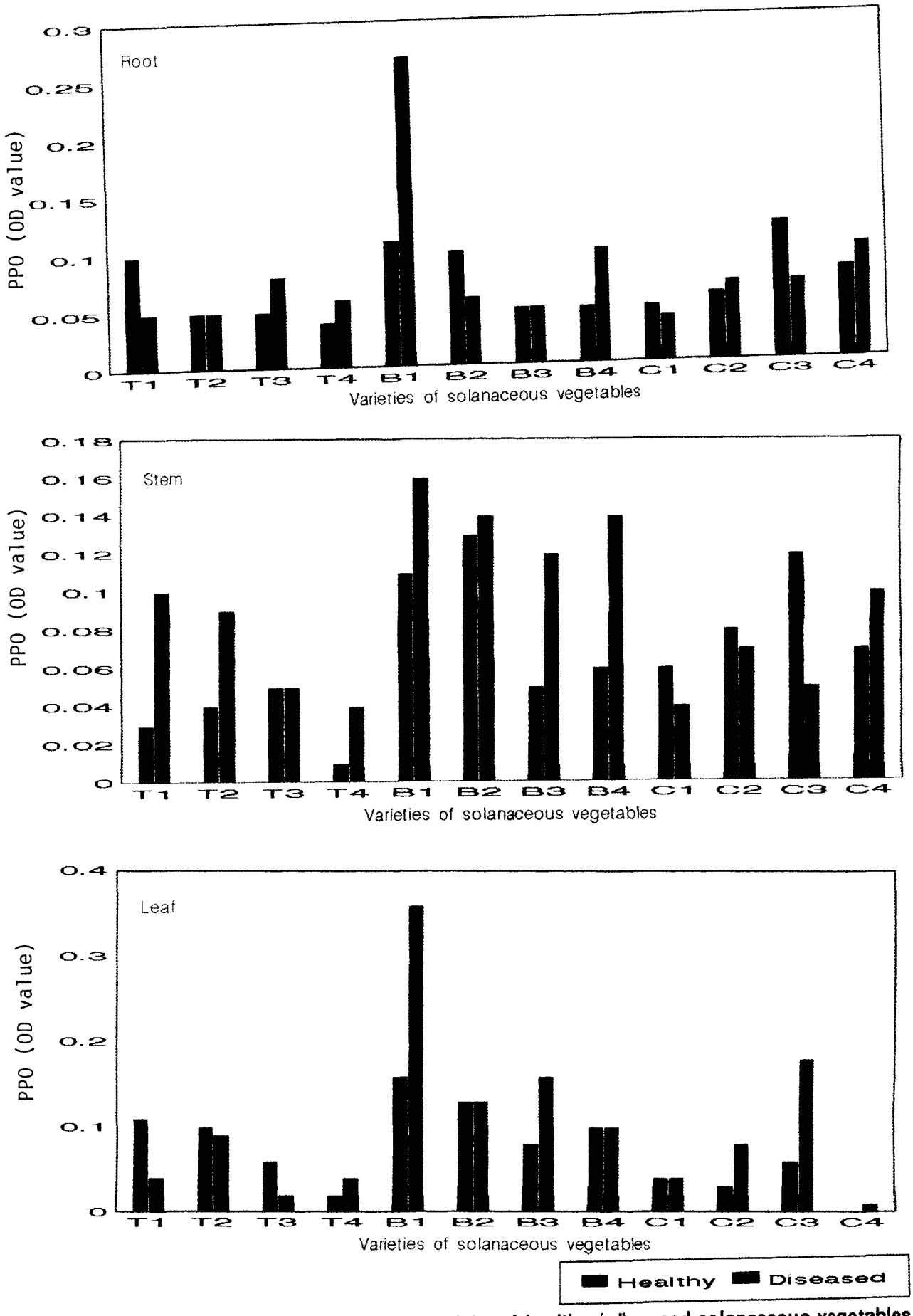


Fig.7. Polyphenol oxidase (PPO) activity of healthy / diseased solanaceous vegetables

activity was highest in Pusa Ruby (S) followed by LE 79-5 (R). In the case of leaf the polyphenol oxidase enzyme activity decreased in all varieties/lines except in Pusa Ruby (S). The enzyme activity was highest in the resistant genotypes both under healthy and diseased condition. The highest activity was recorded in LE 79-5 (R) under healthy condition and in BT-10 (MR) under diseased condition.

In brinjal, the polyphenol oxidase activity increased after infection in the roots of all varieties/lines except in Composite -2 (MR). The enzyme activity was maximum in Swetha (R), both under healthy and diseased condition. The rate of increase was also highest in Swetha (R). In the stem the enzyme activity increased significantly in all the varieties/lines after infection. The resistant genotypes showed higher enzyme activity compared to susceptible ones in both healthy and diseased condition. But the rate of increase was higher in the susceptible genotypes, the highest in Pusa Purple Long (S). The enzyme activity was highest in Composite-2 (MR) under healthy condition and in Swetha (R) under diseased condition. In the leaf also the polyphenol oxidase activity increased in all the varieties/lines except in Pusa Purple Long (S) where a slight decrease was noticed. The enzyme activity was significantly highest in Swetha (R) both under healthy and diseased condition.

In chilli, the difference in polyphenol oxidase activity was not significant in the root after infection. The enzyme activity increased in Manjari (MR) and Pusa Jwala (S) and decreased in Ujwala (R) and Jwalasakhi (MS) due to infection. In the stem the enzyme activity decreased in all varieties/lines except Pusa Jwala (S) after infection. The rate of decrease was highest in Jwalasakhi (MS) followed by Ujwala (R). The activity was maximum in Jwalasakhi (MS) under healthy condition and in Pusa Jwala (S) under diseased condition. In leaf the polyphenol oxidase activity increased in all varieties. The rate of increase was maximum in Jwalasakhi (MS) and minimum in Ujwala (R). Jwalasakhi (MS) also recorded highest polyphenol oxidase activity both under healthy and diseased condition.

4.7.8. Specific activity

A higher specific activity of polyphenol oxidase (per mg of protein) was observed in the resistant genotypes compared to the susceptible ones (Table. 22 and Fig. 8). In the case of tomato root the specific activity increased upon infection in LE 79-5 (R) and LE 470 (MS). The specific activity was highest in BT-10 (MR) under healthy condition and in LE 79-5 (R) under diseased condition. In the stem the specific activity increased in all the varieties/lines due to infection. The specific activity was maximum in LE 79-5 (R) both under healthy

Table. 22 Comparison of specific activity in bacterial wilt resistant and susceptible varieties / lines of tomato, brinjal and chilli under healthy and diseased condition (unit per mg protein at 30°C for one minute)

Varieties / lines	Diseased reaction	Root		Stem		Leaf	
		Healthy	Diseased	Healthy	Diseased	Healthy	Diseased
Tomato							
T1 LE 79-5	R	0.118	0.130	0.132	0.183	0.278	0.128
T2 BT-10	MR	0.136	0.087	0.115	0.155	0.149	0.509
T3 LE 470	MS	0.047	0.067	0.079	0.127	0.089	0.125
T4 Pusa Ruby	S	0.077	0.069	0.09	0.154	0.124	0.165
Brinjal							
B1 Swetha	R	0.115	1.203	0.199	0.175	0.972	0.185
B2 Composite-2	MR	0.125	0.098	0.131	0.179	0.151	0.214
B3 BB-7	MS	0.149	0.178	0.136	0.230	0.143	0.273
B4 Pusa Purple Long	S	0.090	0.174	0.095	0.096	0.132	0.203
Chilli							
C1 Ujwala	R	0.156	0.115	0.300	0.154	0.165	0.080
C2 Manjari	MR	0.151	0.081	0.130	0.102	0.256	0.163
C3 Jwalasakhi	MS	0.173	0.093	0.179	0.083	0.114	0.251
C4 Pusa Jwala	S	0.110	0.114	0.113	0.116	0.096	0.092

R - Resistant MR - Moderately resistant
S - Susceptible MS - Moderately susceptible

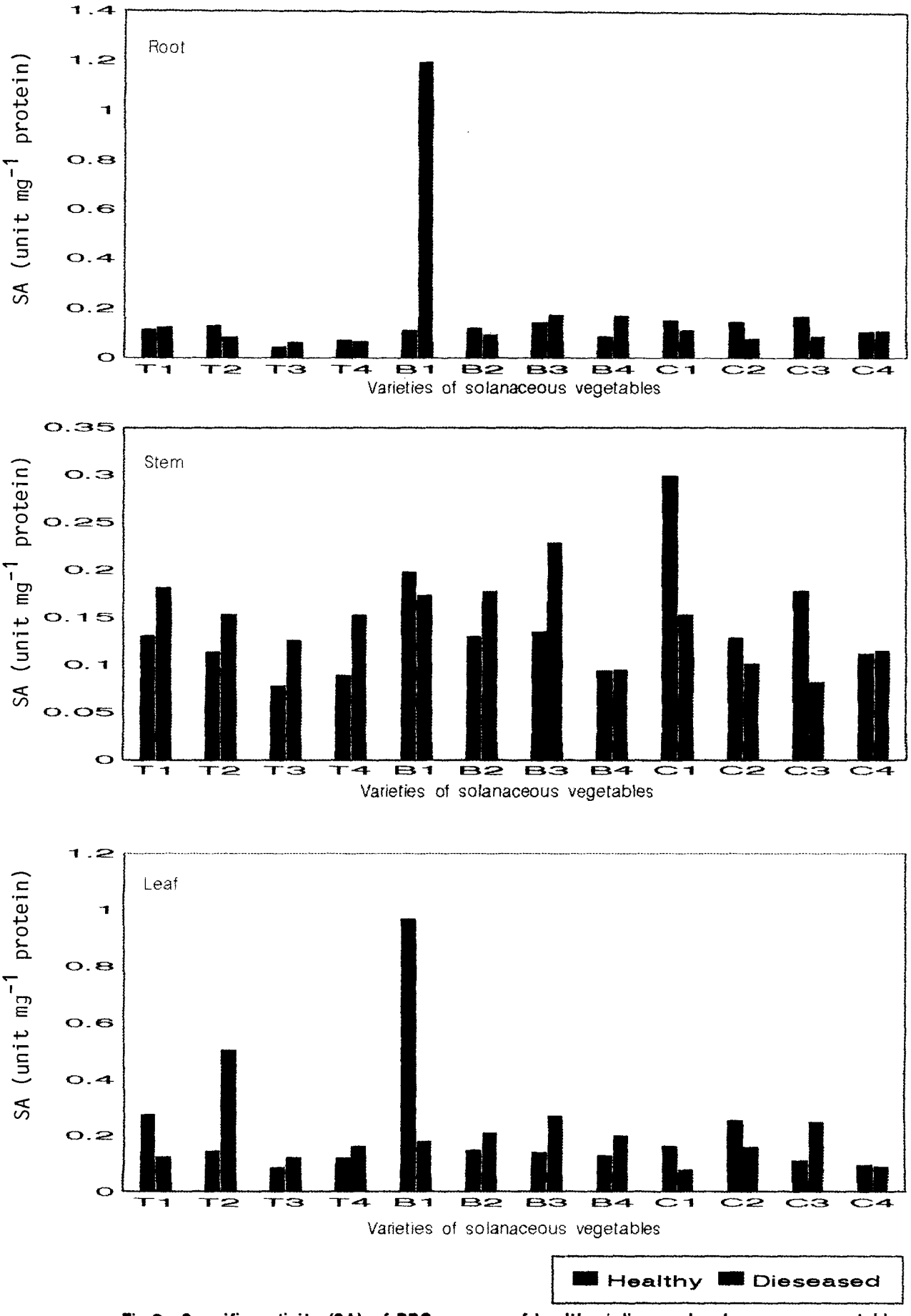


Fig.8. Specific activity (SA) of PPO enzyme of healthy / diseased solanaceous vegetables

condition and diseased condition. In the leaf the specific activity increased in all varieties/lines except in LE 79-5 (R) due to infection. The rate of increase was more in BT-10 (MR) and less in Pusa Ruby (S). The specific activity was highest in LE 79-5 (R) under healthy condition and in BT-10 (MR) under diseased condition.

In brinjal root the specific activity increased in all varieties/lines except in Composite-2 (MR) after infection. The rate of increase was highest in Swetha (R) (9 fold) and lowest in BB-7 (MS). The specific activity was highest in BB-7 (MS) under healthy condition and in Swetha (R) under diseased condition. In the stem the specific activity increased in all the varieties/lines due to infection except in Swetha (R). The specific activity was highest in Swetha (R) under healthy condition and in BB-7 (MS) under diseased condition. In the leaf also the specific activity increased in all the varieties/lines except in Swetha (R). The rate of increase was highest in BB-7 (MS) and lowest in Composite-2 (MR). The specific activity was maximum in Swetha (R) under healthy condition and in BB-7 (MS) under diseased condition.

In chilli the specific activity decreased in all the varieties/lines except in the root and stem of Pusa Jwala (S) after infection. The specific activity was highest in Jwalasakhi (MS) under healthy condition and in

Ujwala (R) under diseased condition. In the stem the rate of decrease was maximum in Jwalasakhi (MS) (5 fold) and minimum in Manjari (MR). The specific activity was highest in Ujwala (R) both under healthy and diseased condition. In leaf the specific activity decreased in all the varieties/lines except in Jwalasakhi(MS). The specific activity was maximum in Manjari (MR) among healthy plants and in Jwalasakhi (MS) among diseased plants.

4.7.9. Peroxidase activity

Significant difference was observed in peroxidase activity in tomato, brinjal and chilli between the varieties/lines and between healthy or diseased condition (Table. 23 and Fig. 9). In tomato root the peroxidase activity increased in all varieties/lines, except in BT-10 (MR) after infection. The rate of increase was highest in LE 470 (MS) and lowest in Pusa Ruby (S). The activity was highest in BT-10 (MR) among healthy plants and was in LE 470 (MS) among diseased plants. In stem the peroxidase activity increased in all the varieties/lines after infection. The activity was highest in BT-10(MR) under healthy condition and in LE 79-5 (R) under diseased condition. The rate of increase after infection was also maximum in LE 79-5 (R). The activity was lowest in Pusa Ruby (S) both under healthy and diseased condition. Unlike

Table. 23 Comparison of peroxidase activity in bacterial wilt resistant and susceptible varieties / lines of tomato, brinjal and chilli under healthy and diseased condition (units per litre)

Varieties/ lines	Disease reaction	Root		Stem		Leaf	
		Healthy	Diseased	Healthy	Diseased	Healthy	Diseased
Tomato							
T1 LE 79-5	R	531.910	580.500	500.000	1428.570	240.380	189.390
T2 BT-10	MR	2941.180	2272.720	1041.670	1136.360	166.670	102.040
T3 LE 470	MS	1851.850	3571.430	588.240	1250.00	384.620	320.510
T4 Pusa Ruby	S	1666.67	1700.680	312.500	359.710	490.200	163.400
CD (0.05)		64.820		24.820		78.370	
Brinjal							
B1 Swetha	R	2000.000	2283.000	1315.790	1785.710	847.460	1121.08
B2 Composite-2	MR	1851.850	2083.330	1515 150	2941.18	2083.33	268.800
B3 BB7	MS	1086.960	2173.330	1470.590	2083.330	137.740	159.740
B4 Pusa Purple Long	S	909.090	1612.900	2272.730	1190.480	375.940	657.890
CD (0.05)		7.330		7.280		8.220	
Chilli							
C1 Ujwala	R	1428.57	2487.56	934.40	2000.000	980.390	934.400
C2 Manjari	MR	1612.900	500.000	462.960	1351.935	151.520	340.000
C3 Jwalasakhi	MS	2941.180	1561.280	510.200	1470.590	176.450	107.300
C4 Pusa Jwala	S	2272.730	3333.330	735.290	1923.080	231.480	757.580
CD (0..05)		212.660		3.340		7.910	

Mean of four replications
R - Resistant MR - Moderately resistant
S - Susceptible MS - Moderately susceptible

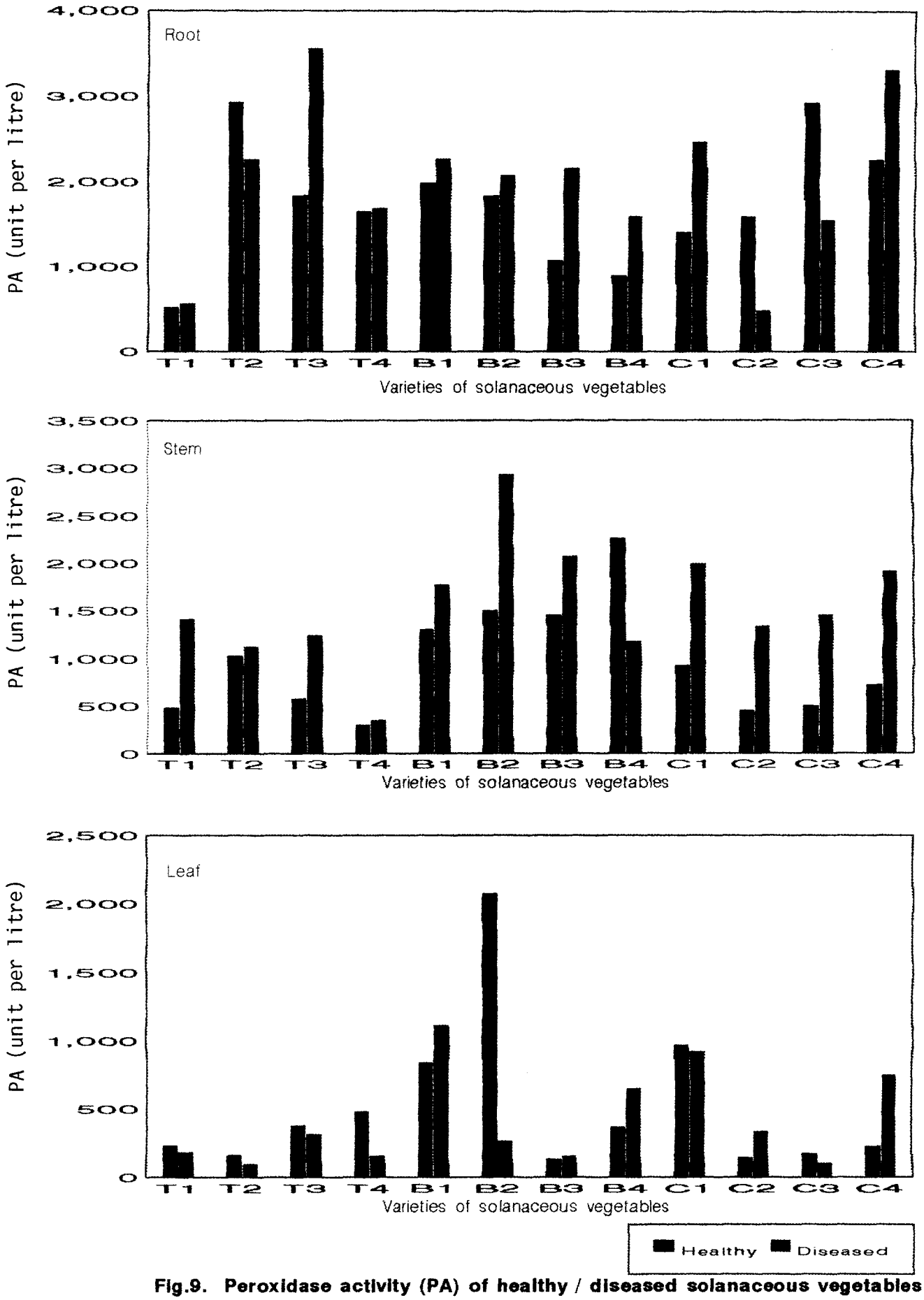


Fig.9. Peroxidase activity (PA) of healthy / diseased solanaceous vegetables

in root and stem, in the leaf the peroxidase activity decreased in all the varieties/lines due to infection. The rate of decrease was highest in Pusa Ruby (S) and lowest in LE 470 (MS). The enzyme activity was maximum in Pusa Ruby (S) under healthy condition and in LE 470 (MS) under diseased condition.

In brinjal root the peroxidase activity increased in all the varieties/lines after infection. Its activity was higher in the resistant genotypes, the highest in Swetha (R) both under healthy and diseased condition. The rate of increase in its activity was maximum in BB-7 (MS). The enzyme activity was lowest in Pusa Purple Long (S) both under healthy and diseased condition. In stem the peroxidase activity increased in all the varieties/lines except in Pusa Purple Long (S) after infection. The enzyme activity was highest in Pusa Purple Long (S) under healthy condition and in Composite-2 (MR) under diseased condition. The rate of increase in peroxidase activity was highest in Composite-2 (MR). In leaf the peroxidase activity increased in all the varieties/lines except in Composite-2 (MR) due to infection. The resistant genotypes showed a higher peroxidase activity compared to the susceptible ones. The rate of increase in activity was highest in Pusa Purple Long (S). The enzyme activity was maximum in Composite-2 (MR) under healthy condition and in Swetha (R) under diseased condition.

In chilli root, the peroxidase activity increased in Ujwala (R) and Pusa Jwala (S) after infection. In the other two varieties the enzyme activity decreased. The rate of increase in activity was highest in Ujwala (R). The enzyme activity was highest in Jwalasakhi (MS) under healthy condition and in Pusa Jwala (S) under diseased condition. In the stem also the peroxidase activity increased in all the varieties/lines after infection. The enzyme activity was highest in Pusa Jwala (S) among healthy plants and in Ujwala (R) among diseased plants. The rate of increase was highest in Manjari (MR). In the leaf the peroxidase activity increased after infection in Manjari (MR) and Pusa Jwala (S), but in Ujwala (R) a slight decrease was noticed.

4.7.10. **Alkaloid**

The changes in alkaloid content in tomato, brinjal and chilli after infection were not significant in most cases (Table. 24 and Fig. 10). In tomato root the alkaloid content decreased in LE 79-5 (R) and did not show any change in BT-10 (MR) and Pusa Ruby (S) after infection. A slight increase was observed in LE 470 (MS). The alkaloid content was highest in LE 79-5 (R) and LE 470 (MS) under healthy condition and in LE 470 (MS) under diseased condition. In the stem the alkaloid content decreased in all varieties/lines after infection. The rate of decrease

Table. 24 Comparison of alkaloid content in bacterial wilt resistant and susceptible varieties / lines of tomato, brinjal and chilli under healthy and diseased condition (in Percentage)

Varieties / lines	Disease reaction	Root		Stem		Leaf	
		Healthy	Diseased	Healthy	Diseased	Healthy	Diseased
Tomato							
T1 LE 79-5	R	10.00	5.00	16.00	12.00	24.00	16.00
T2 BT-10	MR	8.00	8.00	14.00	14.00	16.00	14.00
T3 LE 470	MS	10.00	10.25	16.00	6.00	25.00	26.00
T4 Pusa Ruby	S	8.00	8.00	16.75	15.50	16.00	25.00
CD (0.05)		NS		NS		7.22	
Brinjal							
B1 Swetha	R	6.00	8.00	6.00	10.00	22.00	10.00
B2 Composite-2	MR	6.00	10.00	8.00	10.00	20.00	24.00
B3 BB7	MS	12.00	10.00	6.5	8.00	22.00	20.00
B4 Pusa Purple Long	S	10.00	6.00	16.00	16.00	22.00	20.00
CD (0.05)		2.99		NS		3.71	
Chilli							
C1 Ujwala	R	6.00	4.00	10.00	10.00	24.00	24.00
C2 Manjari	MR	12.00	10.00	10.00	16.00	30.00	32.00
C3 Jwalasakhi	MS	10.00	7.25	14.00	16.00	34.00	46.00
C4 Pusa Jwala	S	10.00	10.00	18.00	4.00	30.00	57.00
CD (0.05)		NS		3.18		6.09	

Mean of four replications
R - Resistant MR - Moderately resistant
S - Susceptible MS - Moderately susceptible NS - Not Significant

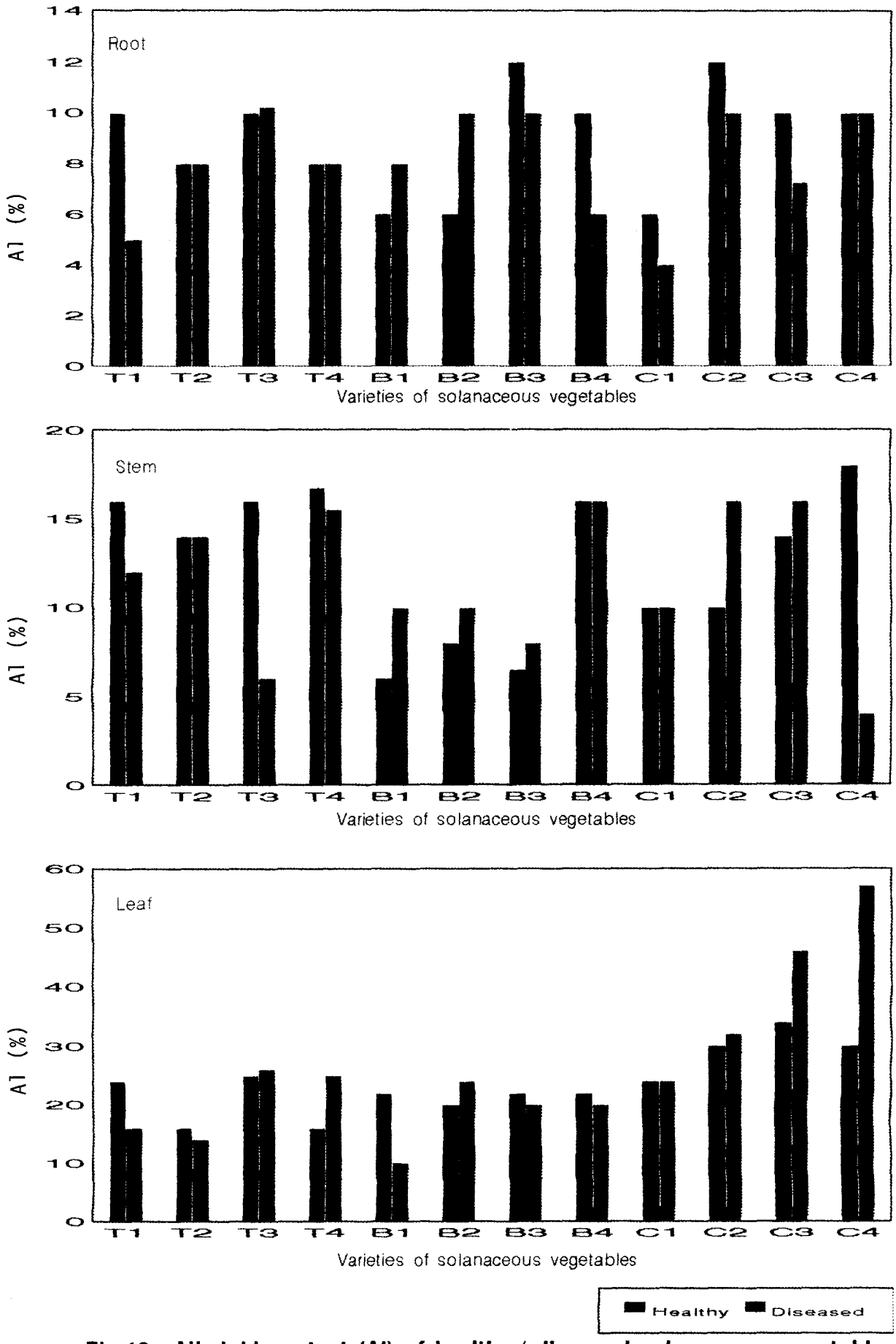


Fig.10. Alkaloid content (Al) of healthy / diseased solanaceous vegetables

was highest in LE 470 (MS). It was maximum in Pusa Ruby (S) and the other varieties/lines did not differ significantly in its content both under healthy and diseased condition. In the leaf the alkaloid content increased in the susceptible genotypes and decreased in the resistant ones after infection. The alkaloid content was highest in LE 470 (MS) both under healthy and diseased condition.

In brinjal root, the alkaloid content increased in the resistant genotypes and decreased in susceptible ones due to infection. The rate of increase after infection was highest in Composite-2 (MR). The alkaloid content was maximum in BB-7 (MS) under healthy condition and in Composite-2 (MR) and BB-7 (MS) under diseased condition. In stem the alkaloid content increased in all varieties/lines after infection. It was maximum in Pusa Purple Long (S), both under healthy and diseased condition. In the leaf the alkaloid content decreased in all the varieties/lines except in Composite - 2 (MR), which showed an increase after infection. The rate of decrease was maximum in Swetha (R).

In chilli root the alkaloid content decreased in all the varieties/lines after infection. The decrease was maximum in Ujwala (R). The alkaloid content was maximum in Composite-2 (MR) both under healthy and diseased condition. In the stem the alkaloid content increased in

Manjari (MR) and Jwalasakhi (MS) after infection and decreased in Pusa Jwala (S). In leaf the alkaloid content increased in all varieties/lines except in Ujwala (R) which recorded no change. The rate of increase was maximum in Pusa Jwala (S). The alkaloid content was highest in Jwalasakhi (MS) under healthy condition and in Pusa Jwala (S) under diseased condition. The alkaloid content was lowest in Ujwala (R) both under healthy and diseased condition.

4.8. Changes in biological factors in resistant and susceptible varieties/lines of tomato, brinjal and chilli upon infection by *R. solanacearum*.

The various biological factors like microorganisms in the rhizosphere soil of resistant and susceptible varieties/lines of tomato, brinjal and chilli are also important in imparting resistance / susceptibility to the host plants. Populations of total microflora (fungi, bacteria, actinomycetes), pseudomonads (virulent *Ralstonia* and avirulent *Pseudomonas*), beneficial microbes (mycorrhiza, Azospirillum), nematodes (parasitic and saprophytic) were studied.

4.8.1. Total microflora

The population of fungi, bacteria and actinomycetes in the rhizosphere soil of tomato, brinjal and chilli are given in (Table. 25 and in Fig. 11 a,b,c.)

Table. 25 Comparison of general microflora in rhizosphere soil of bacterial wilt resistant and susceptible varieties / lines of tomato, brinjal and chilli under healthy and diseased conditions (c.f.u. per plate)

Varieties / lines	Disease reaction	Fungi		Bacteria		Actinomyctes	
		Healthy	Diseased	Healthy	Diseased	Healthy	Diseased
Tomato							
T1 LE 79-5	R	2.035	3.555	2.780	9.480	2.060	9.098
T2 BT-10	MR	1.785	2.355	3.337	8.262	2.870	5.785
T3 LE 470	MS	1.898	1.845	8.060	3.225	2.525	2.735
T4 Pusa Ruby	S	2.998	3.148	5.782	4.790	6.105	5.630
CD (0.05)		0.692		0.634		0.725	
Brinjal							
B1 Swetha	R	4.873	6.060	5.520	4.848	3.960	5.262
B2 Composite-2	MR	1.958	2.733	8.007	8.963	5.822	6.507
B3 BB7	MS	3.730	3.150	4.412	4.660	2.630	2.395
B4 Pusa Purple Long	S	3.965	5.072	6.178	10.700	6.975	5.850
CD (0.05)		0.676		1.045		0.989	
Chilli							
C1 Ujwala	R	3.033	3.495	5.242	4.840	2.543	2.827
C2 Manjari	MR	2.783	2.733	6.983	10.105	4.829	6.743
C3 Jwalasakhi	MS	2.815	2.733	6.918	7.082	6.218	4.977
C4 Pusa Jwala	S	3.953	2.823	6.620	8.970	3.168	5.692
CD (0.05)		NS		NS		1.445	

Mean of four replications
R - Resistant MR - Moderately resistant
S - Susceptible MS - Moderately susceptible NS - Not significant
All the values are after square root transformation

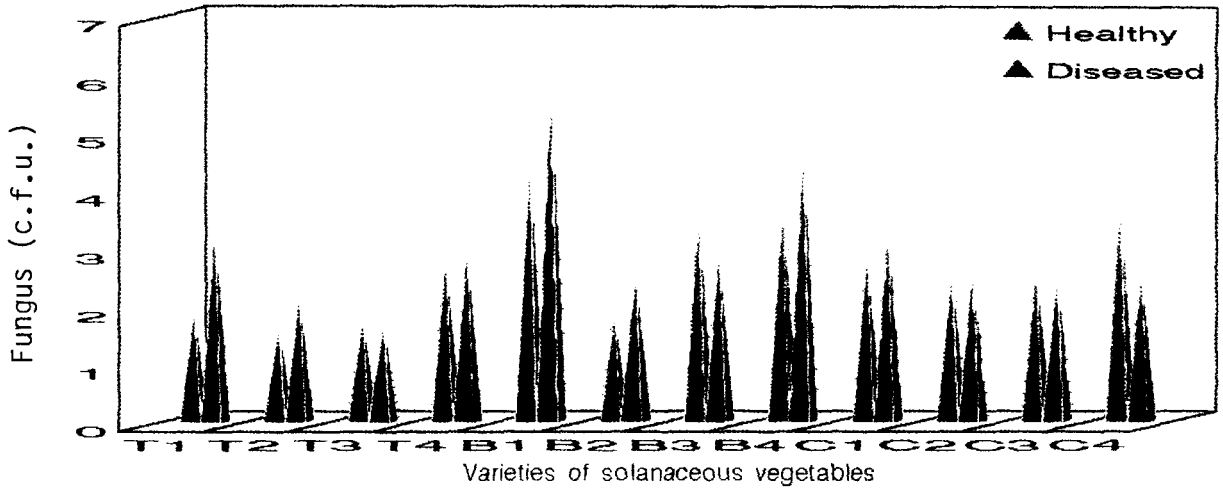


Fig.11(a). Fungal population in rhizosphere soil of healthy / diseased solanaceous vegetables

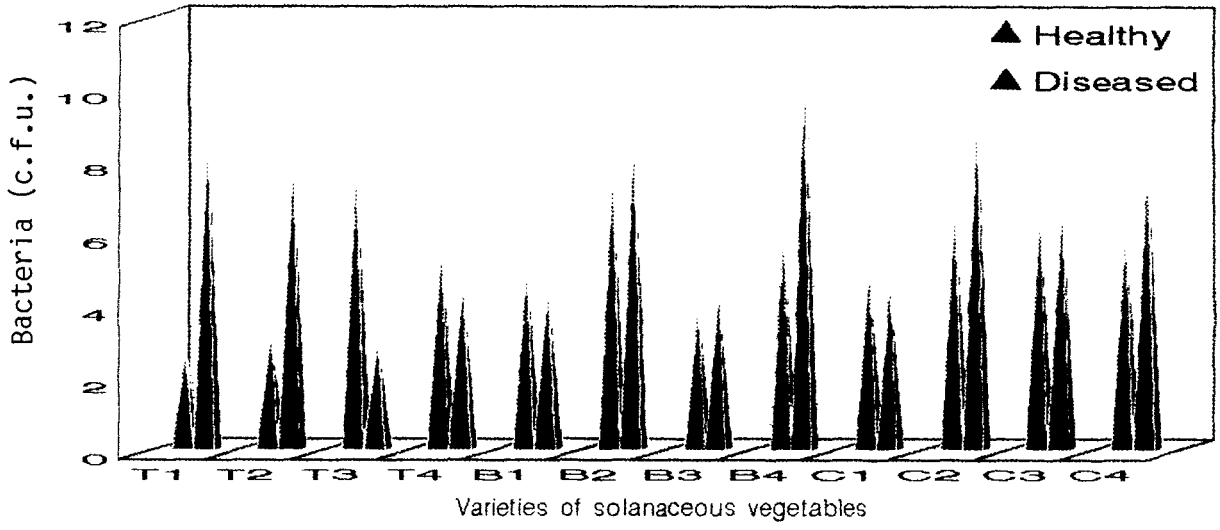


Fig. 11(b). Bacterial population in rhizosphere soil of healthy / diseased solanaceous vegetables

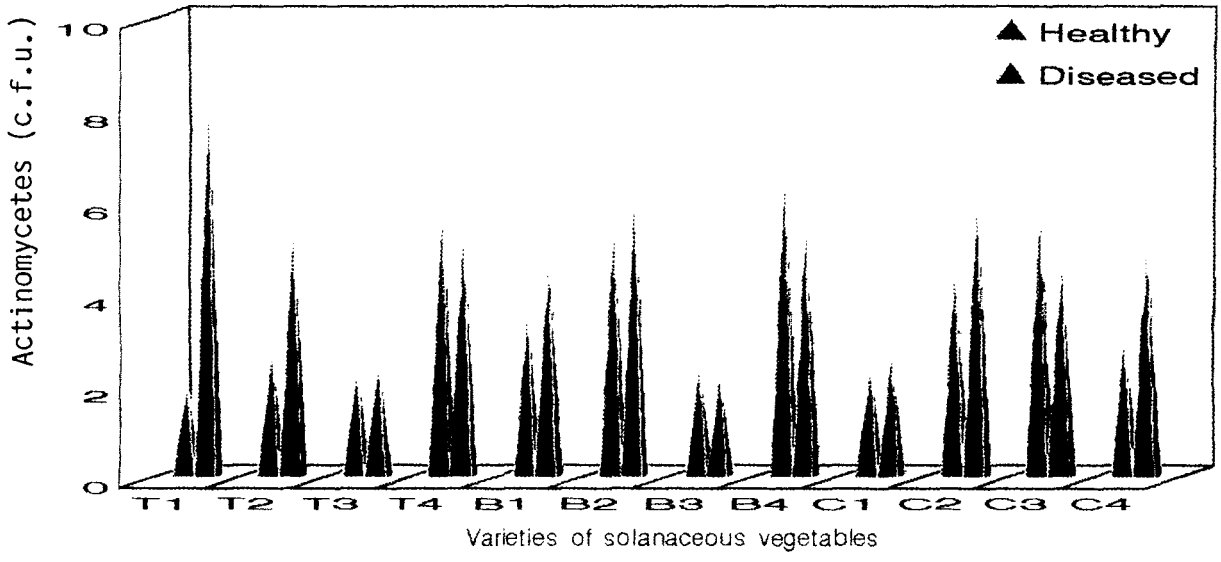


Fig.11(c). Actinomycete population in rhizosphere soil of healthy / diseased solanaceous vegetables

In tomato the fungal population in the rhizosphere soil increased in all the varieties except in LE 470 (MS) under diseased condition. The fungal population was maximum in the Pusa Ruby (S) under healthy condition and in LE 79-5 (R) under diseased condition. It was minimum in BT-10 (MR) and LE 470 under healthy and diseased condition respectively. The bacterial population increased significantly in the resistant genotypes whereas it decreased in the susceptible ones due to infection. The bacterial population was maximum in LE 470 (MS) and minimum in LE 79-5 (R) under healthy condition. Under diseased condition the bacterial population was highest in LE 79-5 (R) and lowest in LE 470 (MS). A two fold increase in population was observed due to infection in LE 79-5 (R). The actinomycete population increased in all the varieties/lines except in Pusa Ruby (S) where it decreased due to infection. The actinomycete population was highest in Pusa Ruby (S) and lowest in LE 79-5 (R) under healthy condition. Under diseased condition the population was highest in LE 79-5 (R) and lowest in LE 470 (MS). The rate of increase in actinomycete population was highest in LE 79-5 (R) and lowest in Pusa Ruby (S).

In brinjal the fungal population increased in all varieties/lines except in BB-7 (MS) due to infection. The population was highest in Swetha (R) both under healthy and diseased condition. The bacterial population increased in all varieties/lines of brinjal except in Swetha (R) which

showed a decrease. The rate of increase was highest in Pusa Purple Long (S) due to infection. The highest population was recorded in Composite-2 (MR) under healthy condition and in Pusa Purple Long (S) under diseased condition. As in tomato, here also the actinomycete population increased in the resistant genotypes and decreased in susceptible ones. The actinomycete population was highest in Pusa Purple Long (S) under healthy condition and in Composite -2 (MR) under diseased condition.

In chilli, the fungal population decreased in all varieties/lines except Ujwala (R) due to infection. The fungal population was highest in Pusa Jwala (S) under healthy condition and in Ujwala (R) under diseased condition. The bacterial population increased due to infection in all the varieties/lines except in Ujwala (R) which showed a decrease. The bacterial population was highest in Manjari (MR) both under healthy and diseased condition. The actinomycete population increased in all varieties/lines except in Jwalasakhi (MS). The maximum actinomycete population was recorded in Jwalasakhi (MS) under healthy condition and in Manjari (MR) under diseased condition.

4.8.2. Pseudomonads

In tomato the resistant genotypes gave an increase in virulent *Ralstonia* population whereas the susceptible ones gave a decrease due to infection (Table.26

and Fig. 12 a,b). The virulent bacterial population was highest in Pusa Ruby (S) under healthy condition and in BT-10 (MR) under diseased condition. In the case of avirulent bacterial population also, the resistant genotypes showed an increase, while the susceptible ones showed a decrease due to infection. The avirulent bacterial population was highest in Pusa Ruby (S) under healthy condition and in BT-10 (MR) diseased condition. The rate of increase was highest in BT-10(MR).

In brinjal, the virulent *Ralstonia* population increased in all varieties/lines except Pusa Purple Long(S), after infection. In Pusa Purple Long (S) bacterial population decreased considerably. The virulent population was highest in Pusa Purple Long (S) under healthy condition and in Composite -2 (MR) under diseased condition. The rate of increase in virulent *Ralstonia* population was highest in Composite-2 (MR). The avirulent *Pseudomonas* population was increased in Composite-2 (MR) and Pusa Purple Long (S) due to infection. The rate of increase was maximum in Composite-2 (MR). In Swetha (R) and BB-7 (MS) the population decreased after infection. The rate of decrease was highest in BB-7 (MS). The avirulent *Pseudomonas* population was highest in Composite- 2 (MR) both under healthy and diseased condition.

Table 26 Comparison of Pseudomonads population in rizhosphere soil of bacterial wilt resistant and susceptible varieties / lines of tomato, brinjal and chilli under healthy and diseased condition (c.f.u.)

Varieties / lines	Disease raaction	Virulent		Avirulent	
		Healthy	Diseased	Healthy	Diseased
Tomato					
T1 LE 79-5	R	1.387	3.180	1.000	2.465
T2 BT-10	MR	1.662	12.875	3.425	11.098
T3 LE 470	MS	1.387	1.000	2.803	1.662
T4 Pusa Ruby	S	5.332	4.797	7.080	6.278
CD (0.05)		1.055		1.516	
Brinjal					
B1 Swetha	R	5.558	5.817	4.590	4.112
B2 Composite-2	MR	5.655	8.293	5.520	10.100
B3 BB7	MS	4.335	4.862	4.237	3.487
B4 Pusa Purple Long	S	10.525	5.665	4.287	6.077
CD (0.05)		0.945		0.629	
Chilli					
C1 Ujwala	R	4.110	4.228	3.152	4.600
C2 Manjari	MR	4.685	3.975	7.170	6.400
C3 Jwalasakhi	MS	6.102	5.698	5.805	4.875
C4 Pusa Jwala	S	3.413	8.825	2.730	3.462
CD (0.05)		2.331		NS	

Mean of four replications

R - Resistant MR - Moderately resistant

S - Susceptible MS - Moderately susceptible

All the values are after square root transformation

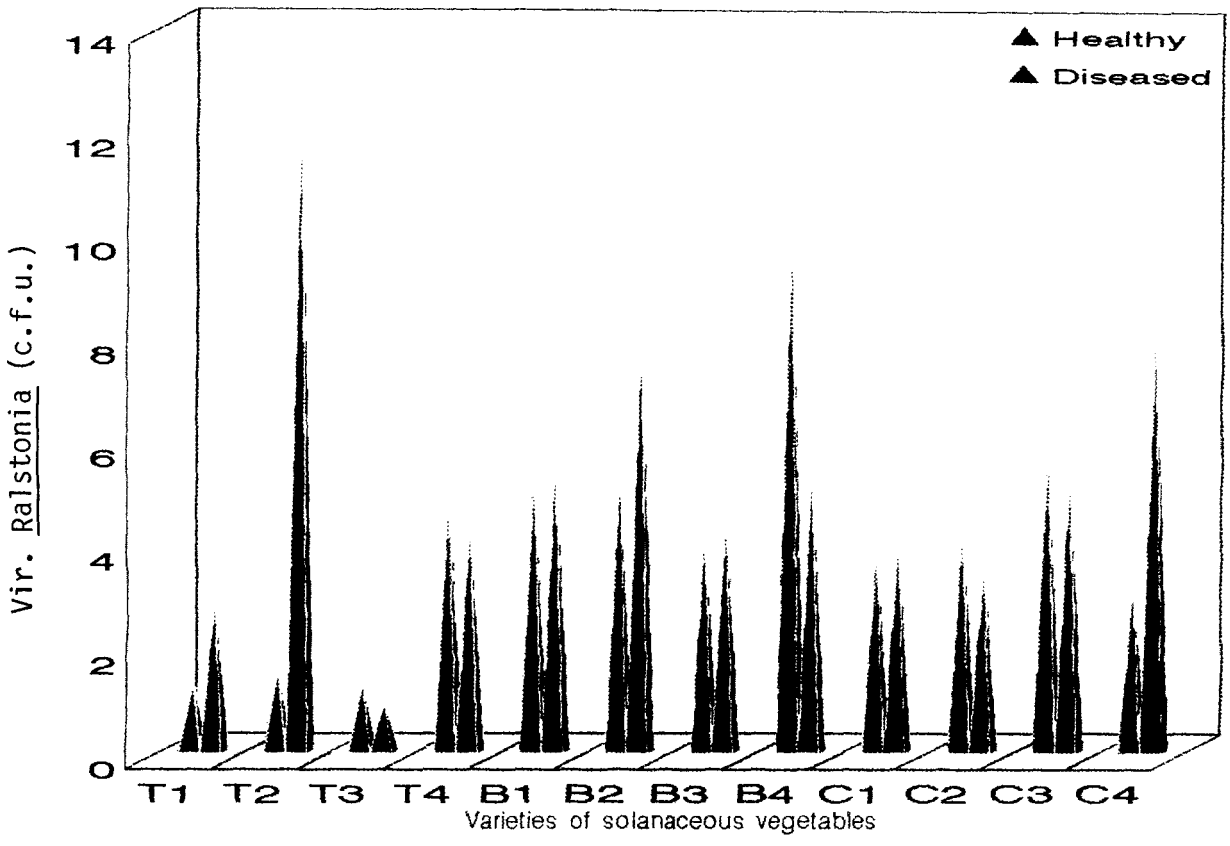


Fig.12(a). Virulent *Ralstonia* population in rhisosphere soil of healthy / diseased solanaceous vegetables

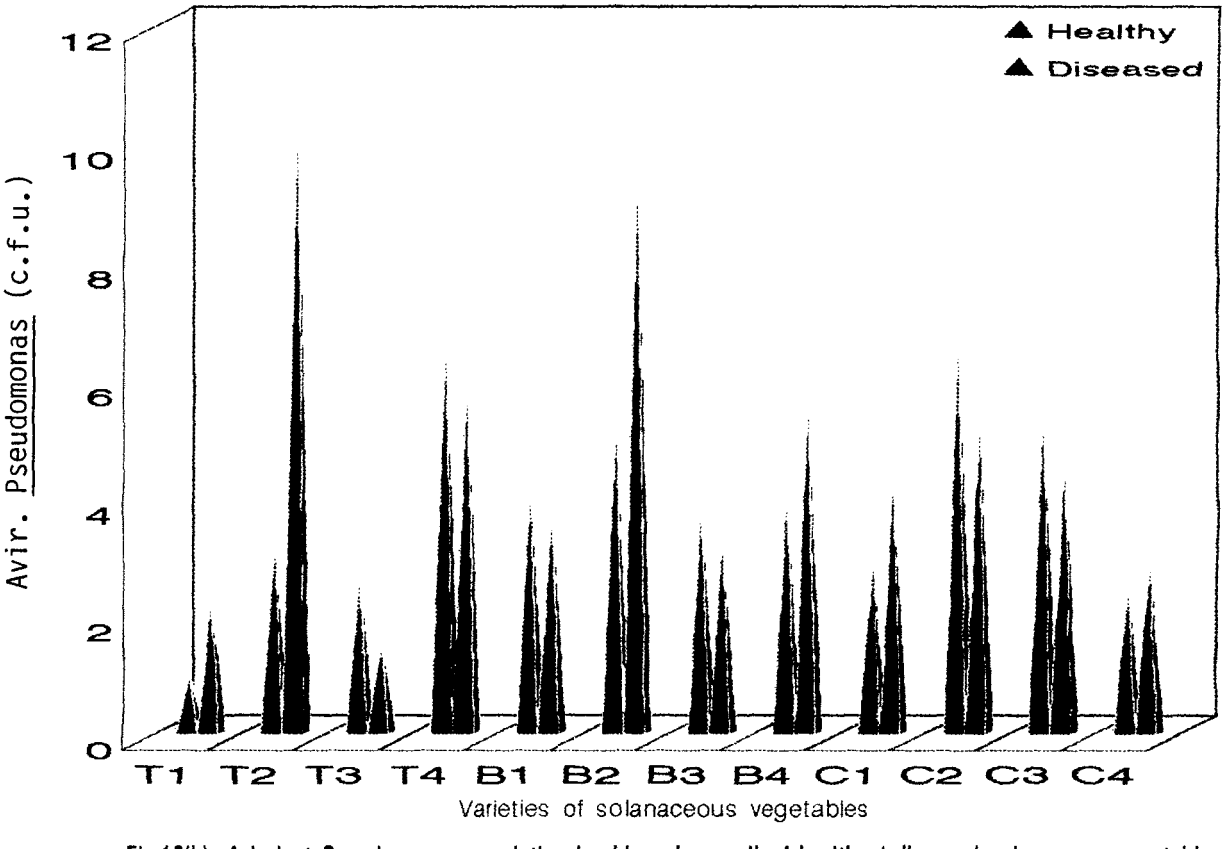


Fig.12(b). Avirulent *Pseudomonas* population in rhizosphere soil of healthy / diseased solanaceous vegetables

In chilli, the virulent *Ralstonia* population increased in Ujwala (R) and Pusa Jwala (S) and decreased in Manjari (MR) and Jwalasakhi (MS) due to infection. The virulent *Ralstonia* population was highest in Jwalasakhi (MS) under healthy condition and in Pusa Jwala (S) under diseased condition. The rate of increase was highest in Pusa Jwala (S). The avirulent *Pseudomonas* population also increased in Ujwala (R) and Pusa Jwala (S) and decreased in Manjari (MR) and Jwalasakhi (MS) upon infection. The avirulent *Pseudomonas* population was highest in Manjari (MR) both under healthy and diseased condition.

4.8.3. Beneficial microbes

Significant difference was not obtained in mycorrhizal population between varieties/lines of tomato, brinjal and chilli and between healthy and diseased condition (Table. 27 and Fig. 13 a,b). In tomato the mycorrhizal population decreased in all the varieties/lines except Pusa Ruby (S) which showed an increase after infection. The mycorrhizal population was highest in LE 470 (MS) under healthy condition and in Pusa Ruby (S) under diseased condition. The population of Azospirillum increased in all the varieties/lines except Pusa Ruby (S) upon infection. The rate of increase was highest in BT -10 (MR). The Azospirillum population was highest in Pusa Ruby (S) under healthy condition and in BT-10 (MR) under diseased condition.

Table.27 Comparison of benificial microbes in rizhosphere soil of bacterial wilt resistant and susceptible varieties / lines of tomato, brinjal and chilli under healthy and diseased condition

Varieties / lines	Disease reaction	Mycorrhiza * (% infection)		Azospirillum ** (c.f.u. per plate)	
		Healthy	Diseased	Healthy	Diseased
Tomato					
T1 LE 79-5	R	39.000	26.000	2.850	2.637
T2 BT-10	MR	33.000	23.000	1.993	5.290
T3 LE 470	MS	48.000	33.000	1.993	3.582
T4 Pusa Ruby	S	41.000	46.750	5.430	3.000
CD (0.05)		NS		0.971	
Brinjal					
B1 Swetha	R	57.000	35.000	2.787	5.960
B2 Composite-2	MR	57.000	41.000	6.215	6.217
B3 BB7	MS	30.000	49.000	3.450	2.803
B4 Pusa Purple Long	S	38.000	57.000	4.905	6.575
CD (0.05)		NS		1.414	
Chilli					
C1 Ujwala	R	35.000	30.000	4.448	4.243
C2 Manjari	MR	34.000	28.000	3.885	7.150
C3 Jwalasakhi	MS	50.000	45.000	9.263	4.675
C4 Pusa Jwala	S	24.000	28.000	5.978	6.370
CD (0.05)		NS		3.045	

Mean of four replications

R - Resistant MR - Moderately resistant

S - Susceptible MS - Moderately susceptible NS - Not significant

* No transformation

** Values are after square root transformation

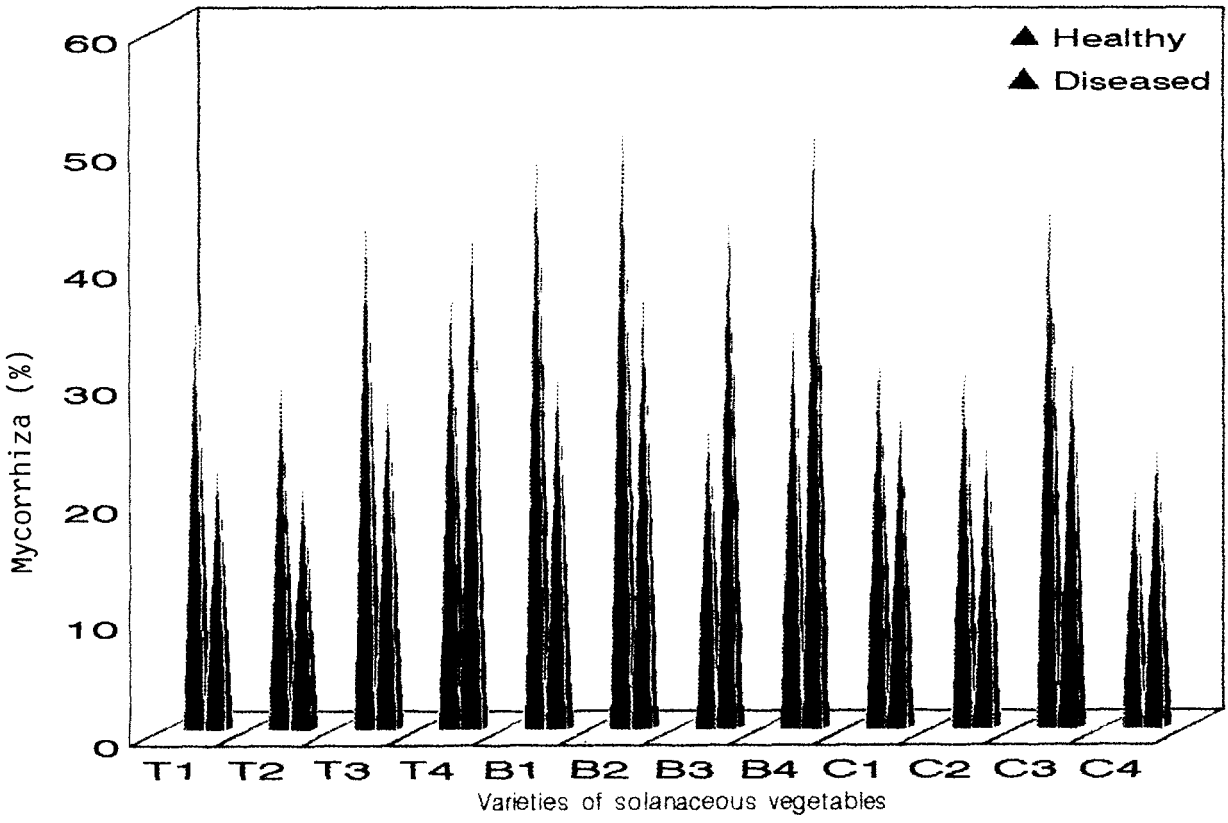


Fig.13(a). Mycorrhizal infection in the root of healthy / diseased solanaceous vegetables

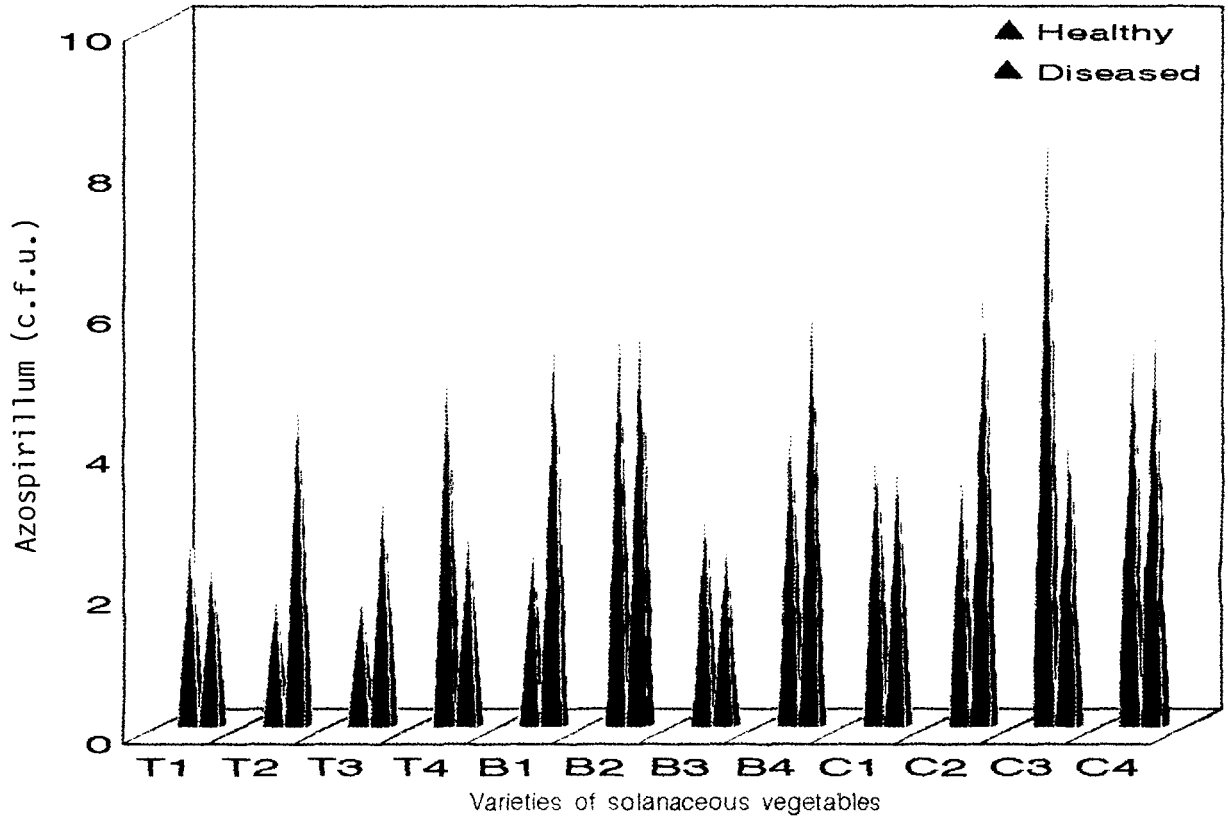


Fig.13(b). Azospirillum population in rhizosphere soil of healthy / diseased solanaceous vegetables

In brinjal the mycorrhiza population decreased in resistant varieties/lines and increased in susceptible ones after infection. It was highest in Swetha (R) and Composite -2 (MR) under healthy condition and in Pusa Purple Long (S) under diseased condition. The rate of increase was highest in BB-7 (MS) and the decrease was maximum in Swetha (R). The Azospirillum population increased in all the varieties/lines except in BB-7 (MS). The population was maximum in Composite-2 (MR) under healthy condition and in Pusa Purple Long (S) under diseased condition. The rate of increase was highest in Swetha (R).

In chilli also the mycorrhiza population decreased in all the varieties/lines except in Pusa Jwala (S), where it increased. The mycorrhiza population was highest in Jwalasakhi (MS) both under healthy and diseased condition. The population was lowest in Pusa Jwala (S) both under healthy and diseased condition. The Azospirillum population decreased in Ujwala (R) and Jwalasakhi (MS) and increased in Manjari (MR) and Pusa Jwala (S) upon infection. The population was maximum in Jwalasakhi (MS) under healthy condition and in Manjari (MR) under diseased condition.

4.8.4. Nematodes

The saprophytic nematode population in tomato decreased in all varieties/lines except in LE 79-5 (R) upon disease incidence (Table. 28 and Fig. 14 a,b). The population was highest in LE 470 (MS) both under healthy and diseased condition. The rate of increase was highest in Pusa Ruby (S). The parasitic nematode population increased in all varieties/lines upon infection. The highest parasitic nematode population was in LE 79-5 (R), but the rate of increase was minimum. Lowest nematode population recorded in BT-10 (MR), both under healthy and disease condition.

In brinjal, the saprophytic nematode population decreased in all the varieties/lines except in Composite-2 (MR) which showed an increase upon disease incidence. It was highest in Swetha (R) both under healthy and diseased condition. The parasitic nematode population increased in all varieties/lines upon disease incidence. The population was highest in Pusa Purple Long (S) under healthy condition and in Swetha(R) under diseased condition. The rate of increase was maximum in Swetha (R) and minimum in Pusa Purple Long (S).

Table. 28 Comparison of nematode population in rizhosphere soil of bacterial wilt resistant and susceptible varieties / lines of tomato, brinjal and chilli under healthy and diseased condition (counts)

Varieties / lines	Disease reaction	Saprophytic nematodes		Parasitic nematodes	
		Healthy	Diseased	Healthy	Diseased
Tomato					
T1 LE 79-5	R	303.00	210.00	25.00	29.00
T2 BT-10	MR	179.00	395.00	14.00	26.00
T3 LE 470	MS	391.00	707.00	15.00	131.00
T4 Pusa Ruby	S	178.00	640.00	23.00	30.00
CD (0..05)			85.77		7.823
Brinjal					
B1 Swetha	R	1026.00	835.00	67.00	109.00
B2 Composite-2	MR	319.00	325.00	34.00	39.00
B3 BB7	MS	150.00	137.00	25.00	36.00
B4 Pusa Purple Long	S	756.00	542.00	72.00	79.00
CD (0.05)			50.05		3.12
Chilli					
C1 Ujwala	R	786.00	164.00	126.00	14.00
C2 Manjari	MR	251.00	98.00	35.00	8.00
C3 Jwalasakhi	MS	35.00	201.00	29.00	24.00
C4 Pusa Jwala	S	221.00	310.00	37.00	31.00
CD (0.05)			12.51		5.40

Mean of four replications

R - Resistant, MR - Moderately resistant

S - Susceptible MS - Moderately susceptible

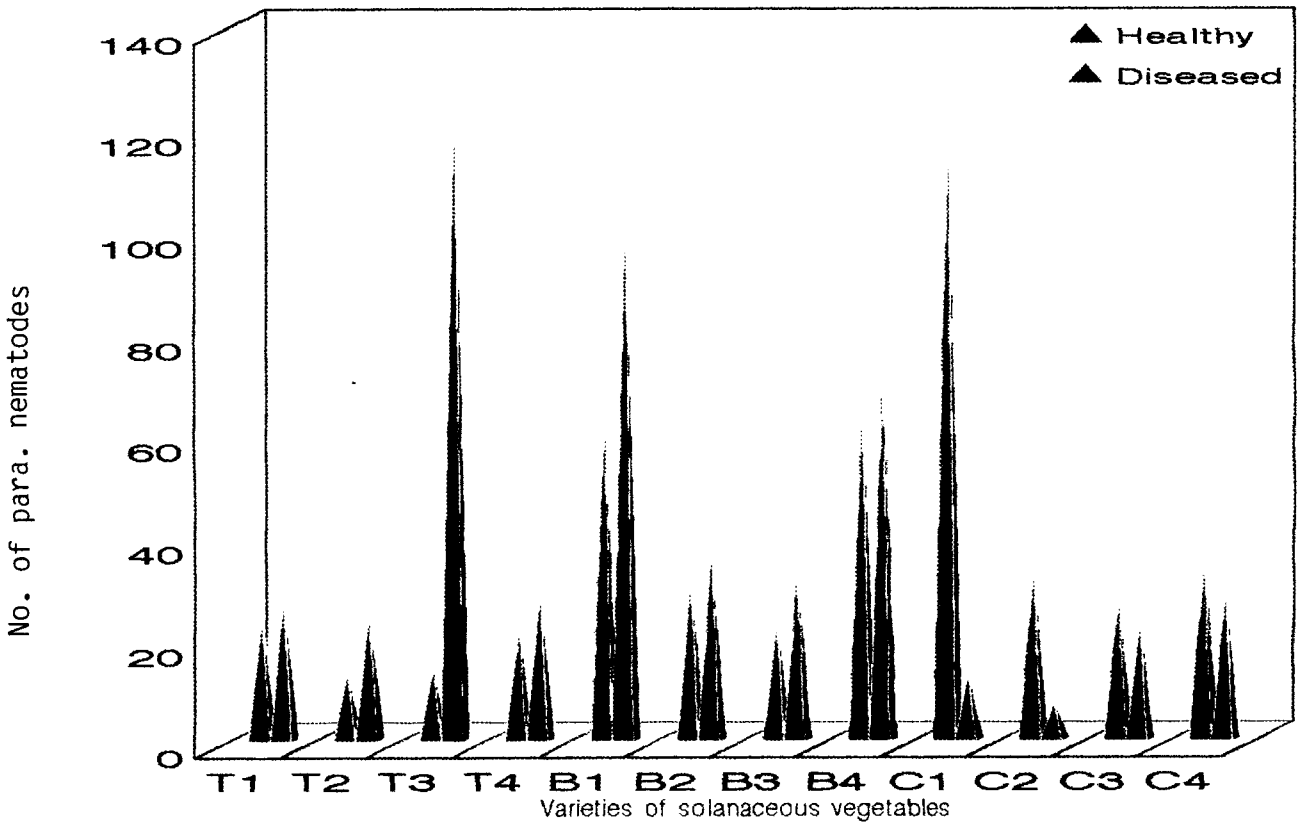


Fig.14(a). Parasitic nematodes in rhizosphere soil of healthy / diseased solanaceous vegetables

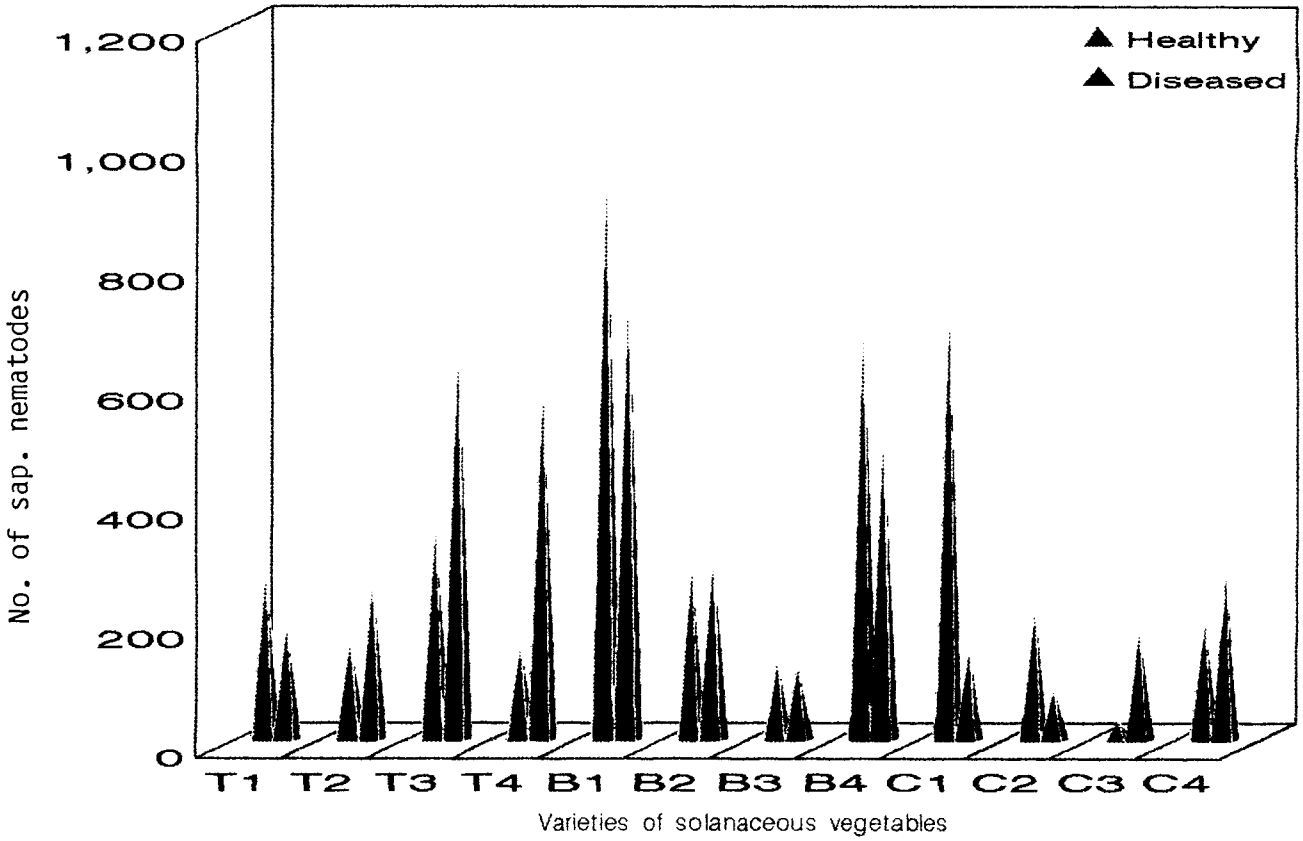


Fig.14(b). Saprophytic nematodes in rhizosphere soil of healthy / diseased solanaceous vegetables

In chilli, the saprophytic nematode population decreased in resistant genotypes and increased in susceptible ones upon disease incidence. The population was highest in Ujwala (R) under healthy condition and in Pusa Jwala (S) under diseased condition. The rate of decrease was highest in Ujwala (R) and the rate of increase was highest in Jwalasakhi (MS). The parasitic nematode population decreased in all the varieties/lines upon disease incidence. The population was highest in Ujwala (R) under healthy condition and in Pusa Jwala (S) under diseased condition. The rate of decrease was maximum in Ujwala (R) and minimum in Pusa Jwala (S).

4.9. Changes in nutritional factors in resistant and susceptible varieties/lines of tomato, brinjal and chilli upon infection by *R.solanacearum*.

Nutrient content of the different parts like root, stem and leaf were assessed under healthy condition as well as under diseased condition. The various nutritional factors studied were nitrogen, phosphorus, potassium, calcium, magnesium, iron, zinc and manganese.

4.9.1. Nitrogen

The nitrogen content of the root of all tested varieties/lines of tomato increased upon infection by *R.solanacearum,* except in the case of LE 79-5 (R)(Table. 29 and Fig. 15). It was in the root of LE 79-5 (R) among the healthy plants and in LE 470 (MS) among diseased plants. Significant difference was not obtained between varieties/lines in their nitrogen content both under healthy and diseased condition. The increase in nitrogen content upon infection was also not significant. There was an increase in nitrogen content upon infection in the stem of all the varieties/lines except in Pusa Ruby (S). In healthy stem the nitrogen content was maximum in the Pusa Ruby (S) and minimum in LE 79-5 (R). It was highest in LE 470 (MS) and lowest in Pusa Ruby (S) among diseased plants. In leaf the nitrogen content decreased upon infection in all the varieties/lines except in LE 470 (MS). It was maximum in Pusa Ruby (S) both under healthy and diseased condition.

In brinjal root the resistant genotype showed a decreasing trend in nitrogen content and the susceptible one showed an increasing trend due to infection. The nitrogen content was highest in Composite-2 (MR) of brinjal but it decreased due to infection. The root of Pusa Purple Long (S) recorded lowest, and it increased by infection.

Table.29 Comparison of nitrogen content in bacterial wilt resistant and susceptible varieties / lines of tomato, brinjal and chilli under healthy and diseased condition (in percentage)

Varieties / lines	Disease reaction	Root		Stem		Leaf	
		Healthy	Diseased	Healthy	Diseased	Healthy	Diseased
Tomato							
T1 LE 79-5	R	2.430	1.860	1.990	2.060	3.630	3.190
T2 BT-10	MR	1.650	2.050	2.280	2.230	4.080	3.340
T3 LE 470	MS	2.330	2.420	2.040	2.920	3.920	4.040
T4 Pusa Ruby	S	1.630	1.710	2.370	1.880	4.600	4.290
CD (0.05)		NS		0.534		NS	
Brinjal							
B1 Swetha	R	1.720	1.260	2.140	2.190	4.050	2.940
B2 Composite-2	MR	1.870	1.150	2.320	2.920	3.400	3.170
B3 BB7	MS	1.540	2.520	2.170	2.440	4.340	3.610
B4 Pusa Purple Long	S	1.210	1.900	1.840	2.620	3.930	3.920
CD (0.05)		0.575		NS		0.902	
Chilli							
C1 Ujwala	R	0.990	2.310	2.590	3.130	5.480	4.960
C2 Manjari	MR	2.120	1.990	1.640	1.940	4.480	3.370
C3 Jwalasakhi	MS	1.390	2.460	1.850	2.000	4.290	4.020
C4 Pusa Jwala	S	1.400	1.360	2.300	2.040	4.380	3.160
CD (0.05)		0.677		NS		0.413	

Mean of four replications
R - Resistant MR - Moderately resistant
S - Susceptible MS - Moderately susceptible NS - Not significant

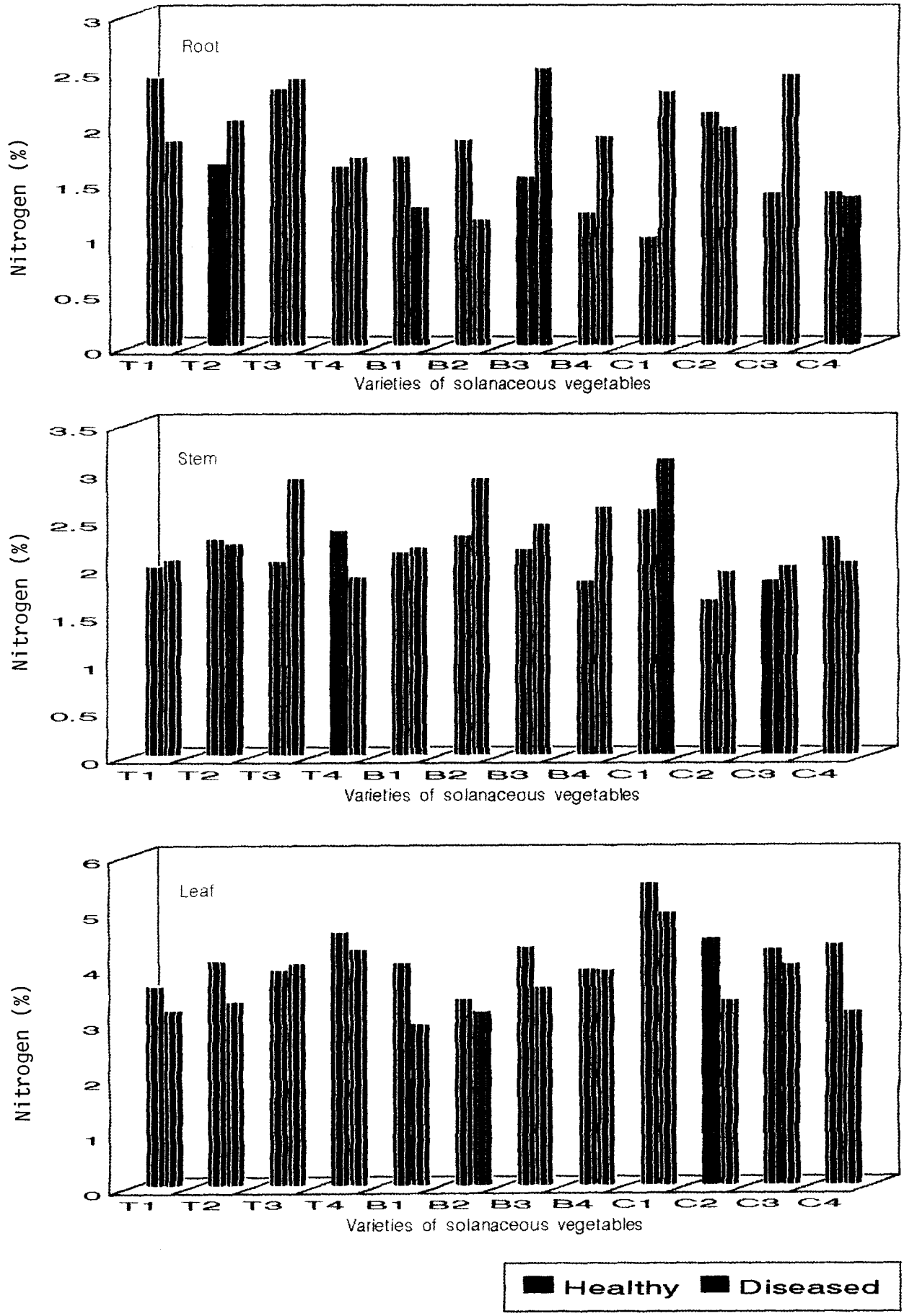


Fig. 15 Nitrogen content in healthy / diseased solanaceous vegetables

Under diseased condition nitrogen content was highest in BB-7 (MS). In stem of brinjal, the nitrogen content increased in all the varieties/lines due to infection. The rate of increase was maximum in Pusa Purple Long (S) and minimum in Swetha (R). It was highest in Composite-2 (MR) both under healthy and diseased condition. The nitrogen content in the leaf of all varieties/lines of brinjal decreased due to infection. The decrease was significant in Swetha (R) and was minimum in Pusa Purple Long (S). The highest nitrogen content was obtained from BB-7 (MS) and lowest from Composite-2 (MR) under healthy condition and under diseased condition, it was highest in Pusa Purple Long (S) and lowest in Swetha (R).

In chilli root Ujwala (R) gave the lowest nitrogen content under healthy condition which increased due to infection. In Manjari (MR) and Pusa Jwala (S), the nitrogen content decreased due to infection. The nitrogen content was highest in Manjari (MR) among healthy plants and was in Jwalasakhi (MS) among diseased plants. In the stem, the nitrogen content increased in all the varieties/ lines except Pusa Jwala (S) due to infection. It was maximum in Ujwala (R) both under healthy and diseased condition. The nitrogen content of the leaf showed that it decreased in all the varieties/lines upon infection. It was highest in Ujwala (R) both under healthy as well as under diseased condition.

4.9.2. Phosphorus

The phosphorus content in the root of tomato increased upon infection in all the varieties/lines except in LE 79-5 (R) (Table. 30 and Fig. 16). Highest phosphorus content was obtained from Pusa Ruby (S) which remained the same under diseased condition. The lowest phosphorus content was obtained in LE 470 (MS) which showed an increase under diseased condition. In the stem, the resistant genotype recorded an increase in phosphorus content due to infection, whereas the susceptible ones showed a decrease. The phosphorus content was highest in Pusa Ruby (S) both under healthy as well as under diseased condition. It was lowest in LE 79-5 (R), but increased due to infection. In leaf also the phosphorus content increased in all the varieties/lines except in LE 470 (MS). Highest phosphorus content of leaf was given by Pusa Ruby (S) both under healthy as well as under diseased condition. Lowest phosphorus content was recorded in LE 79-5 (R) which showed an increase due to infection.

In brinjal root the phosphorus content increased due to infection in all the varieties/lines except in Pusa Purple Long (S) where a slight decrease was noticed. It was highest in Pusa Purple Long (S) and lowest in BB-7 (MS) under healthy condition. The rate of increase due to infection was significantly highest in BB-7

Table. 30 Comparison of phosphorus content in bacterial wilt resistant and susceptible varieties / lines of tomato, brinjal and chilli under healthy and diseased conditions (in percentage)

Varieties / lines	Disease reaction	Root		Stem		Leaf	
		Healthy	Diseased	Healthy	Diseased	Healthy	Diseased
Tomato							
T1 LE 79-5	R	0.237	0.177	0.124	0.229	0.157	0.204
T2 BT-10	MR	0.157	0.172	0.134	0.191	0.191	0.200
T3 LE 470	MS	0.150	0.198	0.229	0.227	0.243	0.227
T4 Pusa Ruby	S	0.271	0.271	0.315	0.258	0.312	0.489
CD (0.05)		0.007		0.025		0.041	
Brinjal							
B1 Swetha	R	0.140	0.169	0.161	0.170	0.183	0.214
B2 Composite-2	MR	0.126	0.132	0.135	0.174	0.188	0.214
B3 BB7	MS	0.055	0.293	0.181	0.286	0.276	0.283
B4 Pusa Purple Long	S	0.270	0.266	0.274	0.281	0.292	0.286
CD (0.05)		0.018		0.015		NS	
Chilli							
C1 Ujwala	R	0.133	0.402	0.173	0.190	0.215	0.249
C2 Manjari	MR	0.126	0.160	0.104	0.167	0.182	0.192
C3 Jwalasakhi	MS	0.267	0.284	0.278	0.271	0.295	0.269
C4 Pusa Jwala	S	0.171	0.257	0.120	0.284	0.197	0.205
CD (0.05)		0.042		0.127		0.027	

Mean of four replications

R - Resistant MR - Moderately resistant

S - Susceptible MS - Moderately susceptible NS - Not significant

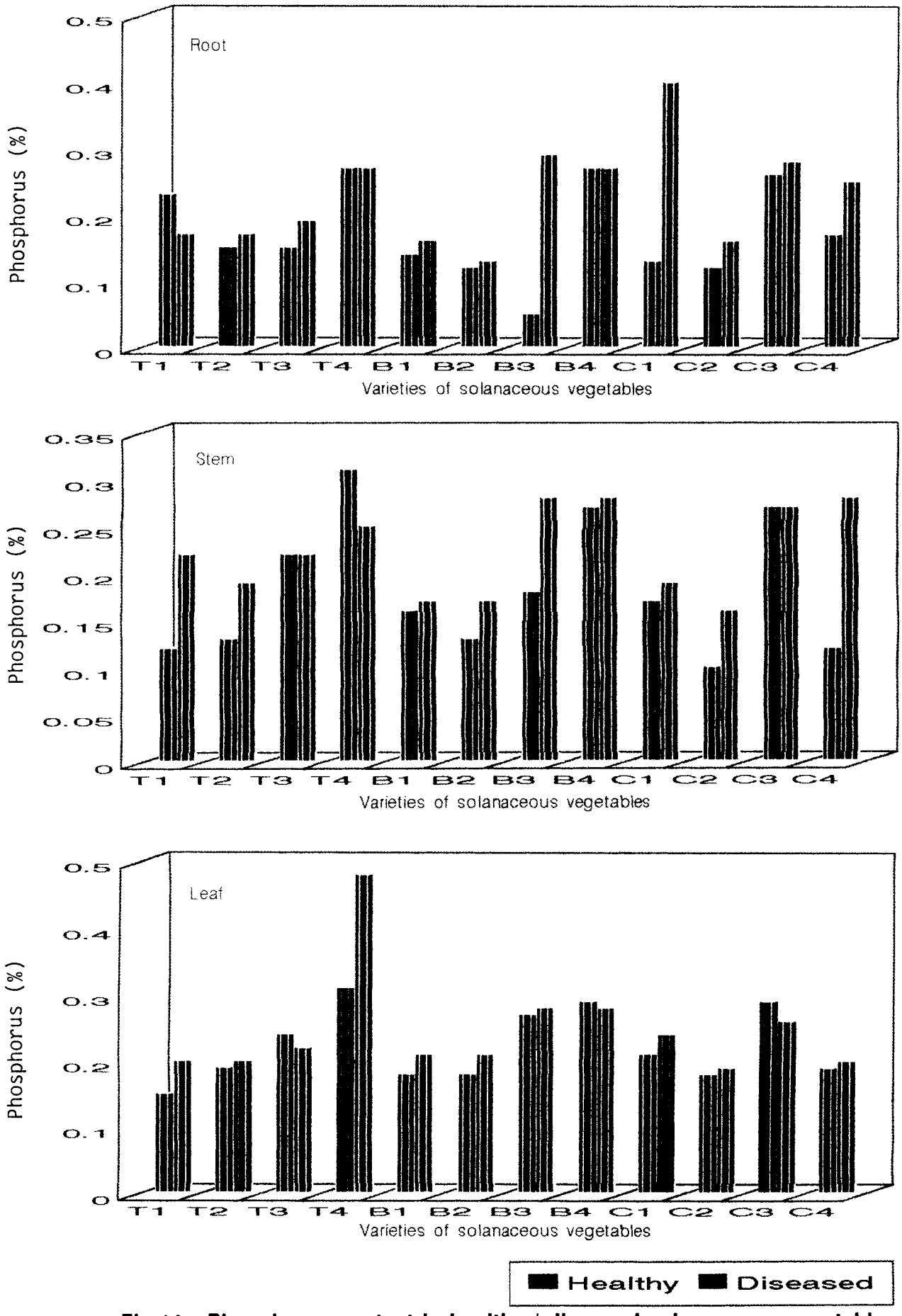


Fig.16. Phosphorus content in healthy / diseased solanaceous vegetables

(MS) and this variety gave the highest phosphorus percent under diseased condition. In the stem also the phosphorus content increased in all the varieties/lines due to infection. The phosphorus content was highest in Pusa Purple Long (S) under healthy condition and in BB-7 (MS) under diseased condition. The leaf of all the varieties/lines of brinjal except Pusa Purple Long (S) showed an increase in phosphorus content due to infection. It was maximum in Pusa Purple Long (S) both under healthy as well as under diseased condition.

In chilli root, the phosphorus content increased in all varieties/lines due to infection. The phosphorus content was highest in Jwalasakhi (MS) and lowest in Manjari (MR) under healthy condition and the maximum content after infection was noticed in Ujwala (R). In stem the phosphorus content increased in all the varieties/lines except in Jwalasakhi (MS) where highest content among healthy plants was noticed. The rate of increase was significantly highest in Pusa Jwala (S) which also recorded the highest phosphorus content under diseased condition. In the leaf the increase in phosphorus content due to infection was observed in all the varieties/lines except in Jwalasakhi (MS). The phosphorus content was highest in Jwalasakhi (MS) both under healthy as well as under diseased condition.

4.9.3. Potassium

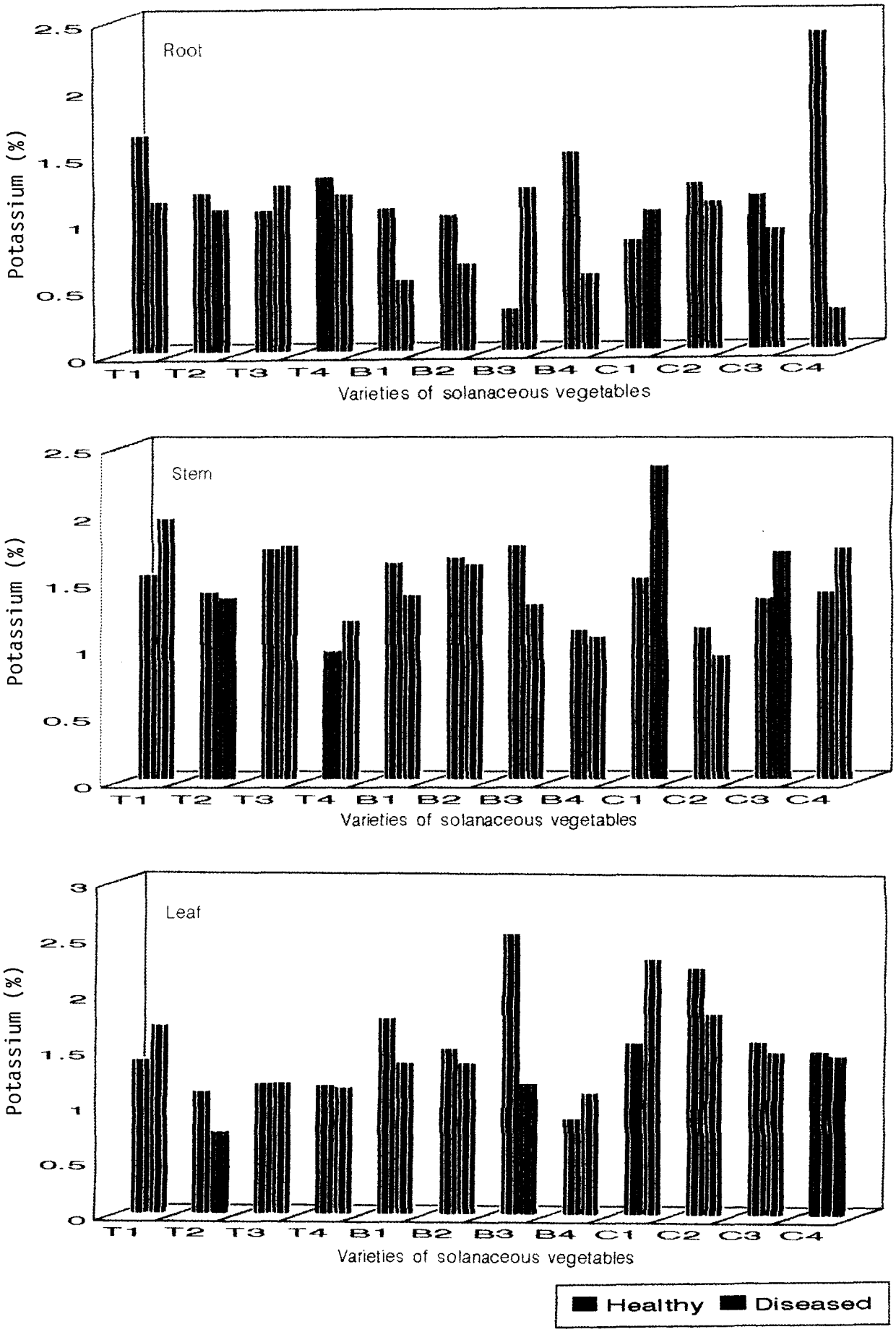
In tomato root, the potassium content decreased significantly due to infection by *R. solanacearum* in all varieties/lines except in LE 470 (MS), where it increased (Table. 31 and Fig. 17). Under healthy condition LE 79-5 (R) recorded significantly highest potassium content and LE 470 (MS) the lowest whereas under diseased condition LE 470 (MS) recorded the highest potassium content. In the stem the potassium content increased in all the varieties/lines except BT-10 (MR) due to infection. The potassium content was highest in LE 470 (MS) under healthy condition and in LE 79-5 (R) under diseased condition. In the leaf the potassium content increased due to infection in LE 79-5 (R) and LE 470 (MS). Significant increase in potassium content was observed in LE 79-5 (R) between healthy and diseased condition. The potassium content was highest in LE 79-5 (R) both under healthy and diseased condition.

In brinjal root the potassium content decreased due to infection in all varieties/lines except in BB-7 (MS). The potassium content was maximum in Pusa Purple Long (S) and minimum in BB-7 (MS) under healthy condition. Under diseased condition the potassium content was highest in BB-7 (MS) and lowest in Swetha (R). In the stem also the potassium content decreased significantly in all the varieties/lines upon infection except in Pusa

Table. 31 Comparison of potassium content in bracterial wilt resistant and susceptible varieties / lines of tomato, brinjal and chilli under healthy and diseased condition (in percentage)

Varieties / lines	Disease reaction	Root		Stem		Leaf	
		Healthy	Diseased	Healthy	Diseased	Healthy	Diseased
Tomato							
T1 LE 79-5	R	1.640	1.140	1.540	1.960	1.400	1.710
T2 BT-10	MR	1.200	1.080	1.410	1.370	1.120	0.750
T3 LE 470	MS	1.070	1.260	1.730	1.760	1.190	1.200
T4 Pusa Ruby	S	1.320	1.190	0.970	1.200	1.180	1.1620
CD (0.05)		0.094		NS		0.237	
Brinjal							
B1 Swetha	R	1.080	0.540	1.630	1.390	1.780	1.380
B2 Composite-2	MR	1.030	0.660	1.670	1.620	1.510	1.380
B3 BB7	MS	0.320	1.230	1.760	1.320	2.540	1.200
B4 Pusa Purple Long	S	1.505	0.580	1.130	1.080	0.880	1.120
CD (0.05)		NS		NS		0.495	
Chilli							
C1 Ujwala	R	0.830	1.060	1.520	2.360	1.570	2.320
C2 Manjari	MR	1.263	1.120	1.150	0.940	2.240	1.830
C3 Jwalasakhi	MS	1.170	0.910	1.370	1.720	1.580	1.490
C4 Pusa Jwala	S	2.380	0.310	1.420	1.750	1.500	1.460
CD (0.05)		0.292		0.235		0.198	

Mean of four replications
R - Resistant MR - Moderately resistant
S - Susceptible MS - Moderately susceptible NS - Not significant



Fig, 17. Potassium content in healthy / diseased solanaceous vegetables

Purple Long (S). It was highest in BB-7 (MS) among healthy plants and among diseased plants it was highest in Composite-2 (MR). In leaf also the potassium content decreased due to infection in all varieties/lines except in Pusa Purple Long (S). The potassium content was highest in BB-7 (MS) and it reduced significantly upon infection. Under diseased condition the potassium content was highest in the resistant varieties/lines.

In chilli root the potassium content decreased in all the varieties/lines except in Ujwala (R) upon infection. The increase in potassium content in the resistant variety due to infection was not significant. The potassium content in Pusa Jwala (S) was highest under healthy condition and lowest under diseased condition. Under diseased condition it was highest in resistant varieties/lines. In the stem the potassium content significantly increased in all varieties/lines due to infection except in Manjari (MR) where a decrease was noticed. The highest potassium content was noticed in Ujwala (R) both under healthy and diseased condition. In the leaf the potassium content decreased in all varieties/ lines upon infection except in Ujwala (R) where a significant increase was noticed. The highest potassium content was noticed in Manjari (MR) under healthy condition and in Ujwala (R) under diseased condition. The rate of decrease was highest in Manjari (MR) when compared to Jwalasakhi (MS) and Pusa Jwala (S).

4.9.4. Calcium

In tomato root, the calcium content decreased significantly upon infection in all the varieties/lines (Table. 32 and Fig. 18). The highest calcium content was recorded in BT-10 (MR) both under healthy as well as in the diseased condition. In the stem the calcium content increased due to infection in all the varieties/lines significantly except in LE 79-5 (R). In the variety, LE 79-5 (R) it was significantly highest under healthy condition and decreased due to infection. The rate of increase in calcium content was highest in Pusa Ruby (S) and lowest in BT-10 (MR). Under diseased condition Pusa Ruby (S) recorded highest calcium content. In the leaf the calcium content decreased upon infection in all varieties/lines except in LE 470 (MS). The calcium content in the leaf was highest in LE 79-5 (R) and decreased due to infection. The calcium content was lowest in Pusa Ruby (S) both under healthy and diseased condition. Under diseased condition LE470 (MS) recorded maximum calcium content.

In brinjal root the resistant genotype recorded a decrease in calcium content, while the susceptible group showed an increase in calcium content upon infection. The calcium content was highest in Swetha (R) among healthy plants and among diseased plants it was

Table. 32 Comparison of calcium content in bacterial wilt resistant and susceptible varieties / lines of tomato, brinjal and chilli under healthy and diseased condition (in percentage)

Varieties / lines	Disease reaction	Root		Stem		Leaf	
		Healthy	Diseased	Healthy	Diseased	Healthy	Diseased
Tomato							
T1 LE 79-5	R	0.225	0.186	0.906	0.715	2.594	1.576
T2 BT-10	MR	0.495	0.424	0.715	0.929	1.839	1.744
T3 LE 470	MS	0.391	0.307	0.388	0.827	2.400	2.439
T4 Pusa Ruby	S	0.388	0.309	0.491	1.280	1.156	0.745
CD (0.05)		NS		0.038		0.144	
Brinjal							
B1 Swetha	R	0.870	0.420	0.843	0.904	0.994	1.028
B2 Composite-2	MR	0.535	0.320	0.975	0.792	1.062	0.654
B3 BB7	MS	0.374	0.414	0.877	0.415	2.139	1.019
B4 Pusa Purple Long	S	0.600	0.641	0.812	0.748	1.202	1.396
CD (0.05)		0.029		0.030		0.056	
Chilli							
C1 Ujwala	R	0.286	0.256	0.239	0.197	0.685	0.418
C2 Manjari	MR	0.894	0.503	0.449	0.428	0.872	0.769
C3 Jwalasakhi	MS	0.308	0.373	0.215	0.234	0.691	0.712
C4 Pusa Jwala	S	0.699	0.218	0.174	0.302	0.405	0.748
CD (0.05)		0.059		0.020		0.031	

Mean of four replications

R - Resistant MR - Moderately resistant

S - Susceptible MS - Moderately susceptible NS - Not significant

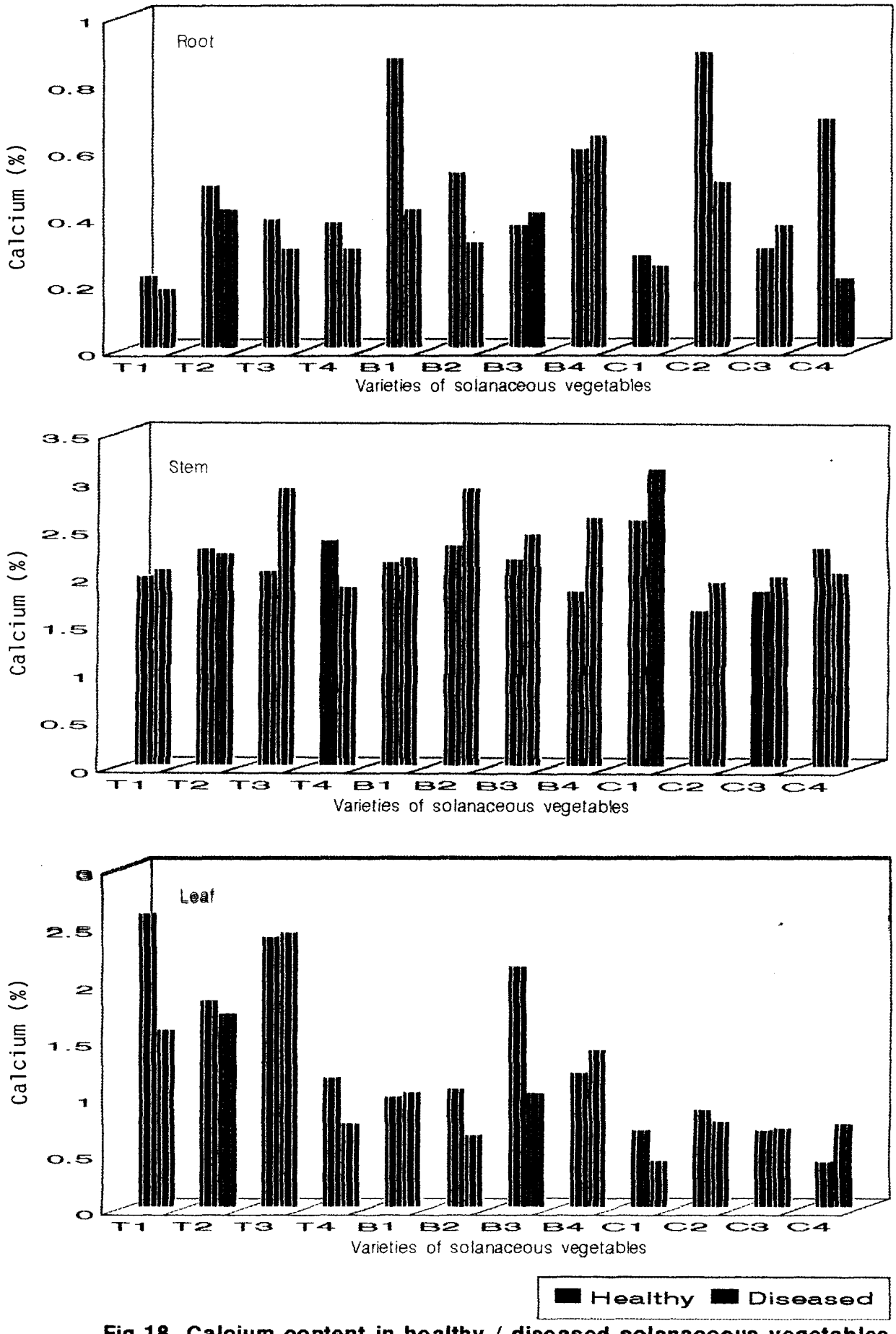


Fig.18. Calcium content in healthy / diseased solanaceous vegetables

highest in Pusa Purple Long (S). In stem, unlike in tomato the calcium content decreased significantly in all the varieties/lines upon infection except in Swetha (R). The calcium content was highest in Composite-2 (MR) under healthy condition and in Swetha (R) under diseased condition. The rate of decrease in calcium content was highest in BB-7 (MS). In the case of leaf the calcium content increased due to infection in Swetha (R) and Pusa Purple Long (S). The calcium content was maximum in BB-7 (MS) leaf and minimum in Swetha (R) under healthy condition. Under diseased condition it was highest in Pusa Purple Long (S).

In chilli root the calcium content decreased due to infection in all varieties/lines except in Jwalasakhi (MS). The calcium content was highest in Manjari(MR) both under healthy as well as under diseased condition. In stem the resistant genotype showed a decrease in calcium content due to infection and the susceptible genotype showed an increase. It was highest in Manjari (MR) both under healthy and diseased condition. In leaf also the same trend was noticed, the resistant genotype showed a decrease in calcium content, while the susceptible ones showed an increase due to infection. The calcium content was highest in Manjari (MR) both under healthy as well as under diseased condition.

4.9.5. **Magnesium**

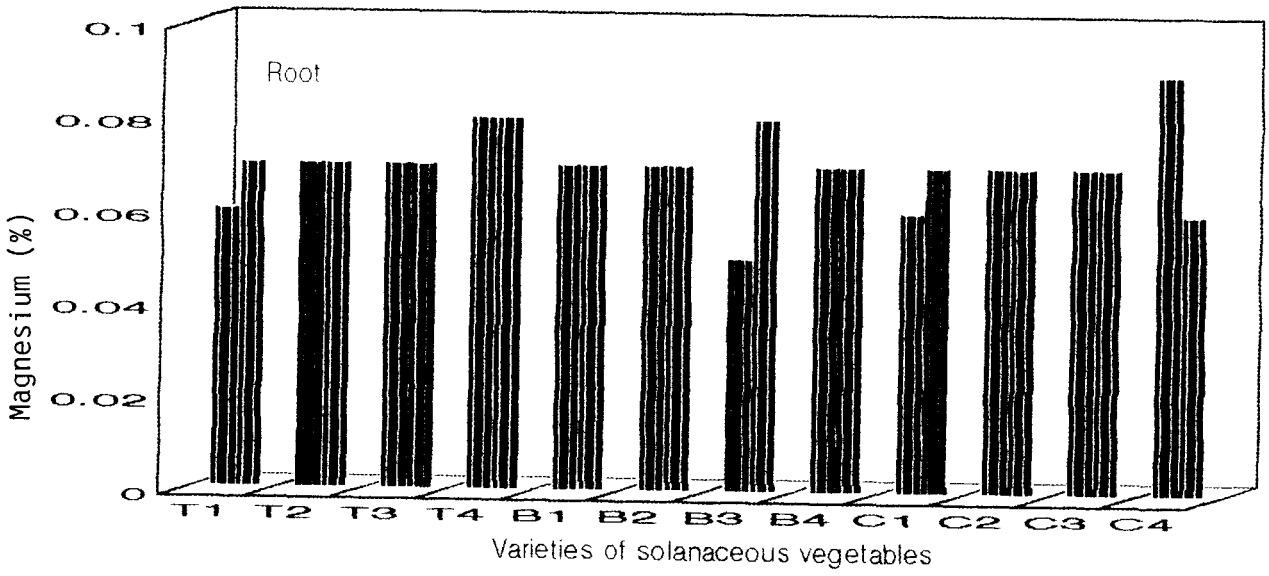
In tomato root, the magnesium content did not show any significant difference between varieties/lines or between healthy as well as diseased condition (Table. 33 and Fig. 19). However the maximum magnesium content was recorded in Pusa Ruby (S) both under healthy and diseased condition. In the stem significant increase in magnesium content was noticed in LE 79-5 (R) and Pusa Ruby (S) upon infection. In other two varieties the magnesium content decreased due to infection. In leaf the magnesium content decreased in all the varieties/lines except in LE 79-5 (R) where a slight increase was noticed. The magnesium content was highest in LE 79-5 (R) both under healthy as well as under diseased condition.

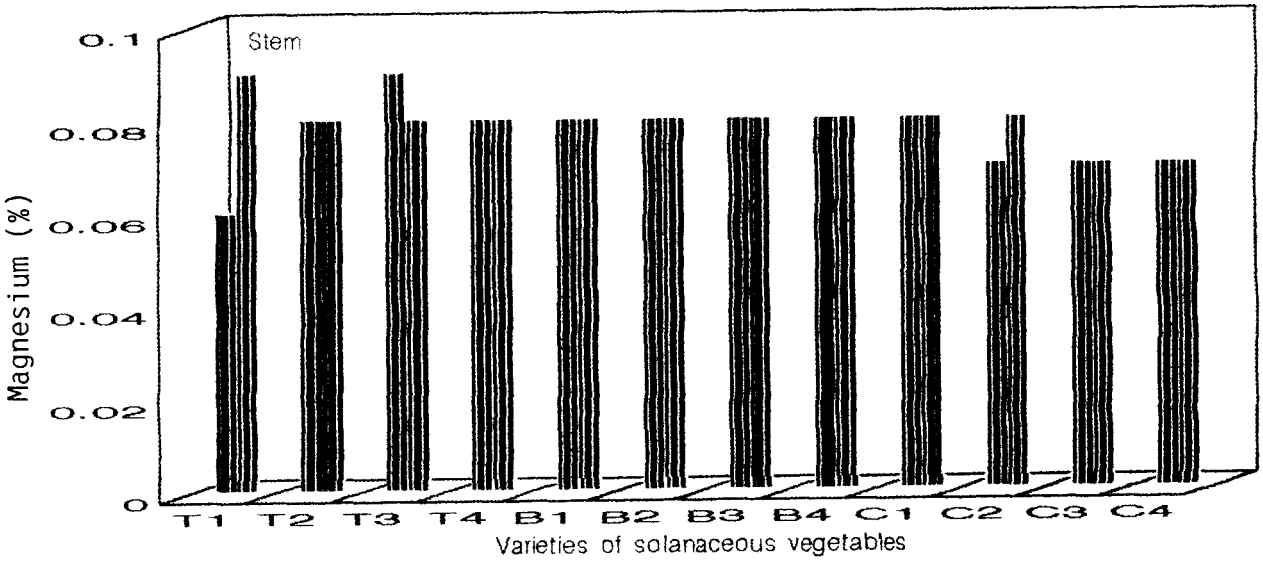
In brinjal root the resistant genotype showed a decrease in magnesium content while the susceptible genotype showed an increase due to infection. The magnesium content was highest in Swetha (R) and lowest in BB-7 (MS) under healthy condition. Under diseased condition, the magnesium content was maximum in BB-7 (MS) and minimum in Composite-2 (MR). In stem the magnesium content decreased significantly due to infection in Composite-2 (MR) and BB-7 (MS). In Swetha (R) and Pusa Purple Long (S) the magnesium content increased due to

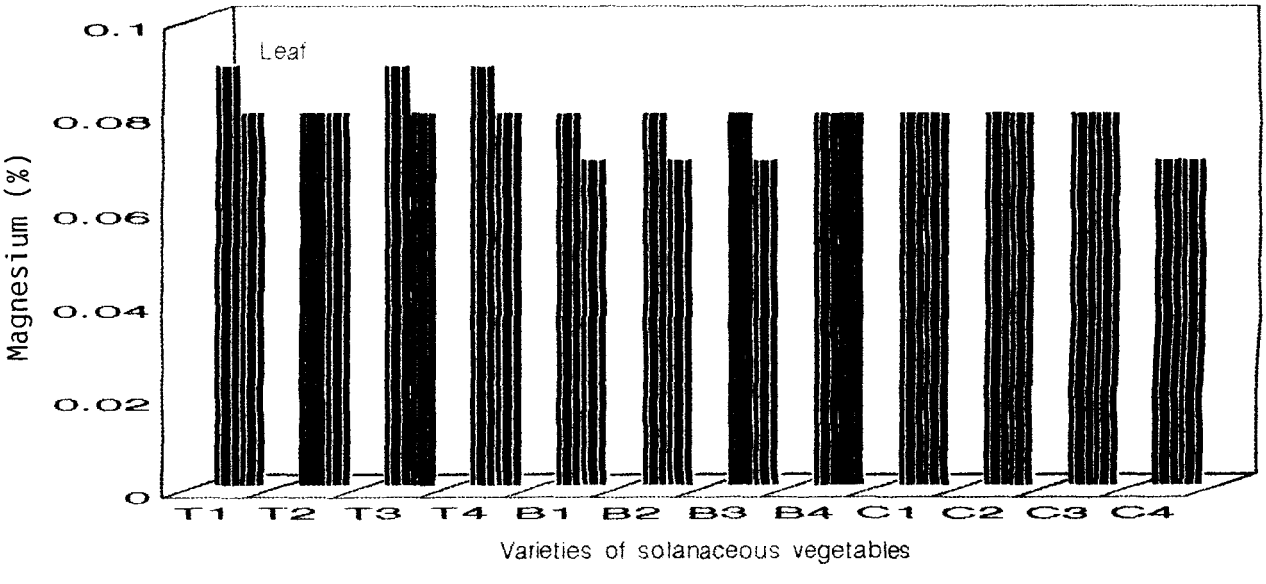
Table. 33 Comparison of magnesium content in bacterial wilt resistant and susceptible varieties / lines of tomato, brinjal and chilli under healthy and diseased condition (in percentage)

Varieties / lines	Disease reaction	Root		Stem		Leaf	
		Healthy	Diseased	Healthy	Diseased	Healthy	Diseased
Tomato							
T1 LE 79-5	R	0.064	0.070	0.062	0.085	0.086	0.087
T2 BT-10	MR	0.073	0.072	0.083	0.078	0.084	0.083
T3 LE 470	MS	0.071	0.070	0.086	0.082	0.086	0.086
T4 Pusa Ruby	S	0.080	0.078	0.077	0.086	0.085	0.083
CD (0.05)		NS		0.004		0.001	
Brinjal							
B1 Swetha	R	0.073	0.072	0.080	0.081	0.077	0.079
B2 Composite-2	MR	0.070	0.066	0.084	0.080	0.082	0.077
B3 BB7	MS	0.052	0.076	0.082	0.078	0.084	0.078
B4 Pusa Purple Long	S	0.067	0.072	0.079	0.080	0.080	0.082
CD (0.05)		0.001		0.002		0.002	
Chilli							
C1 Ujwala	R	0.062	0.072	0.081	0.078	0.084	0.082
C2 Manjari	MR	0.069	0.066	0.068	0.070	0.083	0.082
C3 Jwalasakhi	MS	0.067	0.066	0.071	0.068	0.081	0.082
C4 Pusa Jwala	S	0.085	0.056	0.073	0.071	0.079	0.077
CD (0.05)		0.002		0.001		NS	

Mean of four replications
R - Resistant MR - Moderately resistant
S - Susceptible MS - Moderately susceptible NS - Not significant







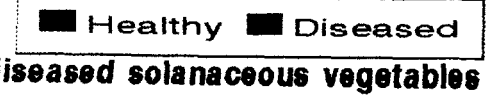


Fig.19. Magnesium content in healthy / diseased solanaceous vegetables

infection. The magnesium content was highest in Composite-2 (MR) and lowest in Pusa Purple Long (S) under healthy condition. Under diseased condition Swetha (R) gave highest content. In leaf also there was an increase in magnesium content upon infection in Swetha (R) and Pusa Purple Long (S). In composite-2 (MR) and BB-7 (MS), the magnesium content decreased due to infection. It was maximum in BB7 (MS) under healthy condition and in Pusa Purple Long (S) under diseased condition.

In chilli root, the magnesium content decreased due to infection in all varieties/lines except in Ujwala (R). The magnesium content was highest in Pusa Jwala (S) under healthy condition and was in Ujwala (R) under diseased condition. In stem the magnesium content decreased due to infection in all varieties/lines except in Manjari (MR) where a slight increase was noticed. The magnesium content was highest in Ujwala (R) both under healthy and diseased condition. In the leaf significant difference was not obtained between varieties/lines and between healthy and diseased condition. However the magnesium content decreased due to infection in all varieties/lines except in Jwalasakhi (MS). It was highest in Ujwala (R) both under healthy and diseased condition.

4.9.6. **Iron**

In tomato root the iron content increased in all the varieties/lines except in Pusa Ruby (S) (Table.34 and Fig. 20). The highest iron content was noticed in Pusa Ruby (S) and lowest in BT-10 (MR) under healthy condition. But among diseased plants BT-10 (MR) recorded maximum and Pusa Ruby (S) recorded minimum iron in the root. In the stem, the iron content increased in all the varieties/lines except in Pusa Ruby (S). Here also the highest iron content was recorded in Pusa Ruby (S) under healthy condition which decreased under diseased condition. The iron content was lowest in LE 79-5 (R) under healthy condition but it increased by 16 fold as a result of infection. In BT-10 (MR), the rate of increase was two fold and recorded the highest iron content under diseased condition. Unlike in root and stem, in leaf the iron content increased significantly in all the varieties/lines due to infection. Highest iron content was noticed in LE 79-5 (R) both under healthy and diseased condition. Lowest content was recorded in Pusa Ruby (S) both under healthy and diseased condition.

In brinjal root, the iron content increased in LE 79-5 (R) and BB-7 (MS) and decreased in Composite-2 (MR) and Pusa Purple Long (S) upon infection. Highest iron content was recorded in Composite-2 (MR) and lowest in Swetha (R) under healthy condition. But the rate of

Table. 34 Comparison of iron content in bacterial wilt resistant and susceptible varieties / lines of tomato, brinjal and chilli under healthy and diseased condition (in percentage)

Varieties / lines	Disease reaction	Root		Stem		Leaf	
		Healthy	Diseased	Healthy	Diseased	Healthy	Diseased
Tomato							
T1 LE 79-5	R	0.226	0.241	0.0113	0.201	0.463	0.620
T2 BT-10	MR	0.115	0.403	0.085	0.323	0.366	0.605
T3 LE 470	MS	0.358	0.374	0.144	0.159	0.344	0.557
T4 Pusa Ruby	S	0.558	0.161	0.320	0.146	0.245	0.301
CD (0.05)		0.012		0.010		0.011	
Brinjal							
B1 Swetha	R	0.059	0.944	0.046	0.109	0.388	1.252
B2 Composite-2	MR	0.259	0.133	0.218	0.200	0.285	0.169
B3 BB7	MS	0.092	0.208	0.072	0.183	0.190	0.640
B4 Pusa Purple Long	S	0.172	0.116	0.064	0.058	0.139	0.178
CD (0.05)		0.019		0.005		0.011	
Chilli							
C1 Ujwala	R	0.199	0.126	0.069	0.059	0.114	0.148
C2 Manjari	MR	0.435	1.169	0.093	0.086	0.122	0.123
C3 Jwalasakhi	MS	0.183	0.296	0.096	0.071	0.085	0.060
C4 Pusa Jwala	S	0.078	0.240	0.056	0.081	0.114	0.233
CD (0.05)		0.016		NS		0.029	

Mean of four replications
R - Resistant MR - Moderately resistant
S - Susceptible MS - Moderately susceptible NS - Not significant

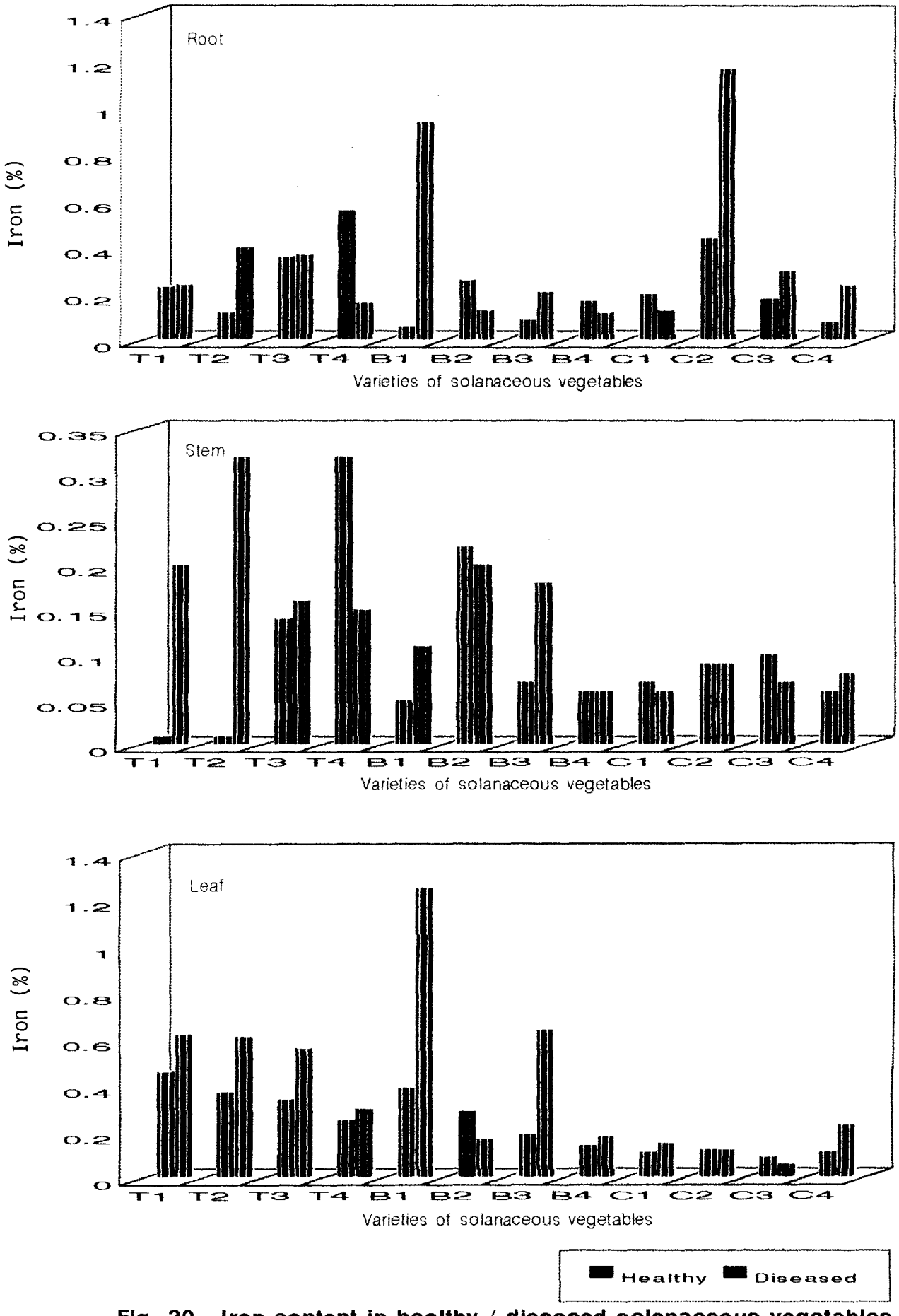


Fig. 20. Iron content in healthy / diseased solanaceous vegetables

increase in iron content was highest (15 fold) in Swetha (R), which gave highest upon diseased condition. It was lowest in Pusa Purple Long (S) under diseased condition. In stem also a similar trend was noticed, an increase in iron content in Swetha (R) and BB-7 (MS) and a decrease in Composite-2 (MR) and Pusa Purple Long (S). The iron content was highest in Composite-2 (MR) both under healthy and diseased condition. It was lowest in Pusa purple long (S) under diseased condition. In leaf, the iron content increased in all the varieties/lines significantly except in Composite-2 (MR) where a decrease was noticed due to infection. The iron content was highest in Swetha (R) both under healthy and diseased condition. The rate of increase in iron content was highest in BB-7 (MS) and minimum in Pusa Purple Long (S).

In chilli root, the iron content increased in all the varieties/lines except in Ujwala (R). The iron content was highest in Manjari (MR) in healthy and diseased condition. Lowest iron content was noticed in Pusa Jwala (S). In the stem the iron content decreased in all the varieties/lines except Pusa Jwala (S) where an increase was noticed. The iron content was highest in Jwalasakhi (MS) among healthy plants and in Manjari (MR) among diseased plants. In the leaf the iron content increased in all the varieties/lines except in Jwalasakhi (MS) due to infection. It was highest in Manjari (MR) under diseased condition.

4.9.7. Zinc

In tomato root the zinc content increased significantly in LE 79-5 (R) and LE 470 (MS) and decreased in BT-10 (MR) and Pusa Ruby (S) upon infection (Table.35 and Fig. 21). The zinc content was highest in LE 470 (MS) in both healthy and diseased condition. In stem the zinc content increased significantly in all the varieties/lines and was maximum in LE 470 (MS) and minimum in Pusa Ruby (S) under healthy condition. It was highest in BT-10 (MR) and lowest in Pusa Ruby (S) under diseased condition. In leaf the zinc content decreased in all the varieties/lines except in LE 79-5 (R), which recorded an increase due to infection. The zinc content was highest in LE 79-5 (R) and lowest in Pusa Ruby(S) both under healthy and diseased condition.

In brinjal root the zinc content decreased in Swetha (R) and Pusa Purple Long (S), and increased in Composite-2 (MR) and BB-7 (MS) due to infection. The zinc content was highest in Swetha (R) under healthy condition and in Composite-2 (MR) under diseased condition. In the stem the resistant genotypes showed an increase in zinc content and the susceptible ones showed a decrease. The zinc content was maximum in Swetha (R) both under healthy and diseased condition. In leaf the zinc content

Table. 35 Comparison of zinc content in bacterial wilt resistant and susceptible varieties / lines of tomato, brinjal and chilli under healthy and diseased condition (in $\mu g g^{-1}$ of sample)

Varieties / lines	Disease reaction	Root		Stem		Leaf	
		Healthy	Diseased	Healthy	Diseased	Healthy	Diseased
Tomato							
T1 LE 79-5	R	66.500	83.900	58.800	76.600	37.400	50.700
T2 BT-10	MR	82.900	82.800	68.400	87.400	37.000	34.600
T3 LE 470	MS	83.500	89.300	81.700	83.600	33.900	33.700
T4 Pusa Ruby		80.200	49.200	51.200	66.600	30.600	27.900
CD (0.05)		5.110		9.500		2.472	
Brinjal							
B1 Swetha	R	113.700	72.000	80.330	96.300	38.400	45.300
B2 Composite-2	MR	65.800	114.900	52.600	80.200	28.800	28.600
B3 BB7	MS	77.200	88.400	65.400	44.200	32.100	36.600
B4 Pusa Purple Long	S	82.000	58.400	64.600	51.000	22.300	33.900
CD (0.05)		NS		3.978		3.394	
Chilli							
C1 Ujwala	R	28.200	44.600	41.200	40.200	56.900	41.200
C2 Manjari	MR	33.600	22.400	37.000	12.100	70.200	61.900
C3 Jwalasakhi	MS	26.800	33.300	32.600	22.400	45.300	51.300
C4 Pusa Jwala	S	64.100	22.600	37.300	36.900	66.900	59.700
CD (0.05)		6.076		3.340		2.891	

Mean of four replications

R - Resistant MR - Moderately resistant

S - Susceptible MS - Moderately susceptible NS - Not significant

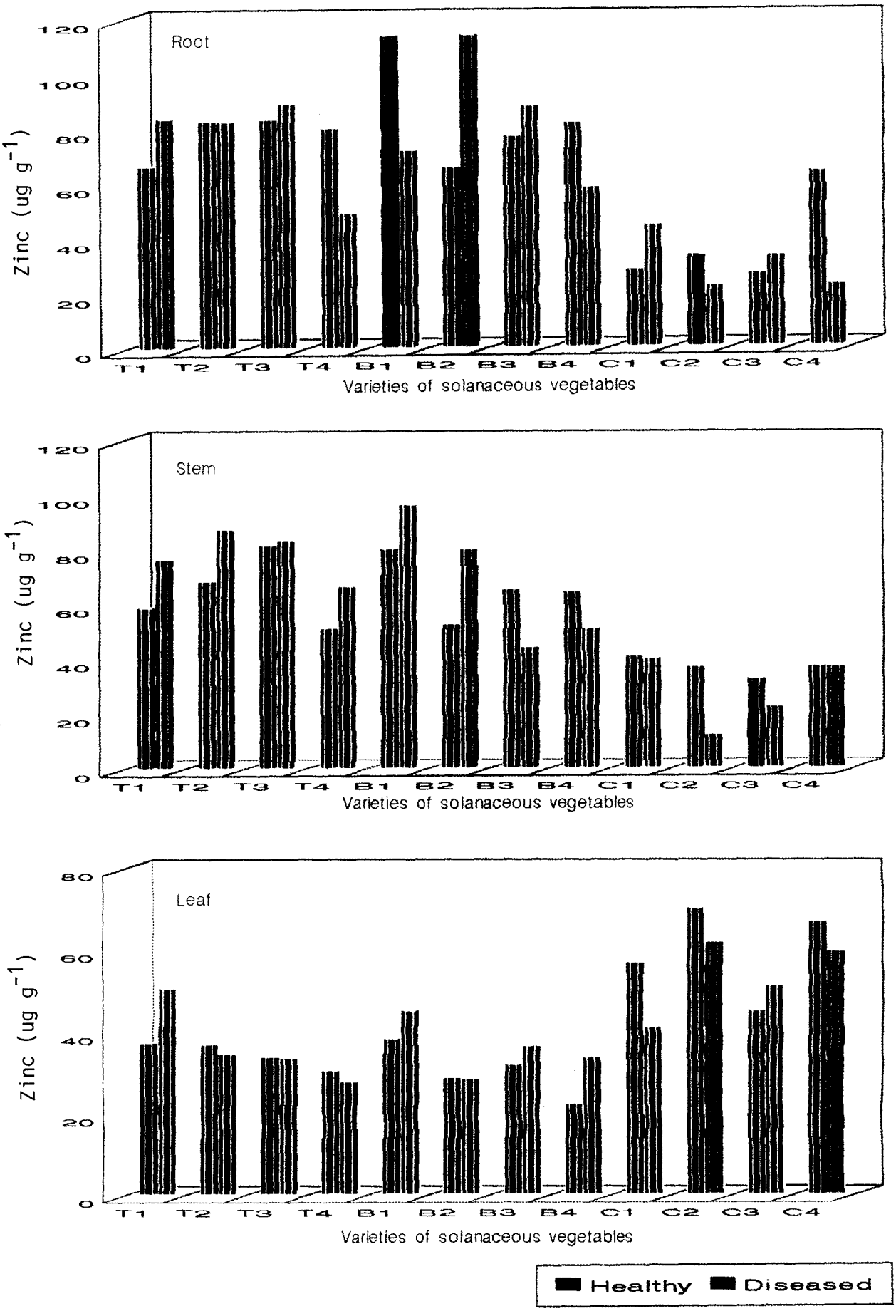


Fig.21. Zinc content in healthy / diseased solanaceous vegetables

significantly increased in all the varieties/lines except in Composite-2 (MR) which showed a slight decrease due to infection. The zinc content was highest in Swetha (R) both under healthy and diseased condition. Pusa Purple Long (S) recorded the lowest zinc content among healthy plants and Composite-2 (MR) among diseased plants.

In chilli root zinc content significantly increased in Ujwala (R) and Jwalasakhi (MS) and decreased in Manjari (MR) and Pusa Jwala (S). The variety, Pusa Jwala (S) recorded the highest zinc content among healthy plants and Ujwala (R) among diseased plants. In stem the zinc content decreased in all varieties/lines due to infection. The zinc content was highest in Ujwala (R) both under healthy and diseased condition. In leaf the zinc content significantly decreased in all varieties/lines except in Jwalasakhi (MS) which recorded an increase upon infection. The zinc content was highest in Manjari (MR) both under healthy and diseased condition.

4.9.8. Manganese

In tomato root the manganese content increased in all the varieties/lines upon infection (Table. 36 and Fig. 22). The manganese content was highest in LE 470 (MS) both under healthy and diseased condition. But the highest

Table. 36 Comparison of manganese content in bacterial wilt resistant and susceptible varieties / lines of tomato, brinjal and chilli under healthy and diseased conditions (in $\mu g g^{-1}$ of sample)

Varieties / lines	Disease reaction	Root		Stem		Leaf	
		Healthy	Diseased	Healthy	Diseased	Healthy	Diseased
Tomato							
T1 LE 79-5	R	75.900	306.400	332.900	370.500	632.300	931.200
T2 BT-10	MR	165.750	191.700	183.700	557.800	400.300	1122.000
T3 LE 470	MS	507.900	629.600	417.700	591.400	1024.900	1126.600
T4 Pusa Ruby	S	170.100	182.200	411.00	173.900	1108.200	1117.000
CD (0.05)		39.914		13.172		44.329	
Brinjal							
B1 Swetha	R	177.900	184.100	305.800	310.100	372.300	597.000
B2 Composite-2	MR	385.700	262.700	750.300	659.600	917.800	557.700
B3 BB7	MS	134.400	668.400	436.300	172.500	793.200	365.700
B4 Pusa Purple Long	S	305.300	231.100	697.700	374.700	680.900	539.080
CD (0.05)		12.270		16.940		6.156	
Chilli							
C1 Ujwala	R	444.200	147.600	117.900	188.800	177.000	295.100
C2 Manjari	MR	556.100	276.600	642.000	266.200	888.300	580.800
C3 Jwalasakhi	MS	490.500	514.100	737.800	611.000	1021.100	1468.300
C4 Pusa Jwala	S	258.900	213.500	148.100	387.550	1206.20	830.000
CD (0.05)		13.996		13.968		24.631	

Mean of four replications

R - Resistant MR - Moderately resistant

S - Susceptible MS - Moderately susceptible

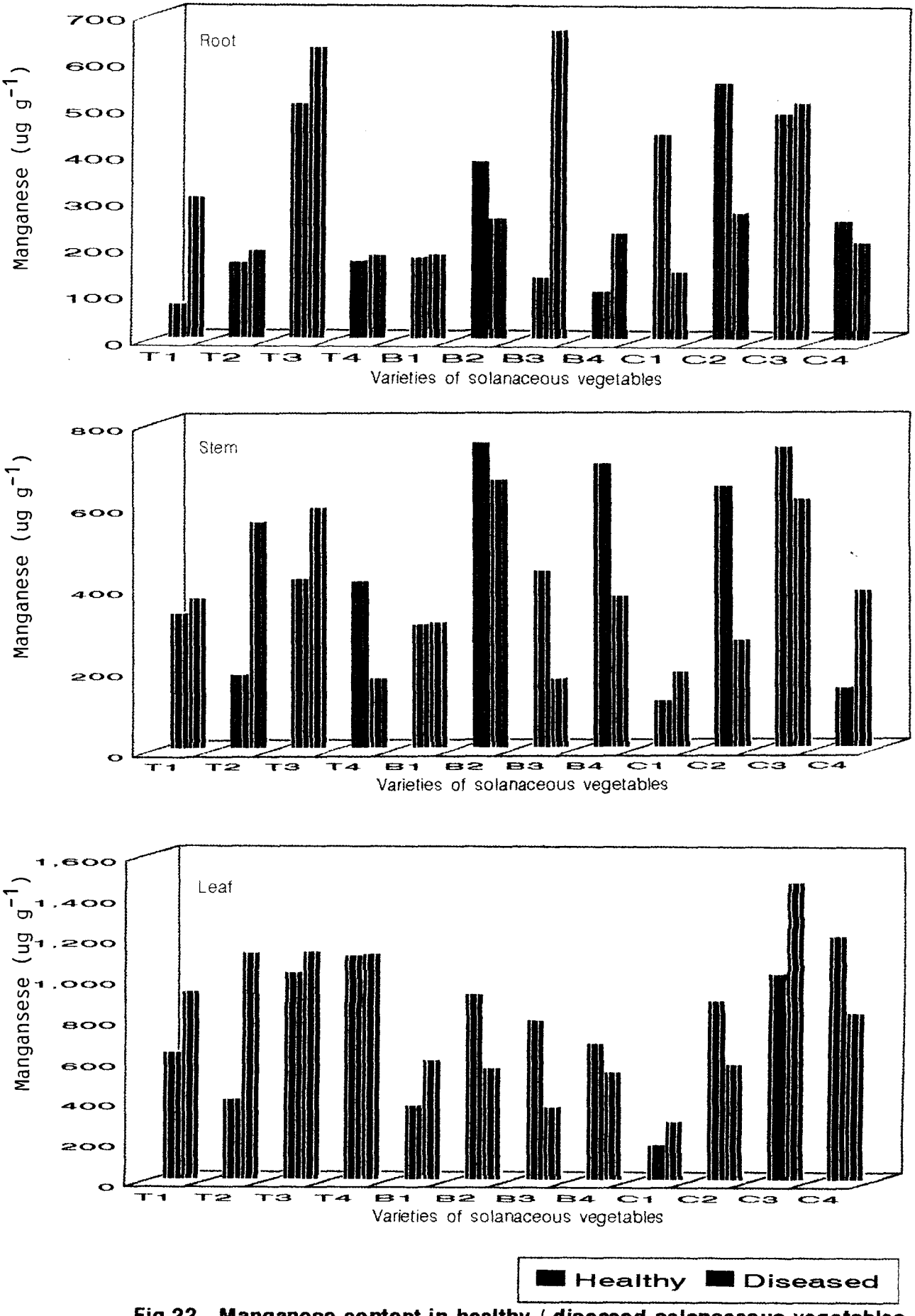


Fig.22. Manganese content in healthy / diseased solanaceous vegetables

rate of increase was noticed LE 79-5 (R), (3 fold). In stem the manganese content increased in all varieties/lines except in Pusa Ruby (S) due to infection. The manganese content was highest in LE 470 (MS) both under healthy and diseased condition. But the rate of increase was highest (two fold) in BT-10 (MR). In Pusa Jwala (S) it decreased due to infection. In leaf the manganese content increased in all the varieties/lines upon infection. The manganese content was more in the susceptible genotypes both under healthy and diseased condition when compared to be resistant ones. The manganese content was highest in Pusa Ruby (S) under healthy and in LE 470(MS) under diseased condition.

In brinjal root, the manganese content increased in Swetha (R) and BB-7 (MS) and decreased in Composite-2 (MR) and Pusa Purple Long (S) due to infection. The manganese content was highest in Composite-2 (MR) under healthy condition and in BB-7 (MS) under diseased condition. In stem , the manganese content decreased significantly in all the varieties/lines except in Swetha (R), where an increase was noticed due to infection. The highest manganese content was recorded in Composite-2 (MR) both under healthy and diseased condition. In the leaf also the manganese content significantly increased in Swetha(R), and decreased in all other varieties/lines upon infection. The

manganese content was highest in Composite-2 (MR) under healthy condition and in Swetha (R) under diseased condition.

In chilli root, the manganese content decreased in all the varieties/lines except in Jwalasakhi (MS) upon infection. The manganese content was highest in Manjari (MR) among healthy plants and in Jwalasakhi (MS) among diseased plants. In stem an increase in manganese content was recorded in Ujwala (R) and Pusa Jwala (S) and decrease in Manjari (MR) and Jwalasakhi (MS) upon infection. The manganese content was highest in Jwalasakhi (MS) both under healthy and diseased condition. In the leaf the manganese content increased significantly Ujwala (R) and Jwalasakhi (MS) and decreased in Manjari (MR) and Pusa Jwala (S) upon infection. The manganese content was highest in Pusa Jwala (S) under healthy condition and in Jwalasakhi (MS) under diseased condition.

Discussion

DISCUSSION

In the tropical countries, bacterial wilt incited by *Ralstonia solanacerum* is the major constraint in the cultivation of solanaceous vegetables. In Kerala tomato, brinjal and chilli are the important solanaceous vegetables, which are heavily infected by the bacterial wilt pathogen. This bacteria is a fastidious soil borne organism with lot of pathogenic potential to infect the most important solanaceous vegetables. So the bacterial wilt has become a perennial problem for the cultivation of solanaceous vegetables in Kerala. Ever since its description in 1896 by Erwin F. Smith, various studies have been conducted by so many workers all over the world to contain and manage the disease. In this context host resistance is one of the most important approaches for management of any disease. Numerous studies have been conducted by various workers in this direction with less success. This might have been possibly due to the pathogenic variability, peculiarities of geographical areas, variations in agroclimatic conditions, instability of host resistance and lack of proper understanding of the mechanism of resistance.

In view of this situation, the present study was undertaken to understand the biochemical, biological and nutritional factors underlying the bases of resistance in tomato, brinjal and chilli, and to have a comparative picture of the bases of resistance in these plants.

The pathogen from different crops also were isolated and compared for any possible variations. A total number of forty three varieties / lines each of the above crops were screened in a wilt sick plot and were classified. The plants have been grouped into categories namely resistant, moderately resistant, moderately susceptible and susceptible based on the categorisation by Mew and Ho (1976).

The results of the studies on isolation, purification and characterisation of the pathogen *R. solanacearum* from tomato, brinjal and chilli showed that slight variations exist between the isolates in cultural and morphological characters. The slime production and fluidity were more in brinjal and tomato isolates and hence can be considered as more virulent than chilli isolate. This was corroborated with the findings of Husain and Kelman (1958). There were slight variations in the biochemical and physiological properties of the isolates

like production of hydrogen sulphide, production of levan, arginine hydrolase activity, urease activity and fermentation of carbohydrates. In most of the characters tested, the isolates behaved almost alike and such variations in different characteristics of the pathogen from different hosts have been already reported by many workers and such slight variations do occur in these type of studies. For example Samuel (1980) reported positive reaction of arginine hydrolase and urease activity while Nayar (1982) and Jyothi (1992) reported negative activity of arginine hydrolase. It seems likely that uniformity in the properties may not be possible, as there will be variations in the isolates studied and the conditions of the study. Based on the results of the present study combined with pathogenicity tests, the pathogenic isolates of tomato, brinjal and chilli could be characterised and identified under *Ralstonia solanacearum* (Smith) Yabuuchi *et al.*, race 1 biovar III for tomato and chilli, and *R.solanacearum* (Smith) Yabuuchi *et al.*, race 1 biovar V for brinjal. This biovar grouping is based on a comparison of the studies conducted by Hayward (1994 b), He *et al.*, (1983) and Kumar *et al.*, (1993). The biovar differences observed with the brinjal isolate is justified by its differential behaviour on fermentation of sugar alcohols like sorbitol and dulcitol. The brinjal isolate seems to

be little different from the others as differential behaviour is shown in some of the biochemical properties like production of levan, arginine hydrolase activity, urese test etc.

The cross inoculation studies with the three isolates on tomato, brinjal and chilli produced wilt symptoms alike confirming their cross inoculability. Jyothi (1992) also reported the same type of results with his cross inoculation studies. This clearly shows that even though there is a biovar variation with brinjal isolate, it is producing typical symptoms on other hosts, tomato and chilli.

The studies on *in vitro* sensitivity of the bacterial isolates to antibiotics revealed that there was no sensitivity to penicillin by all the isolates. The other antibiotics were uniformly sensitive to all the isolates, ambistryn-S being most sensitive to tomato isolate and streptocyline for the others. It is quite likely that the pathogen being a gram negative organism it will not show any reaction to penicillin and relative difference in sensitivity to other antibiotics might be due to slight pathogenic variabilities.

The results of the study on toxigenic property of the bacterial isolates revealed that, the toxic metabolites were not thermolabile and not host specific, but induced wilt symptoms in detached twigs and seedlings of tomato, brinjal and chilli. The isolates of the bacterium produced different amounts of precipitate of the toxin under uniform condition. Samuel (1980) also could obtain similar results with the ginger isolate of the pathogen *R. solanacearum*. This may be due to the variation in the virulence of the bacterium.

With little exceptions, the bacterial isolates from tomato, brinjal and chilli behaved alike in cultural, morphological, and biochemical properties combined with pathogenicity, cross inoculability, antibiotic sensitivity and toxigenicity.

However Hayward (1994 b) was of opinion that biovar classification is a special purpose classification which is primarily in the context of epidemiology, rather than taxonomy and this can be best utilised by plant pathologists and plant breeders which facilitates characterisation of strains in epidemiological investigations and which relates to virulence, pathogenicity and host range.

Based on the screening varieties / lines of tomato, brinjal and chilli, LE 79-5, Swetha and Ujwala were selected as resistant varieties for tomato, brinjal and chilli respectively. The resistance of LE 79-5 was also reported by Sadhankumar (1995), Swetha by KAU (1996), Composite-2 by Singh (1996), Ujwala by KAU (1988) and Manjari by Jyothi (1992).

The susceptibility of the varieties was also reported by many workers. (Pusa Ruby by Sadhankumar, 1995; Pusa Purple Long by Sitaramaiah *et al.*, 1984; Pusa Jwala by Markose, 1996).

In the present study on the biochemical and biological bases of host resistance, the biochemical parameters like total phenol, OD phenol, soluble sugars, amino acids, soluble protein, enzyme activities and alkaloids; biological factors like total microflora, virulent *Ralstonia*, avirulent *Pseudomonas*, beneficial microflora and nematode populations have been attempted to elucidate the role of any of these parameters in imparting resistance / susceptibility. In addition the nutritional factors that may have some role in disease resistance were also studied.

The changes observed in the various biochemical constituents were not uniform due to infection by *R.solanacearum*. Since the resistant genotype is also showing around 20 per cent infection, a true comparison with the resistant plants was not possible. In this, the different varieties grouped as resistant, moderately resistant, moderately susceptible and susceptible are based on classification by Mew and Ho (1976). The comparisons were made between content of the factors in the root, stem and leaf (healthy and diseased) of tomato, brinjal and chilli. The crop to crop variations also are likely to exist between tomato, brinjal and chilli due to the differences in their genetic make up.

In the case of tomato, the biochemical parameters showed significant variation between the resistant and susceptible genotypes and between healthy and diseased. Also variations were observed between the different plant parts like root, stem and leaf. In the case of phenolics, a high total phenol content was noticed in the susceptible varieties of tomato compared to resistant genotypes under healthy condition. In brinjal and chilli a reverse trend was noticed. OD phenol content was higher in root of resistant genotypes of tomato, brinjal and chilli, but a reverse trend noticed in stem. Upon

infection, the total phenol content increased in tomato and chilli irrespective of plant parts and it remained at the highest level in resistant genotypes under diseased condition. A decrease in total phenol was noticed in the roots of resistant genotype of brinjal. In the case of OD phenol, it increased after infection in all plants parts of tomato and chilli except in the stem of susceptible genotypes. The rate of increase and the highest content after infection was noticed in the resistant genotypes. In brinjal root, a decrease in OD phenol content was noticed after infection in all the varieties / lines but an increase was noticed in the stem and leaf.

The reduction of phenolics in brinjal due to infection was observed by Sharma *et al.*, (1993) in the case of *Diaporthe vexans* infection. Further it may be due to the immediate oxidation to more toxic compounds like quinones by the oxidising enzymes like polyphenol oxidase and peroxidase (Mahadevan, 1970).

The increased total phenol content in the resistant varieties / lines after infection by *R. solanacerum* was also reported by Sadhankumar (1995) in tomato and Markose (1996) in Chilli. The root of resistant genotypes possessed higher OD phenol content compared to the

susceptible genotypes prior to infection in tomato, brinjal and chilli. Several other workers (Rajan, 1985; Gangappa, 1986; Geetha, 1989; Sadhankumar, 1995 and Markose,1996) also had the same results. But the increased content of OD phenol in the root prior to infection in tomato, brinjal and chilli and the reverse trend in the stem and leaf showed the importance of OD phenol in resistant reactions at the point of infection by the pathogen, rather than in bacterial multiplication or symptom expression. The high toxicity of OD phenols and its role in resistance was also reported by Mahadevan (1966). Hunter (1978) reported that Orthodihydroxy phenolic compounds such as caffeic acid, and chlorogenic acid, and orthoquinones and tanins were shown to strongly inhibit the activities of extracellular enzymes produced by microorganism.

The phenolic compounds in plants do have a definite role in the resistant and susceptible reactions exhibited by the plant. The quantity and quality of the phenolics vary with the healthy plant species and varieties, the stage and parts of the crop and the environmental conditions. In general there was an increase in the phenolics due to infection as a part of plant defence reaction against the pathogen. In the present study also the above phenomenon was clearly exhibited.

The total and OD phenol content of the different plant parts of the three crops under healthy and diseased condition did not follow a common trend. The brinjal crop showed much variations in the pattern and distribution of phenolics. According to Goodman *et al.* , (1967), a comparison of the susceptible and resistant infected varieties have not always revealed a positive correlation between phenol content and resistance. This apparent inconsistency may be due to inherent differences in phenol levels of the tested varieties which exists independently of infection.

In general, the phenolics were higher in susceptible genotypes under healthy condition and increased upon infection, remained highest in the resistant genotypes. Phenolics in high concentrations are toxic to plant cells themselves (Tepper and Anderson, 1984), and as such their synthesis will be conditioned by the infection of the plant by the pathogen. This view has been endorsed by Vidhyasekaran (1990) that in many plant pathogen interactions, the synthesis of phenolics is activated after infection and the high amount of phenolics synthesised rapidly suppress the pathogen development.

The soluble sugar content decreased after infection by *R. solanacearum* in tomato, brinjal and chilli. An increase in soluble sugar was noticed in the resistant variety of tomato, LE 79-5 and in leaf of three crops. Under healthy condition the soluble sugar content was higher in susceptible genotypes of tomato and resistant genotypes of brinjal and chilli. But under diseased condition it was higher in the susceptible genotypes in root and stem of all crops. In the leaf the soluble sugar content was higher in the resistant genotypes before and after infection.

Eventhough the soluble sugar content of the different parts of the three crops differed in the healthy condition, it was uniformly higher in the root and stem of susceptible genotypes upon infection. According to Vidhyasekaran (1990) sugars are the preferred nutrients for the pathogens and the preferential utilisation of sugars by pathogen result in the non production of pectic and cellulolytic enzymes by the pathogen and the infection is hindered. Further increased sugar content may enhance the synthesis of phenolics (Vidhyasekaran, 1974 a, b and c) and other defence chemicals (Emmanouil and Wood, 1981). The present study also is in line with the above observations. The decrease in soluble sugar content observed in the study due to infection in all the crops might be due to the increased utilisation by the pathogen in preference to other nutrients and also for the synthesis of phenolics.

Sugars are precursors for synthesis of phenolics and other defence chemicals and hence the resistant genotype possess a higher soluble sugar content compared to the susceptible genotype. In the present study the presence of more soluble sugars in the susceptible genotype upon infection might be due to the lack of conversion to phenolics and other defence chemicals. Decrease in total, non reducing and reducing sugars was also recorded in aubergines infected by *Diaporthe vexans* (Sharma *et al.*, 1993). So it is evident that in the susceptible genotypes of the crops, accumulation of sugars indicate its non conversion to phenolics and other defence chemicals. This is exemplified by the decrease in phenolic content in the susceptible genotypes of the crops after infection.

The total free amino acids, number of amino acids and soluble proteins were higher in susceptible varieties / lines of all the crops under healthy condition and upon infection, there was an increase of all the above components in all the plant parts of all crops, with an exception of brinjal showing a difference in pattern of soluble protein content. The rate of increase of all the above constituents was also higher in the resistant genotypes. This is the common trend with minor variations with tomato in total amino acid and in stem of tomato and brinjal in soluble protein.

Patel and Walker (1963) observed in bean plants inoculated with *Pseudomonas phaseolicola,* an appreciable alteration in the amino acid content in susceptible varieties than in resistant varieties. Saxena and Prasad (1995) also noticed a high level of amino acid and low protein content in the susceptible tomato to *Fusarium solani* damping off. The accumulation of amino acid concentration due to infection in susceptible varieties / lines may be due to the blockage of protein synthesis or may be due to protein degradation which results in the accumulation of ammonia in the tissues and this may lead to the formation of newer amino acids. The excess of a single amino acid may induce resistance, or imbalance of amino acids in host may induce resistance (Goodman *et al.,* 1967). The susceptibility of varieties of tomato to *P. solanacearum* with high protein levels were also reported by Hanudin (1987)

Dewit and Bakkar (1980) and Gabriel and Ellingboe (1982) observed that protein synthesis is an important factor in disease resistance, the synthesised proteins may not be inhibitory to pathogen. They mostly activate the synthesis of defence chemicals. The preformed proteins may not be involved in the disease resistance process. Leach *et al.,* (1983) explained the appearance of new proteins when lipopolysaccharides of *P. solanacearum*

was infiltered into tobacco cultivar. The accumulation of new protein as well as the increase in relative content of two other proteins were correlated with the appearance of resistance to bacterial multiplication in tobacco tissues. Post infectional increase in soluble protein content was also reported by Markose (1996) in resistant variety of chilli, Ujwala.

Infection being a host parasite interaction, the conditions governing resistance / susceptibility are numerous and it will not be appropriate to assign definit roles to a group of compounds like total free amino acids, number of amino acids and soluble protein. However in the present observations where the increased total free amino acids, number of amino acids and soluble proteins content noticed in the resistant genotypes after infection suggest their involvement in the protein metabolism where in there may be either blocking of protein biosynthesis or may be subjected to degradation of proteins with accumulation of amino acids. Detailed studies are required to elucidate the role of individual components of protein, free amino acids and number of amino acids in the protein metabolism in relation to defense reaction of the plants.

Among the host enzymes tested for their activity in relation to host resistance, the activity of polyphenol oxidase varied considerably between the resistant and susceptible genotypes. In the healthy plants, both tomato and brinjal recorded higher enzyme activity in resistant plants, whereas in chilli the activity was comparatively less. After infection more activity was observed in the susceptible genotypes of tomato and chilli and in the resistant genotype of brinjal. The enzyme activity decreased in the resistant genotypes of tomato and chilli, and increased in brinjal. In the case of root of tomato and chilli, upon infection, there was an increase in phenol content(Table 15), indicating a possible lesser activity of the enzyme (Table 20) whereas, in brinjal the trend was reversed.

The specific activity of the enzyme increased due to infection in tomato and brinjal. In chilli a decrease in specific activity was noticed after infection. The specific activity remains at the highest level in the resistant genotypes compared to the susceptible ones both under healthy and diseased condition in all the three crops. Polyphenol oxidase catalyses the hydroxylation of monophenols to O-diphenols and the dehydrogenation of O-

diphenols to O-diquinones (Vanghu *et al.*, 1988). In most of the plants the enzyme exists in a latent state with respect to their *in vitro* activities (Cary *et al.*, 1992) The increase in polyphenol oxidase activity due to infection was reported by Maine and Kelman (1961). Many workers reported higher increase in polyphenol oxidase activity in resistant plants compared to susceptible ones after infection (Retig,1974 in Fusarium wilt of tomato; Obukowicz and Kennedy,1981 in tomato against *P.solanacearum*; Bashan *et al.*, 1987 in tomato against *P.syringae* pv. *tomato*; Markose, 1996 in chilli against *P.solanacearum).* Singh and Singh (1989) reported an increase in phenols and decrease in flavanols immediately after infection, which was much less marked in the resistant, than the susceptible material and was associated with increased activity of enzymes studied, leading to the formation of more quinones and other oxidation products in the resistant varieties and resulting in reduced multiplication and inactivation of virus. Duan *et al.*, (1994) studied correlation between bacterial wilt resistance and polyphenol oxidase activity in groundnut and reported that no significant difference was observed between resistant and susceptible genotypes before inoculation. But after inoculation, maximum enzyme activity was observed after six days of inoculation in

resistant lines, while in susceptible ones it took 10 days. Liao *et al.*, (1994) also made such observation in ground nut.

In general a higher polyphenol oxidase activity was expected in healthy resistant plants than in susceptible ones. In the present study, this trend was observed in the case of tomato and brinjal, but upon infection the activity was higher in susceptible genotypes of tomato and chilli. The increased polyphenol oxidase activity in root of susceptible varieties / lines of tomato and chilli after infection may be due to the delayed polyphenol oxidase activity in the susceptible plants when compared to resistant plants. The root being the primary foci of infection the changes in polyphenol oxidase activity in root may have more relevance in relation to infection. The studies conducted by various workers on the activity of polyphenol oxidase with different crops did not suggest a common trend in the healthy and diseased condition and also between resistant and susceptible varieties. Polyphenol oxidase being a key enzyme in the synthesis of toxic metabolites and other defense chemicals, its presence and content in the plant has got paramount importance in the defense reaction.

The peroxidase activity was higher in healthy susceptible varieties / lines of tomato and chilli, but in brinjal it was more in resistant variety. Upon infection the activity increased in all crops both susceptible and resistant. The rate of increase upon infection was higher in the resistant varieties / lines of tomato and chilli and the same trend was shown in susceptible varieties / lines of brinjal. Due to infection, among the stem of all the three crops, the enzyme activity was highest in the resistant variety.

The earliness in peroxidase activity in resistant plants due to infection was also observed by Joy (1995) in rice due to *Magnaporthe grisea* infection. Similar increase in peroxidase activity in the suspension cultured cells of resistant varieties of tomato to *Verticillium albo-atrum* has been reported by Mohan and Kollattukudy (1990). The earlier peroxidase activity of root was also reported by Retig (1974) where he could get significant increase in peroxidase activity with in 24 hrs. after inoculation in Fusarium wilt resistant tomato. In susceptible plants similar increase was observed 24 hours later. In the resistant plants alone the stem tissues showed high peroxidase activity, three days after inoculation.

Peroxidase is the key enzyme in synthesis of lignin (Vidhyasekaran,1988). The results obtained in the present study when viewed in the light of results of similar workers clearly shows that peroxidase increased uniformly upon infection in both resistant and susceptible varieties / lines. In the case of tomato and chilli, higher rate of increase upon infection was observed in the resistant varieties / lines. Brinjal varieties / lines behaved in a different way. This differential behaviour of brinjal varieties / lines upon infection is seen in other parameters also. The increase of peroxidase upon infection and also rate of increase in the resistant genotypes might have positive role in the defence mechanism of the plants.

The studies on alkaloid content was attempted to correlate any possible role of these alkaloids of tomato, brinjal and chilli on disease resistance and also to observe any difference in resistant and susceptible varieties / lines. There was no appreciable difference in the alkaloid content of different crops among healthy and diseased plants. The trend observed was that in resistant plants, there was a decrease in alkaloid content upon infection in tomato and chilli and an increase was observed with brinjal. In the susceptible plants there was no difference in alkaloid content with tomato and chilli, but with brinjal, a decrease was observed.

The studies on alkaloid content of the three different crops in relation to the resistance of the varieties to infection by *R. solanacearum*, did not show any conclusive indication. The alkaloid content of the different crops did not show any significant variation between healthy and diseased plants. In general, the alkaloid content decreased in root of resistant varieties of tomato and chilli, whereas in brinjal an increase was noticed. The higher tomatine content in resistant lines of tomato was reported by Mohanakumaran et al., (1969); Devi (1978) and Rajan (1985). The decrease in tomatine content after infection was also reported by Rajan (1985). From the present study it is evident that the alkaloid content has a role in disease resistance in the case of tomato. Whereas in brinjal and chilli the results are inconclusive. In the absence of sufficient literature on the studies on alkaloid content of the three different crops and since only the total alkaloids were studied it may be necessary to have more detailed studies to arrive at definite conclusion. However the results of the present study will serve as indications for future work.

Total microflora (Fungi, bacteria and actinomycete) population increased in the resistant genotypes of all crops after infection, except for

bacterial population in brinjal and chilli. In brinjal and chilli bacterial population decreased in resistant genotypes and increased in susceptible ones. The rate of increase of actinomycete population was highest in resistant genotypes of tomato and brinjal and in susceptible genotypes of chilli.

The increase in microbial population when a shift from healthy to diseased condition is suggestive of the relative increase of the microbial population and consequent saprophytic competition. Since the crops are different the root exudates of the plants also might vary and has got a direct effect on the preferential colonisation of the microorganisms . Further soil factors also can play a crucial role especially the pH, temperature, moisture etc. A perusal of literature revealed that there was no literature on the direct effect of the pathogen saprophyte interaction. But however in combination with soil amendments a decrease in pathogenic population due to saprophytic competition was reported by Yao *et al.*,(1994). In the present study the increased colonisation of microbes in the healthy susceptible and resistant diseased plants have got relative significance in the disease. Disease being an interaction of two metabolic systems conditioned by the environment, here the soil environment and the microbial population in it have got a decisive role in the causation of disease.

The population of virulent *Ralstonia* and avirulent *Pseudomonas* was studied under different host parasite combinations. It was observed that under healthy condition the population of virulent *Ralstonia* was higher in the susceptible plants of all the crops. But with induction of disease the situation changed to an increased population in diseased resistant genotypes compared to diseased susceptible ones where a decrease in population was noticed. But in chilli, the virulent *Ralstonia* population increased in the susceptible genotypes also.

The virulent *Ralstonia* population was highest in the susceptible varieties / lines of tomato, brinjal and chilli under healthy condition. This is due to the increased susceptibility which may include the root exudates and other biochemical factors present in the rhizosphere of susceptible plants and there might be some variations in the resistant genotypes.

Moffet and wood (1984) observed an increased population of *R. solanacearum* in soil during symptom development and declined with the death of infected plant. They also noticed a 1000 fold increase in pathogen population in the root zone of susceptible tomato cultivar Floradel compared with the root zone of resistant line.

Hartman *et al.,* (1991) had reported difference in population density of *P. solanacearum* in soil associated with roots of wilted plants and non wilted plants. The change in *R. solanacearum* population in chilli from tomato and brinjal was also reported by Prior *et al.* , (1994). According to them the difference in latent infections between susceptible and resistant egg plants were similar to those observed on tomatoes. The minor differences observed in the population of virulent *Ralstonia* in the different crops are of minor importance as population alone is not the single factor that govern subsequent infections.

Although significant difference was not obtained between healthy and diseased plants in mycorrhizal infection, the resistant genotypes recorded a decrease in mycorrhizal association after infection. The resistant genotypes recorded a higher mycorrhizal population under healthy condition. In the susceptible genotypes, an increase in mycorrhizal population was recorded after infection and highest population was in the susceptible ones after infection.

It is a general observation that mycorrhizal colonisation result in decrease of pathogenic invasion (Garcia *et al.*, 1988 b). In the present study, we could

not establish a positive correlation between mycorrhizal colonisation and disease resistance. However in brinjal and chilli, a higher population of mycorrhiza was noticed in resistant plants. But upon infection the trend was changed and the susceptible groups sustained a higher population of mycorrhiza. Since the present study is only an estimation of existing population and in the absence of VAM inoculation studies it will not be possible to assess the ability of these organisms on disease control.

Significant difference was not obtained in Azospririllum population between healthy and diseased plants. However the resistant plants of tomato and chilli recorded a decreased Azospirillum population under diseased condition.

In the studies on the effect of Azospirillum population in the resistance of solanaceous crops to *R.solanacearum* no valuable information could be gathered. Eventhough there are positive response of disease control and increase in yield in tomato inoculated with *Azospirillum brasilense* (Bashan et al., 1989; and Sanhita *et al.,* 1995). Since the present study was limited to only estimation of existing population of Azospirillum and its correlation with disease resistance, here again detailed inoculation studies are required to arrive at definite conclusions.

The saprophytic nematode population decreased in the resistant genotypes of tomato and chilli and all varieties / lines of brinjal due to infection. But it increased in the susceptible varieties / lines of tomato and chilli after infection. The resistant genotypes recorded a higher saprophytic nematode population compared to the susceptible ones under healthy condition. Unlike the saprophytes the parasitic nematode population increased in all except in chilli upon infection. The parasitic nematode population was highest in resistant genotypes of tomato and chilli and in susceptible genotypes of brinjal under healthy condition. But after infection the population was highest in the susceptible genotypes of tomato and chilli and in resistant genotype of brinjal. The occurrence of *Meloidogyne incognita* which is a common associated nematode organism with the bacterial wilts could not be recorded in this study. The increased nematode population recorded in susceptible genotypes might be due to the change in the metabolism of the host plant favourable for nematode population under diseased condition.

In tomato and brinjal the resistant plants recorded an increase in parasitic nematode population and virulent *Ralstonia* population, and a decrease in VAM

infection under diseased condition. But under healthy condition the virulent *Ralstonia* population was highest in the susceptible genotypes and the VAM colonisation and nematode population were higher in resistant genotypes.

The decrease in nematode population in the susceptible plants in tomato and chilli may be due to the increased virulent *Ralstonia* population. Similar decrease in root knot index or nematode activity was also recorded by Haider *et al.*,(1987) in tomato and Kermarrec *et al.*, (1994) in aubergines. The absence of nematode galls in any of the plant samples used in the present study may be due to the colonisation of VAM on root and presence of *R.solanacearum* in rhizosphere soil. Similar observations were made by Singh *et al.*, (1990) and Mittal *et al.*, (1991) in tomato where the presence of VAM fungi in the roots was inhibitory to the formation of nematode galls. The higher VAM colonisation in resistant plants has a positive role in providing resistance to resistant plants of tomato, brinjal and chilli even if their nematode population was high. The increase in pathogen population after infection indicated that once the bacterial pathogen enters the plants, its multiplication is not affected by VAM colonisation. The increase in nematode population in the resistant plants can be attributed to the decrease in virulent *Ralstonia* population and favourable root exudates, but under diseased

condition, the toxic metabolites of the resistant host plant may not be helpful for nematode multiplication and colonization.

In the present study an attempt was also made on the effect of host nutrition on disease resistance and susceptibility. The nutritional factors like nitrogen, phosphorus, potassium, calcium, magnesium, iron, zinc and manganese were studied both under healthy and diseased condition.

Among the various nutritional factors studied, nitrogen content of root, stem and leaf did not show much significant differences under healthy and diseased condition. However, nitrogen content decreased in the root of resistant genotypes of tomato and brinjal and in the leaf of all crops after infection. The root of resistant genotypes of chilli and stem of resistant genotypes of all three crops recorded an increase in nitrogen content due to infection.

The increase in nitrogen in affected tissue may be due to the accumulation of nitrogen absorbed and no further utilization takes place due to the diseased condition. The increase in nitrogen content was reported by Gupta *et al.*,(1992) in ground nut leaflets due to leafspot pathogens.

The decrease in nitrogen in resistant plants may be because of its utilisation in the production of amino acids or protein or phenol metabolites which are of host origin against the pathogen upon infection. In susceptible plants the nitrogen content increased, may be due to the interaction of host and pathogen.

The decrease in nitrogen might be due to attenuated activity of nitrate reductase and urease and enhanced activity of oxidative and non oxidative deaminase as observed in coriander due to stem gall as reported by Prasad *et al.*, (1989).

Decrease in nitrogen can also be due to loss as root exudate as reported by Kishore *et al.*, (1990) in mustard seedlings raised from seeds stored with *Aspergillus flavus* or hindered absorption of solute and subsequent translocation. Similar observations were also made by Prasad *et al.*,(1997) in *Lathyrus sativus* infected with *Peronospora lathyri-palustris.*

The results of the present study did not show any precise role of the nitrogen metabolism of the crops in the resistant / susceptible reactions of the plants. The data obtained with different crops did vary, but not

significantly. So in the absence of significant variation between the crops and crop varieties the role of nitrogen nutrition could not be assessed properly.

The phosphorus content was highest in the susceptible genotypes both under healthy and diseased condition. Due to infection by *R. solanacearum*, an increase in phosphorus content was noticed in all with a few exception. The increase in phosphorus content may be due to the higher mycorrhizal colonisation in susceptible root of three crops. Sutic and Sinclair (1991) reported that mycorrhizal fungi may enhance the availability of phosphorus and other elements which would otherwise be unaccessible to plants. Gupta *et al.*, (1992) also observed in groundnut an increase in phosphorus content after infection by leafspot pathogen.

The results of the study on phosphorus indicated that accumulation of phosphorus is seen in susceptible varieties both under healthy and diseased condition. Whereas in resistant plants the trend is reversed. This is suggestive of the fact that phosphorus nutrition has either little role in governing the resistance / susceptibility reaction or probably the nitrogen: phosphorus balance might play a better role than

the nutrients independently. This is evident from the results of the studies on nitrogen content of the plants. An inverse relationship of nitrogen and phosphorus was reported by Kenaga (1974) on tomato affected by wilt disease. It has also been reported that phosphorus is essential for many diverse functions in the plant metabolism affecting its growth (Chaboussou, 1987 and Malavolta, 1980). So the role of phosphorus in the metabolism of plants is vital and nutritional balances rather than independent elements do decide the resistance / susceptibility.

Significant difference was not obtained in potassium content either between varieties or between healthy and diseased condition. Also the potassium content did not follow a regular pattern. Prasad *et al.*, (1997) also reported that no change was observed in phosphorus, potassium and calcium content between healthy and diseased leaflets in *Lathyrus sativus* infected by *Peronospora lathyri-palustris.*

The calcium content was high in the resistant genotypes especially in stem under healthy condition. After infection the calcium content decreased in resistant genotypes and increased in susceptible ones. The susceptible genotypes recorded a higher calcium content after infection.

Calcium is reported to alter the host pectin metabolism. The increase in calcium content in the root of resistant plants under healthy condition will provide an increase in calcium at the site of infection of *R.solanacearum* and this may release the host cell bound pectin methyl esterase (PME) and activate it. Calcium may combine with dimethylated pectic materials to form water-insoluble calcium polypectate which is resistant to degradation by pectic enzymes produced by pathogens (Bateman and Lumsden, 1965 and Corden, 1965).

The results in the present study is in line with the reports of Yamazaki and Hoshina (1995). They showed that calcium content in root alone do not contribute to resistance since the calcium content in susceptible varieties increased after infection, but in resistant varieties high calcium content in stem adds to the resistance quality of the host plant. They also reported that the disease development was rapid in the susceptible tomato cv. Ponderosa at all calcium concentrations. But in moderately resistant varieties the increase in calcium concentration reduced disease severity. Resistance was negated at low concentration in Hawaii 7991 (highly resistant). Pathogen population in stems decreased with increasing calcium concentration. Yamazaki *et al.*, (1996) also made a similar observation of high calcium uptake by highly resistant tomato cultivars.

The result of the present study showed a positive correlation on the effect of calcium nutrition on resistance / susceptibility. Increased calcium content was observed in the resistant genotypes of plants and upon infection the calcium content was reduced and susceptible varieties / lines showed higher content possibly due to the enzymic degradation of host cells by the pathogen.

Magnesium content did not show any regular pattern either in healthy and diseased plants. In general a decrease in magnesium content was observed except in the resistant variety of tomato. Locascio *et al.*, (1988) reported that leaf tissue concentration of calcium and magnesium were higher in capitan which was intermediate in its expression to bacterial wilt resistance. Here the magnesium content was higher in stem and leaf of resistant plant both under healthy and diseased condition. It is quite logical that the resistant plants had a higher content of magnesium in their stem and leaf.

The iron content increased in the resistant genotypes of tomato and brinjal, but decreased in chilli after infection. A low iron content was noticed in the susceptible genotypes of tomato and brinjal and a high iron content in susceptible genotype of chilli after infection.

Also the susceptible genotypes of tomato and brinjal and the resistant genotype of chilli recorded higher iron content under healthy condition. Under diseased condition the resistant genotypes recorded higher iron content in tomato and brinjal. So chilli exhibited difference in iron utilisation / accumulation with that of tomato and brinjal in relation to resistance / susceptibility. The increase in iron upon diseased condition in resistant plants may be due to the accumulation of iron which resulted by the complex formation in diseased leaflets (Agrios, 1978) and its retention there. This may impart resistance to host. Similar increase in iron content in groundnut leaflets due to leaf spot pathogens was also reported by Gupta *et al.*, (1992).

High level of iron in tomato induced more toxin production by *Fusarium oxysporum* f. sp. *lycopersici* and increased wilt incidence (Woltz and Jones, 1971). The high iron content in the susceptible varieties / lines of tomato and brinjal may help more toxin production by *R.solanacearum*, thereby making it more susceptible. In chilli, the mechanism of resistance / susceptibility is different. Similar accumulation of iron in diseased leaflets of *Lathyrus sativus* infected by *Peronospora lathyri - palustris* was reported by Prasad *et al.*, (1997).

From the above observations the iron content seems to play a role in disease resistance reaction by way of increased utilisation and accumulation, and in susceptible varieties / lines the reaction may be that of production of toxins by pathogen.

The zinc content increased due to infection by *R. solanacearum* in resistant genotypes of tomato and chilli, but decreased in susceptible ones; and in all varieties / lines of brinjal. The zinc content was higher in the susceptible varieties / lines under healthy condition and in resistant varieties / lines under diseased condition in tomato and chilli. In brinjal the zinc content was high in resistant genotypes both under healthy and diseased condition.

The decrease in zinc content in resistant tomato and chilli helped to increase the root exudation of amino acids, sugar and phenolic compounds which may impart resistance to the attack by *R. solanacearum* and when zinc content increases, these exudates decreases there by resistance is decreased in susceptible genotypes. Similar observations were made by Zhang (1991). According to him zinc deficiency increased root exudation of amino acids, sugar and phenolic compounds in sunflowers, *Phaseolus vulgaris*, tomatoes, apples and cotton. The release of

these substances decreased with increasing zinc concentrations. Root exudates of zinc deficient sunflower and tomato plants mobilised 1.6 to 2.1 and 2.7 to 3.5 times more iron and manganese from calcareous soil than those of zinc sufficient plants.

There is also a report of zinc increasing the virulence of pathogens by activating the toxin production by them (Woltz and Jones, 1971; Prasad and Chaudhury, 1974). The increase in zinc content in the susceptible genotypes of tomato and chilli may enhance the toxin production by *R. solanacearum* and thus increases the susceptibility.

Zinc also is reported to alter carbohydrate metabolism (Kalyansundaram, 1954) and in brinjal this may be the mechanism as the zinc content is higher in both healthy and diseased condition in resistant plants.

Increase in zinc in diseased groundnut leaflets due to leaf spot pathogen was also reported by Gupta *et al.*, (1992) and decrease in zinc in *Lathyrus sativus* infected with *Peronospora lathyri - palustris* was reported by Prasad *et al.*, (1997).

The literature revealed contrasting effect of zinc on disease resistance / susceptibility. In the present study also it was not possible to assign definit positive role for zinc in defence reaction of plants.

The manganese content decreased in the root of all varieties / lines of tomato, brinjal and chilli after infection. In stem and leaf the resistant genotypes recorded an increase in manganese in all the crops and the susceptible genotypes recorded higher manganese content both under healthy and diseased condition.

It is evident from this data that high manganese content, under healthy condition renders more susceptibility of the crop to the pathogen.

Contrasting reports were also there in which Gupta *et al.*, (1992) reported an increase in manganese content in the diseased leaflets due to leaf spot pathogen and Prasad *et al.*, (1997) reported a decrease in manganese content in *Lathyrus sativus* leaves infected with *Peronospora lathyri-palustris*.

The present study on the influence of role of nutritional factors like nitrogen, phosphorus, potassium, calcium, magnesium, iron, zinc and manganese has revealed

the following observations. This study was super imposed on the plants studied for biochemical and biological aspects and a nutritional study in the strict sense was not conducted. Only plant nutrient analysis under healthy and diseased condition of the resistant and susceptible genotypes of plants were conducted. The study revealed that nitrogen content increased upon infection in the resistant group. Phosphorus was high in susceptible group both under healthy and diseased condition and the content increased upon infection. The potassium and magnesium content of the plant did not give any definite positive trend for resistance even though it is expected to be factors imparting resistance to plants in general. However calcium content was high in healthy resistant genotypes ,but decreased upon infection. Iron and zinc content was high in susceptible genotypes under healthy condition and increased in resistant genotypes due to infection. Manganese was high in susceptible genotypes both under healthy and diseased condition.

The results of the present study when reviewed in the light of available literature highlights the possibility of the relative balance and proportion of the major and minor elements that is of importance than of their individual independent content. This has been amply exemplified by the relative contents and the resistance /

susceptibility noticed in the case of nitrogen and phosphorus. Further the inefficacy noticed with potassium and magnesium which are supposed to be very important in imparting resistance to plants also is revealing. It is also observed that calcium, iron and zinc do contribute positively to the resistance of the plant.

Biochemical, biological and nutritional bases of disease resistance in the three solanaceous crops, namely tomato, brinjal and chilli vary considerably between crops and their varieties. In most of the parameters studied either an increase or decrease in quantity was noticed in each factor after infection irrespective of the resistance or susceptibility of the variety for each crop. The rate of increase of these factors also was found to vary.

In tomato the varieties / lines studied showed that the biochemical factors like total phenol, OD phenol, amino acids, soluble protein, specific activity and peroxidase activity; biological factors like total microflora (fungi, bacteria, actinomycetes), Azospirillum and parasitic nematodes; nutritional factors like phosphorus and magnesium showed an increasing trend after infection, whereas soluble sugars, alkaloids, potassium and calcium showed a decreasing trend(Table 37) .

Table. 37 Comparison of the higher content and changes of biochemical, biological and nutritional factors of tomato, brinjal and chilli upon infection by *R.solanacearum.*

Factors	Tomato		Brinjal		Chilli	
	Healthy	Diseased	Healthy	Diseased	Healthy	Diseased
Total Phenol	S +	R	R -*	S	R +	R
OD Phenol	R +	R	R -	S	R +	R
Soluble sugars	S -	S	R -	S	R -	R
Amino acid	S +	S	R +	S	S +	S
Soluble protein	S +	R	R -*	S	S +	S
Polyphenol oxidase activity	R -*	S	R +	R	S -	S
Specific activity	R +	R	R +	R	R -	R
Peroxidase activity	S +	R	R +	R	S +	R
Alkaloid	R -	S	S +*	S	S -	S
Fungi	S +	R	R +	R	S +	R
Bacteria	S +	R	S +	S	S +	S
Actinomycetes	S +	R	S +	S	S +	S
Virulent *Ralstonia*	S +*	R	S +*	R	S +	S
Avirulent *Pseudomonas*	S +*	R	R +	R	R +	R
Mycorrhiza	S -*	S	R -*	S	R -*	R
Azospirillum	S +	S	S +	S	=	=
Saprophytic nematodes	R -*	S	R -	R	R -	S
Parasitic nematodes	R +	S	S +	R	R -	S
Nitrogen	=	=	R -*	S	S +*	R
Phosphorus	S +	S	S +	S	R +	S
Potassium	R -	S	S -	R	S +	R
Calcium	R -	S	R -	S	R -	S
Magnesium	S +	S	R -	R	S +*	R
Iron	S +*	R	S +*	R	R +	S
Zinc	S +*	R	R -	R	S +*	R
Manganese	S +	R	S +*	S	=	=

R Resistant plant , S - Susceptible plant,
= Not much variation, + Increase
- Decrease, * only in resistant genotypes

Variations were noticed between resistant genotypes and susceptible ones in certain parameters. The polyphenol oxidase activity, mycorrhiza population and saprophytic nematode population decreased after infection in the resistant genotypes of tomato. Virulent *Ralstonia* and avirulent *Pseudomonas* population, iron, zinc and manganese increased in the resistant genotypes only after infection.

However, among the biochemical factors studied OD phenol and specific activity were higher in resistant plants both under healthy and diseased condition. In addition under healthy condition, polyphenol oxidase activity and alkaloid contents were higher in the resistant plants and under diseased condition, total phenol, soluble protein, and peroxidase activity were higher in the resistant plants. Among the biological factors, the nematode populations were high in resistant plants under healthy condition and total microflora and virulent *Ralstonia* and avirulent *Pseudomonas* population were higher in resistant plants under diseased condition. Among the nutritional factors potassium and calcium were high in resistant plants under healthy condition, and iron, manganese and zinc were high in resistant plants under

diseased condition. The above factors may help the resistant plants in their defense mechanism either pre-infectionally or post infectionally.

In tomato, the biological and nutritional factors are important in defense mechanism showing high contribution to resistant plants in addition to biochemical factors.

The brinjal crop also showed variation in biochemical parameters like amino acids, polyphenol oxidase activity, specific activity and peroxidase activity; biological factors like total microflora , avirulent *Pseudomonas,* Azospirillum and parasitic nematodes; phosphorus of nutritional factors where they increased after infection whereas OD phenol, soluble sugars, saprophytic nematodes, potassium, calcium, magnesium, and zinc decreased due to infection (Table. 37).

In brinjal only the resistant genotypes showed a decrease in total phenol, soluble protein, mycorrhiza population and nitrogen content after infection where as they showed an increase in alkaloid content, virulent *Ralstonia* population, iron and manganese content. A reverse trend was noticed for all these parameters in the susceptible genotypes.

Here all the biochemical parameters tried showed a higher content in the resistant genotypes except alkaloid under healthy condition. Under diseased condition the enzyme activities (polyphenol oxidase activity, specific activity and peroxidase activity) were higher in the resistant genotypes. Among the biological factors, the fungi, avirulent *Pseudomonas,* mycorrhiza and saprophytic nematodes were higher under healthy condition, and fungi, virulent *Ralstonia,* avirulent *Pseudomonas,* and nematode populations were higher in resistant genotypes under diseased condition. The nutritional factors like nitrogen, calcium, magnesium and zinc were high in resistant group under healthy condition and potassium, magnesium, iron and zinc under diseased condition. All these factors may contribute to the resistance mechanism of brinjal as a preinfectional or post infectional defense mechanism. It is evident that in brinjal the biochemical factors are important as they are all present in higher quantity in the resistant plants under healthy conditions and they showed a decreasing trend after infection except in the case of enzyme activities and amino acid.

In chilli, the biochemical factors like total phenol, OD phenol, amino acids, soluble protein, peroxidase activity; biological factors like total microflora,

virulent *Ralstonia* and avirulent *Pseudomonas* populations; nutritional factors like phosphorus, potassium and iron increased upon infection. Soluble sugars, polyphenol oxidase activity, specific activity, alkaloid content, nematode populations, and calcium content decreased after infection (Table.37).

A decrease in mycorrhizal population and an increase in nitrogen, magnesium, and zinc was noticed in the resistant genotypes of chilli and a reverse trend in the susceptible genotypes.

Among the biochemical factors studied the resistant plants recorded higher OD phenol, soluble sugar, and specific activity both under healthy and diseased condition. In addition the peroxidase activity was also higher in the resistant plants under diseased condition. Among the biological factors the avirulent *Pseudomonas* and mycorrhizal populations were higher in resistant plants both under healthy and diseased condition. Nematode populations were higher in resistant plants under healthy conditions, and fungal population under diseased condition. Among the nutritional factors studied phosphorus, calcium and iron were higher in resistant plants under healthy condition, and nitrogen, potassium, magnesium and zinc were

higher under diseased condition. As all these factors may contribute to resistant mechanism of the host plant, both preinfectional and post infectional defense mechanisms are equally important in the case of chilli.

The three crops behaved uniformly showing an increase of amino acids, peroxidase activity, total microflora population and phosphorus content, and a decrease of soluble sugars and calcium content upon infection.

Tomato, brinjal and chilli also showed variation in their biochemical, biological and nutritional factors under healthy and diseased condition. Among the three crops, tomato and chilli showed uniformity in some of the factors. The content of OD phenol, amino acids, peroxidase activity, fungal and nematode populations and zinc content follow the same pattern both under healthy and diseased condition (Table. 38). The susceptible genotypes of tomato and chilli recorded higher total phenol, amino acid, peroxidase activity, fungal population and zinc content under healthy condition, and amino acids and nematode populations under diseased conditions. Their resistant genotypes recorded higher OD phenol and nematode populations under healthy condition, and higher OD phenol,

peroxidase activity, fungal population and zinc content under diseased condition. Brinjal crop showed variation in parasitic nematode population both under healthy and diseased condition when compared to tomato and chilli. Also under healthy condition the resistant genotypes recorded higher OD phenol, amino acid, peroxidase activity, fungal population, saprophytic nematodes and zinc content, and under diseased condition the susceptible genotypes recorded higher OD phenol and amino acid content, and resistant genotypes recorded higher peroxidase activity, fungal populations, nematode populations and zinc content.

Tomato and chilli showed similarities mostly on biochemical parameters and nematode populations and brinjal is different in these parameters compared to the other two. In this context it is worthwhile to note the biovar variation of brinjal isolate as biovar V, while the other two are biovar III (Hayward, 1994 b).

Tomato and brinjal showed uniformity in virulent *Ralstonia* population, nitrogen, phosphorus, iron and manganese both under healthy and diseased condition. Under healthy condition, the resistant genotypes of these two crops recorded higher nitrogen content; and the susceptible genotypes recorded higher virulent *Ralstonia*

population, phosphorus, iron and manganese. Under diseased condition the resistant genotypes recorded higher virulent *Ralstonia* population and iron content, and the susceptible genotypes were high in nitrogen, phosphorus and manganese content. Chilli showed variation in the above factors compared to tomato and brinjal. The iron content was just the reverse as that of tomato and brinjal. Under healthy condition the phosphorus, iron and manganese content were high in resistant genotypes, and virulent *Ralstonia* and nitrogen was high in susceptible ones. Virulent *Ralstonia* population was high in susceptible genotypes under diseased condition.

Tomato and brinjal showed similarity mainly in virulent *Ralstonia* population and nutritional factors and chilli differed from these two crops in the above factors.

Brinjal and chilli are similar in alkaloid and potassium content, and bacterial, actinomycete population and avirulent *Pseudomonas* population (Table. 38). Their susceptible genotypes recorded higher alkaloid, bacterial and actinomyctes population and resistant genotypes recorded higher avirulent *Pseudomonas* population both under healthy and diseased condition. The potassium content is higher in susceptible genotypes under healthy condition and

Table. 38 Similarities between tomato, brinjal and chilli on higher content of various biochemical, biological and nutritional factors

	Healthy	Diseased		Healthy	Diseased
Group I	Tomato and chilli			Brinjal	
	R	R	OD phenol	R	S
	S	S	Amino acid	R	S
	S	R	Peroxidase activity	R	R
	S	R	Fungi	R	R
	R	S	Saprophytic nematodes	R	R
	R	S	Parasitic nematodes	S	R
	S	R	Zinc	R	R
Group II	Tomato and Brinjal			Chilli	
	S	R	Virulent *Ralstonia*	S	S
	R	S	Nitrogen	S	S
	S	S	Phosphorus	R	S
	S	R	Iron	R	S
	S	S	Manganese	R	S
Group III	Brinjal and Chilli			Tomato	
	S	S	Alkaloid	R	S
	S	S	Bacteria	S	R
	S	S	Actinomycetes	S	R
	R	R	Avirulent *Pseudomonas*	S	R
	S	R	Potassium	R	R

R - Resistant
S - Susceptible

is in resistant ones under diseased condition. Tomato showed variation with high alkaloid and potassium content in resistant genotypes and avirulent *Pseudomonas* population in susceptible ones under healthy condition. Bacterial and actinomycete populations were high in resistant genotypes under diseased condition.

Brinjal and chilli showed uniformity in biological factors and alkaloid and potassium content and tomato is variable in the above factors to brinjal and chilli.

Under healthy condition the resistant genotypes of all the three crops recorded higher OD phenol, specific activity, saprophytic nematodes and calcium content and susceptible ones recorded higher bacteria, actinomycete, virulent *Ralstonia* and Azospirillum population(Table. 39).

Under diseased condition, the resistant genotypes recorded higher specific activity, fungal and avirulent *Pseudomonas* population and susceptible genotypes recorded higher amino acids, alkaloids, Azospirillum population, phosphorus and calcium content.

Table. 39 Similarities of various factors in tomato, brinjal and chilli under healthy and diseased condition.

Factors	Condition
HEALTHY CONDITION	
OD Phenol	R
Specific activity	R
Bacteria population	S
Actinomycetes	S
Virulant Ralstonia	S
Azospirillum	S
Saprophytic nematodes	R
Calcium	R
DISEASED CONDITION	
Amino acid	S
Specific activity	R
Peroxidase	R
Alkaloid	S
Fungal population	R
Avirulent Pseudomonas	R
Azospirillum	S
Phosphorus	S
Calcium	S

R - Resistant
S - Susceptible

All the three crops recorded uniformity in specific activity, Azospirillum population and calcium content both under healthy and diseased condition. Resistant genotypes recorded high specific activity, and susceptible ones recorded high Azospirillum population. Calcium content was high in resistant under healthy and in susceptible under diseased condition.

In the present attempt to search and locate some common biochemical and biological bases for disease resistance in solanaceous vegetables viz. tomato, brinjal and chilli, it was not possible to identify such common bases. Disease being an interaction of two metabolic systems conditioned by environment, the possible inability to have some common base is evident. Here eventhough the pathogen employed is *Ralstonia solanacearum* there was variation in the biovars of the organism. Each host pathogen interaction may not necessarily follow the same pattern.

However in the case of tomato, brinjal and chilli, the bases of resistance seems to be conditioned by the pre and post infectional changes in the particular host parasite interactions. In the case of tomato and chilli the mechanism of biochemical variations are almost

following a common pattern without much similarities in biological and nutritional factors. In tomato and brinjal, more similarities were noticed in the nutritional factors only, in the defense mechanism. In brinjal and chilli the biological factors seem to play a similar role in the defense. Thus the crops as well as the interaction of the host parasites did not follow a common pathway or trend in relation to host resistance and no common bases could be arrived at.

Since the mechanism of resistance of crop plants by itself is complex and conditioned by genetic, nutritional and environmental factors, interaction of these parameters, do decide resistance / susceptibility, need not necessarily follow a common pathway. In the light of the above facts the attempt to arrive at a common base for bacterial wilt resistance in three solanaceous vegetables tomato, brinjal and chilli from this heterogenous factors was not successful for the three crops taken together. But it was possible to outline the important parameters that conditions resistance in individual crops.

Summary

SUMMARY

Investigations on biochemical, biological and nutritional bases of resistance in solanaceous vegetables against bacterial wilt incited by *Ralstonia solanacearum* (Smith) Yabuuchi *et al.*, has been carried out in the present study.

Isolations of the pathogen from tomato, brinjal and chilli were conducted and characterised by morphological, biochemical and physiological tests upto biovar level. The cross inoculation studies showed that the three isolates from tomato, brinjal and chilli produced wilt symptoms alike confirming their cross inoculability. Based on these studies the tomato and chilli isolate could be characterised and identified as *Ralstonia solanacearum* race I biovar III and brinjal isolate as *R. solanacearum* race I biovar V.

The *in vitro* sensitivity studies to antibiotics showed that the tomato isolates was most sensitive to the antibiotic ambistryn-S and others to streptocycline. The study on toxigenic property of the bacterial isolates revealed that the toxic metabolites were not host specific, but induced wilt symptoms in tomato, brinjal and chilli alike.

Out of the forty three varieties / lines screened for bacterial wilt resistance, one variety / line belonging to each category of resistant, moderately resistant, moderately susceptible and susceptible genotypes of tomato, brinjal, and chilli were selected. The varieties / lines selected for tomato, brinjal and chilli were LE 79-5, Swetha and Ujwala for resistant genotypes; BT-10, Composite-2 and Manjari for moderately resistant genotypes; LE 470, BB-7 and Jwalasakhi for moderately susceptible genotypes and Pusa Ruby, Pusa Purple Long and Pusa Jwala for susceptible varieties respectively. These selected genotypes were used for further biochemical, biological and nutritional studies. Root, stem and leaf of each selected variety / line were utilised for biochemical and nutritional studies. The biological factors were studied using the rhizosphere soil of these genotypes.

The studies on biochemical, biological and nutritional parameters of the healthy plants of four categories of tomato, brinjal and chilli revealed that there is no common trend in the biochemical constituents in the different plants and plant parts. In tomato, the OD phenol content and polyphenol oxidase enzyme activity; in brinjal all the biochemical parameters studied except alkaloids and in chilli the phenol content were higher in the resistant genotype respectively. In the case of biological factors the resistant genotype maintained a

higher population of nematodes, avirulent *Pseudomonas* and mycorrhiza, and the susceptible genotype recorded a higher population of total microflora and virulent *Ralstonia*. The nutritional factors did not show a common pattern or trend under healthy condition except for calcium which was higher in resistant genotype of the three crops.

Changes in the various biochemical, biological and nutritional factors upon infection by *R.solanacearum* were also studied. In the case of phenolics, a high total phenol content was noticed in the susceptible varieties / lines of tomato and chilli compared to resistant genotype under healthy condition. In brinjal and chilli the trend was reversed. Upon infection, the total phenol content increased in tomato and chilli irrespective of plant parts and it remained at the highest level in resistant genotype under diseased condition. A decrease in total phenol was noticed in the root of resistant genotype of brinjal.

OD phenol content was higher in root of resistant genotype of tomato, brinjal and chilli, but a reverse trend noticed in stem under healthy condition. After infection it increased in all plant parts of tomato and chilli except in the stem of susceptible ones. In brinjal root, a decrease in OD phenol content was noticed after infection in all the varieties / lines, but an increase was noticed in the stem and leaf.

The soluble sugar content decreased after infection by *R.solanacearum* in tomato, brinjal and chilli. An increase in soluble sugar was noticed in the resistant variety of tomato, LE 79-5 and in leaf of three crops. Under healthy condition it was higher in susceptible genotype of tomato and resistant genotype of brinjal and chilli. But under diseased condition it was higher in the susceptible genotype in root and stem of all crops.

The total free amino acids, number of amino acids and soluble proteins were higher in susceptible varieties / lines in all crops under healthy condition and upon infection there was an increase in the above components and were higher in resistant genotype.

Among the host enzymes tested for their activity in relation to host resistance, the activity of polyphenol oxidase was higher in resistant plants of tomato and brinjal and in susceptible plants of chilli under healthy condition. After infection more activity was observed in the susceptible genotype of tomato and chilli and in the resistant genotype of brinjal. The enzyme activity decreased in the resistant genotype of tomato and chilli, and increased in brinjal.

The population of virulent *Ralstonia* and avirulent *Pseudomonas* was studied under different host parasite combinations. Under healthy condition the population of virulent *Ralstonia* was higher in the susceptible plants of all the crops. But with induction of disease it increased in resistant genotype and decreased in susceptible ones. But in chilli,it increased in the susceptible genotype also.

Significant difference was not obtained between healthy and diseased plants in mycorrhizal infection and Azospirillum population. However the resistant genotype recorded a decrease in their population due to infection. The resistant genotype recorded a higher mycorrhizal population under healthy condition.

The saprophytic nematode population was higher in resistant genotype and decreased due to infection. The parasitic nematode population increased in all except in chilli upon infection. It was highest in resistant genotype of tomato and chilli and in susceptible ones of brinjal under healthy condition. But after infection this trend was reversed.

Among the various nutritional factors studied, nitrogen content of root, stem and leaf did not show much significant differences under healthy and diseased condition.

The phosphorus content was highest in the susceptible genotype both under healthy and diseased condition. Due to infection by *R.solanacearum*, an increase in phosphorus content was noticed in most of the plant parts.

Significant difference was not obtained in potassium content either between varieties / lines or between healthy and diseased condition.

The calcium content was high in the resistant genotype especially in stem under healthy condition. After infection the calcium content decreased in resistant genotype and increased in susceptible ones. The susceptible genotype recorded a higher calcium content after infection.

Magnesium content did not show any regular pattern either in healthy and diseased plants.

The iron content increased in the resistant genotype of tomato and brinjal, but decreased in chilli after infection. Under healthy condition the susceptible plants of tomato and brinjal and resistant plants of chilli recorded higher iron content.

The zinc content increased due to infection by *R.solanacearum* in resistant plants of tomato and chilli, but decreased in their susceptible plants; and in all varieties / lines of brinjal. The zinc content was higher in the susceptible varieties / lines under healthy condition and in resistant varieties / lines under diseased condition in tomato and chilli. In brinjal the zinc content was high in resistant genotype both under healthy and diseased condition.

The manganese content decreased in the root of all varieties / lines of tomato, brinjal and chilli after infection, but increased in stem and leaf of resistant genotype. The susceptible ones recorded higher manganese content both under healthy and diseased condition.

Considerable variations were noticed in biochemical, biological and nutritional factors between crops and or their plant parts in tomato, brinjal and chilli. Among the three crops tomato and chilli showed similarities in biochemical parameters, nematode populations and zinc content. Tomato and brinjal showed similarity mainly in virulent *Ralstonia* population and nutritional factors. Brinjal and chilli showed uniformity in biological factors, alkaloid and potassium content.

All the three crops recorded uniformity in specific activity, Azospirillum population and calcium content both under healthy and diseased condition.

Thus the study revealed that it was not possible to arrive at common bases for resistance to bacterial wilt in tomato, brinjal and chilli taken together. However it was possible to outline the important parameters that conditions resistance in individual crops.

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* Originals not seen.

BIOCHEMICAL AND BIOLOGICAL BASES OF RESISTANCE IN SOLANACEOUS VEGETABLES AGAINST BACTERIAL WILT INCITED BY *RALSTONIA SOLANACEARUM* (SMITH) YABUUCHI *ET AL.*

By

T. SHEELA PAUL

ABSTRACT OF THE THESIS

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Faculty of Agriculture

Kerala Agricultural University

Department of Plant Pathology

COLLEGE OF HORTICULTURE

VELLANIKKARA, THRISSUR 680 654

KERALA, INDIA

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ABSTRACT

An investigation on biochemical, biological and nutritional bases of resistance in solanaceous vegetables against bacterial wilt incited by *Ralstonia solanacearum* (Smith) Yabuuchi *et al.*, has been attempted.

The pathogen *R. solanacearum* was isolated from respective hosts and characterised by various morphological, cultural, biochemical and physiological tests upto biovar level.

The three isolates were cross inoculable, and were sensitive to Ambistryn and Streptocycline. Based on these studies the tomato and chilli isolates were identified as *Ralstonia solanacearum* race I biovar III and that from brinjal as *R. solanacearum* race I biovar V.

The study on toxigenic property of the bacterial isolates revealed that the toxic metabolites were not host specific.

Out of the 43 varieties / lines screened , 12 varieties / lines were selected, one each from resistant, moderately resistant, moderately susceptible and susceptible

categories. The varieties / lines selected were LE 79-5, BT-10, LE 470 and Pusa Ruby for tomato; Swetha, Composite-2, BB-7 and Pusa Purple Long for brinjal and Ujwala, Manjari, Jwalasakhi and Pusa Jwala for chilli.

The studies on biochemical, biological and nutritional factors in tomato, brinjal and chilli showed considerable variation between crops, between varieties/ lines, and between plant parts. However the root being the primary foci of infection by *R. solanacearum* the biochemical reactions in root is considered more important than other plant parts. Among the biochemical factors, the OD phenol and specific activity increased due to infection and the content was higher in the resistant genotype (LE 79-5) both under healthy and diseased condition in tomato. In brinjal, the polyphenol oxidase activity, specific activity and peroxidase activity increased due to infection and were higher in resistant genotype (Swetha) both under healthy and diseased condition. In chilli, total phenol and OD phenol, increased due to infection and were higher in resistant plants (Ujwala) under healthy and diseased conditions. The soluble sugar content and specific activity were also higher in resistant plants both under healthy and diseased condition even though a decrease was observed due to infection .

In tomato, the resistant genotype showed a higher content of OD phenol, polyphenol oxidase activity, specific activity and alkaloids under healthy condition; and total phenol, OD phenol, soluble protein, specific activity and peroxidase activity under diseased condition. In brinjal, the resistant genotype recorded higher content of total phenol, OD phenol, soluble sugars, amino acids, soluble protein, polyphenol oxidase activity, specific activity and peroxidase activity under healthy condition; and polyphenol oxidase activity, specific activity and peroxidase activity under diseased condition. In chilli, the resistant genotype recorded higher total phenol, OD phenol, soluble sugars and specific activity under healthy condition; and total phenol, OD phenol, soluble sugars, specific activity and peroxidase activity under diseased condition.

Among the biological factors, the total microflora (fungi and actinomycetes), Pseudomonads and parasitic nematodes increased due to infection in resistant genotype whereas beneficial microbes recorded a decrease in population in resistant genotype by infection.

In tomato the resistant genotype recorded higher nematode population under healthy condition and higher total microflora, virulent *Ralstonia* and avirulent *Pseudomonas* under diseased condition. In brinjal the

resistant genotype recorded higher population of fungi, avirulent *Pseudomonas*, mycorrhiza and saprophytic nematodes under healthy condition, and fungi, virulent *Ralstonia*, avirulent *Pseudomonas* and nematodes under diseased condition. In chilli, the resistant genotype recorded higher populations of avirulent *Pseudomonas*, mycorrhiza and nematodes under healthy condition and fungi, avirulent Pseudomonas and mycorrhiza under diseased condition.

Among the nutritional factors, in tomato the resistant genotype recorded higher content of potassium and calcium under healthy condition and iron, zinc and manganese under diseased condition. In brinjal the resistant genotype recorded higher content of nitrogen, calcium, magnesium and zinc under healthy condition; and potassium , magnesium, iron and zinc under diseased condition. In chilli, the resistant genotype recorded higher content of phosphorus, calcium and iron under healthy condition; and nitrogen, potassium magnesium and zinc under diseased condition.

Thus the study revealed that it was not possible to arrive at common bases for resistance to bacterial wilt in tomato, brinjal and chilli taken together. However it was possible to outline the important parameters that conditions resistance in individual crops.