GENETICS OF BLAST RESISTANCE AND BIOCHEMICAL COMPOUNDS ASSOCIATED WITH DISEASE RESISTANCE IN FINGER MILLET (*Eleusine coracana* G.)

M. BYRE GOWDA

DEPARTMENT OF GENETICS AND PLANT BREEDING
UNIVERSITY OF AGRICULTURAL SCIENCES
BANGALORE
1997

GENETICS OF BLAST RESISTANCE AND BIOCHEMICAL COMPOUNDS ASSOCIATED WITH DISEASE RESISTANCE IN FINGER MILLET (*Eleusine coracana* G.)

M. BYRE GOWDA

Thesis submitted to the
University of Agricultural Sciences, Bangalore
in partial fulfilment of the requirements
for the award of the Degree of

Doctor of Philosophy
in
GENETICS AND PLANT BREEDING

BANGALORE MARCH 1997

Affectionately Dedicated to

My Beloved Parents

DEPARTMENT OF GENETICS AND PLANT BREEDING
UNIVERSITY OF AGRICULTURAL SCIENCES
BANGALORE

CERTIFICATE

"This is to certify that the thesis entitled "**GENETICS OF BLAST RESISTANCE AND BIOCHEMICAL COMPOUNDS ASSOCIATED WITH DISEASE RESISTANCE IN FINGER MILLET (*Eleusine coracana* G.)**" submitted by **Mr.M.BYRE GOWDA,** in partial fulfilment of the requirements for the degree of **DOCTOR OF PHILOSOPHY** in **GENETICS AND PLANT BREEDING** to the University of Agricultural Sciences, Bangalore, is a record of research work carried out by him under my guidance and supervision, and that no part of the thesis has been submitted for the award of any other degree, diploma, associateship, fellowship or other similar titles.

Bangalore
Date: 5th Mar. 1997

(B.T.SHANKARE GOWDA)
MAJOR ADVISOR

APPROVED BY:

Chairman:

(B.T.SHANKARE GOWDA)

Members:

(A.SEETHARAM)

(M.UDAYA KUMAR)

(S.VISWANATH)

(S.K.THIMMAIAH)

ACKNOWLEDGEMENTS

I wish from my heart my profound sense of gratitude, appreciation and indebtness to the Chairman of my Advisory Committee, ***Prof. B.T.Shankare Gowda****, Geneticist, Project Co-ordinating Unit (Small Millets), whose pragmatic ideas, able guidance, inspiring encouragement, constant supervision and sustained interest during the course of study always been a great inspiration. I thank him for his invaluable suggestions and constructive criticisms throughout the period of research work and preparation of manuscript.*

I was really fortunate to have ***Dr. A.Seetharam****, Project Co-ordinator, All India Co-ordinated Small Millets Improvement Project, Bangalore in my Advisory Committee. I am highly indebted to him for suggesting the problem, his inspiring guidance, precious suggestions provided throughout the period of experimentation and critical review of the manuscript. I thank profusely for the kind help for providing necessary field, laboratory facilities and chemicals, without his whole hearted support it could have been really impossible to work to the satisfaction.*

I owe my heartiest gratitude to the members of my Advisory Committee, ***Dr. M.Udaya Kumar****, Professor and Head, Department of Crop Physiology,* ***Prof. S.Viswanath****, Pathologist, Project Co-ordinating Unit (Small Millets) and* ***Dr. S.K.Thimmaiah****, Assistant Professor of Biochemistry for their valuable suggestions and for reviewing the manuscript.*

I am highly indebted to ***Dr.M.Mahadevappa****, Vice Chancellor, UAS, Dharwad and former member of my Advisory Committee,* ***Dr. R.S.Kulkarni****, Professor and Head, Department of Genetics and Plant Breeding and* ***Dr. M.V.Nagaraja Setty****, Senior scientist (Pulses) for their valuable suggestions and support during the course of study.*

Although, I learn that all my words of gratitude can not be a substitute for the help and the support by ***Jayarame Gowda****, Assistant Professor, AICRP on Sunflower for* *his skilfull involvement in statistical analysis and depictions used in the text. I am doing this duty to mitigate my cordial feelings.*

*My sincere thanks to **Dr. Nagaraj**, Associate Professor, Plant Pathology, **Y.Viswanatha Shetty**, Assistant Professor of Soil Science, RRS, Shimoga, **Mr. M.S.Nagaraja**, Ph.D. Scholar of Soil Science, **Dr. Radhakrishna**, Associate Professor of Microbiology, **Dr. T.K.Siddarame Gowda**, Professor of Biotechnology, **Dr. K.T.Krishne Gowda**, Agronomist (Small millets), **Dr.K.T.Rangaswamy**, Junior Pathologist (Pulses) and **Mr.M.Chandrappa**, Assistant Professor (Small Millets) for their kind help to conduct various chemical analysis.*

*I am equally thankful to **Dr.S.Ramesh**, Research Associate, Sunflower Scheme and **Mr. K.Seenappa**, Associate Professor, AICIRP on sunflower for their involvement in statistical analysis and preparation of manuscript.*

*My warm thanks to **Mr.B.M.Ramakrishna**, Assistant Professor and **Mr.Chikke Gowda**, Field Assistant and other staff members of AICRP on Small Millets for helping me in conducting the experiments. My thanks are due to my collegues **Mr.Chandra Prakash**, **C.S.Jagadeesh Babu**, **B.C.Shankaralingappa** and other friends who helped me in one way or the other during the study.*

*My major debt is no doubt to my family. I owe a great deal to my parents, wife **Smt. B.R.Gayathri**, children **B.Surakshith** and **B.Parikshith**, in-laws **Mrs. Susheelamma**, **Mrs. Prema** and **Mr. B.M.Ramaiah**, brothers, sister, brother-in-laws, sister-in-law and co-brother for their commendable co-operation, understanding and forbearance during the period of study. I also wish to express my deep sense of gratitude to my sister, **Smt.Anasuyamma** and brother-in-law, **P.Nagaraj** for their encouragement and enthusiastic support throughout my study programme.*

*I am also thankful to **Dr. P.Narayanaswamy**, whose patience and calmness has resulted in presenting my work in a very high order and quality.*

5th March, 1997
Bangalore

(M.BYRE GOWDA)

CONTENTS

LIST OF TABLES

LIST OF FIGURES

INTRODUCTION

I INTRODUCTION

Finger millet commonly known as 'ragi' is one of the important food crops and largely grown in southern states of India. It is a staple food of rural and working people in many states in general and south east and central Karnataka in particular. Its straw is a valuable cattle feed. The grains are nutritionally superior to many cereals providing protein, minerals especially calcium (0.34% on weight basis) and vitamins in abundance to the poor class, where the need for such ingredients is maximum. As such, the finger millet is considered as a nourishing food by the people who put in manual labour and also preferred because of its long sustenance providing energy for a long time after consumption.

In India, finger millet is grown annually over an area of 2.15 million hectares with a production of 2.68 million tonnes. Karnataka alone produces 1.44 million tonnes in an area of 0.94 million hectares, which accounts for nearly 44 per cent of area and 54 per cent of total production under the crop in the country. The other finger millet growing states are Tamil Nadu, Orissa, Maharashtra, Andhra Pradesh, Uttar Pradesh, Bihar and Gujarath (Anon., 1996).

Finger millet is a hardy crop and is free from diseases. However, in recent years, many fungal and viral pathogens have been infecting the crop leading to significant grain and fodder yield losses. Among the diseases, blast incited by *Pyricularia grisea* is the most serious affecting all aerial parts at all stages of crop growth-from seedling to grain filling, causing yield losses to the tune of 36.4 per cent in some years under favourable conditions (Viswanath and Seetharam, 1986).

With the spread of high yielding varieties and the change in cultural practices which accompanied green revolution, there has been a shift away from traditional cultural practices. Traditional varieties have been replaced by high yielding varieties. However, most of these varieties lack in-built resistance, since at the time of development of these varieties importance was not given to incorporate resistant genes. Further, intensive cultivation practices with high levels of nitrogen application has resulted in their increased susceptibility to infection. Although chemical control is highly effective, it is neither feasible nor economical as the crop is cultivated by marginal farmers under dry land conditions. Further, disease control through application of fungicides pose many environmental hazards. Under such circumstances, developing genotypes with high level of resistance to blast along with high grain yield is the only alternative in combating the disease.

Disease resistance is the ability of the plants to prevent, restrict or retard disease development. Plants have their own built-in resistance mechanisms against almost all microorganisms, but in a few cases the pathogen may overcome the defense barrier with their offensive chemicals and cause disease. The pathogen may invade the host by circumventing the recognition process of the host. The plants upon recognizing the invader, synthesize several toxic chemicals such as phenolic compounds, phytoalexins, lignin and some hydrolytic enzymes to ward off the pathogen (Vidyashekaran, 1988). In the battle between the pathogen and the plants, sometimes plants may lose the battle. If the mystery of disease resistance is unraveled, scientists can engineer plants to win the battle, even when the pathogens have an array of offensive chemicals.

Inspite of the extensive studies done on biochemical and physiological basis of plant parasitic relationships, there are wide gaps in our fundamental knowledge on association of plant genes with their biochemical products. This necessitates a thorough understanding of the biochemical parameters conferring resistance/susceptibility and using them as an index of resistance in segregating populations and germplasm lines even in the absence of epiphytotics.

Though rapid strides have been made in the identifying and cloning of disease resistant genes and characterization of gene products in many crops, finger millet has received very little attention. Recently, efforts have been made to know the genetics of blast resistance and the association of biochemical compounds- proteins, phenols and tannins with blast disease in a limited number of resistant and susceptible finger millet varieties (Seetharam and Ravikumar, 1993; Ravikumar *et al.*, 1995). However, no concerted effort has been made in the past to study the genetics of biochemical compounds and their association with blast disease and grain yield in the segregating populations which helps in planning the resistance breeding programmes on a sound footing. In the present study, the genetics of blast resistance and the biochemical compounds conferring resistance/susceptibility were investigated in two planned crosses by estimating the narrow sense heritability which includes mainly additive component (fixable) and is more reliable in deciding selection programmes. The study was also intended to further elucidate the role of biochemical compounds in imparting resistance/susceptibility in the segregating populations. The material so developed was also utilized to study the genetics of yield and some of its components and their association with blast disease and biochemical compounds.

With this in background, the present investigations were undertaken with the following specific objectives:

1. to study the nature of inheritance of blast disease, protein, phenol, tannin, yield and yield components,
2. to study the role of protein, phenol and tannin in imparting resistance/susceptibility and their effect on grain yield,
3. to estimate the relative contribution of different characters on blast disease and grain yield, and
4. to formulate the strategies for combining yield, blast resistance and grain quality.

REVIEW OF LITERATURE

II REVIEW OF LITERATURE

Finger millet or ragi (*Eleusine coracana* Garten.) is attacked by many diseases. Of these, blast caused by *Pyricularia grisea* is the most destructive fungal disease. While it is true that chemical control of blast is possible, in reality it can not be practiced due to monitory and other constraints. So, resistance breeding is of utmost importance.

McRae (1922) first reported an epiphytotic form of blast on finger millet causing grain losses up to 50 per cent. Later, Venkatarayan (1947) estimated 80 to 90 per cent yield loss under favourable conditions. Rath and Mishra (1975) working on the nature of losses due to neck blast on yield components reported a significant loss of 40 to 49 per cent grain number per panicle, 4 to 10 per cent increase in spikelet sterility and 7 to 25 per cent decrease in spikelets per panicle. Crop loss due to blast has been reported by many workers (Rao, 1982 and 1990; Seetharam and Viswanath, 1983; Viswanath and Seetharam, 1986).

2.1 Blast disease of finger millet

2.1.1 Pathogen

The blast causing organism *Pyricularia* spp. belong to class - Deutoromycetes, Order - Moniliales and Family -Moniliaceae. The blast fungus has marked pathogenic variability infecting many species of the family Poaceae. The two most common and morphologically similar species are *Pyricularia oryzae* and *Pyricularia grisea* (Paul, 1980). Blast on finger millet was first reported by Park (1937) from Ceylon. But the casual organism was called by earlier workers as *P. oryzae* (Hansford, 1943; Ramakrishnan, 1948).

According to Ramakrishnan (1948) *Pyricularia* from finger millet are cross inoculable. Wallace (1950) stated that the *Pyricularia* on finger millet is morphologically similar to *P. oryzae* but is almost certainly *P. setariae*. Ramakrishnan (1948) observed no appreciable differences in morphological characteristics among four isolates of *Pyricularia*-rice, finger millet, foxtail millet and *Digetaria indiginata*. So, it is reasonable to include morphologically related species under one species. But most of the literature, however, is found under *P. oryzae* on rice; while *P. grisea* is the earliest name given to group of fungi and therefore should be used according to the rules of nomenclature. Sprague (1950) while preparing the index of plant diseases gave the name *P. oryzae* for the fungus only on the rice and *P. grisea* for other cereals/grasses. Therefore it is appropriate to refer the casual organism on blast in finger millet as *P. grisea*.

The severity of blast depends on the climatic conditions. The fungus is known to prefer low temperatures ($<20^{\circ}$C) with high humidity, heavy rainfall and low light for outbreaks (Viswanath and Chennamma, 1988). Jain *et al.*(1994) while assessing the stable resistance of blast in finger millet, reported that moderate temperatures between 21°C to 29°C with more than 80 per cent mean atmospheric relative humidity during reproductive period favoured the disease development.

2.1.2 Symptoms

The pathogen can infest the crop at all stages of growth from seedling to post flowering stage. Small, brown, circular to elongated spots appear on leaves which coalesce and develop into large elongated or spindle shaped spots with yellowish margins and greyish green centres. Later, the centres become grey or whitish grey under humid conditions, an olive grey outgrowth of fungal spores develop at the centre of the spots. The infection during heading stage occurs on the neck region resulting in not only in blackening of the area but also in weakening of the tissues and consequent breaking of the ears. Similar infections occur at the basal part of the panicle branches including the fingers. Ears affected at the neck become chaffy and if there is any grain set at all, they are poorly filled. When infection occurs near the base of fingers they fail to develop further, though rest of the ear might grow normally.

2.2 Sources of resistance to blast disease in finger millet

Serious efforts were made during 1980's for identifying the sources of resistance by screening large number of germplasm lines maintained at Bangalore. Viswanath *et al.*(1986a) screened 1941 germplasm accessions. They found 30 entries resistant to finger blast; 281 entries to neck blast and 18 entries to leaf blast.

Viswanath *et al.*(1986b) identified cultivars IE 1012, HPBIE 11-1, MR 3, MR 2 and MR 1 as resistant in that order for both neck and finger blast. Jena and Patnaik (1987) assessed 120 finger millet varieties and reported that GE 3482 was immune to the disease infection while GE 3542 and GE 3502 were resistant, and GE 3482, GE 3502, GE 3490 and GE 3073 were moderately resistant.

Ravikumar *et al.*(1990) evaluated 316 accessions over four seasons. Seven genotypes; GE 75, GE 669, GE 866, GE 1309, GE 1407 and GE 1409 showed resistance to both neck and finger blast across environments.

Twenty five cultures were assessed for their resistance by Somashekara *et al.*(1991). None of the cultures were resistant to leaf blast but HPBIE 11-1 had small sized lesions. IE 1012 was completely immune for neck and finger blast. There was poor correlation between leaf and neck blast (r= 0.04), leaf and finger blast (r=0.27) infection, Somashekara *et al.*(1992) reported that I81 E and IE 1012 were completely free from blast infection.

Realizing the need for identifying the sources of resistance to blast disease in the assembled germplasm of 4000 accessions at the Small Millets Co-ordinating Unit, University of Agricultural Sciences, Bangalore, an elaborate programme was drawn up in a phased manner by growing each year a representative collections of about 1000 accessions. The disease incidence ranged from 0 to 80.4 per cent and 0 to 99.0 per cent for neck and finger blast, respectively. The study resulted in 286 entries which were free from both neck and finger blast and showed high level of resistance (Ramakrishna *et al.*, 1996).

It is evident from the above that, high degree of resistance is present in the available germplasm which could be transferred through appropriate breeding techniques.

2.3 Studies on role of biochemical compounds on disease resistance and grain yield

Higher organisms constantly are challenged by insects, viruses, bacteria and fungi trying to explore different habitats as nutrient source. In the course of evolution both partners of the interaction evolve together and develop mechanisms either to benefit from the interaction or to battle for survival. Plants have developed an impressive array of defensive mechanism to cope with different biotic and abiotic stresses. These mechanisms either have a antimicrobial effect or serve to reinforce the cell wall (Baron and Zambryski, 1995). Also, resistance mechanisms have been classified as 'passive' or 'constitutive' defenses which are present in uninoculated plants and 'active' mechanisms which are induced by microbial challenge (Ride, 1985; Nicholson and Hammerschmidt, 1992). Consequently, healthy plants may contain a wide range of substances with antimicrobial activity and the involvement of these secondary metabolites in host plant resistance are reviewed below.

2.3.1 Phenolics

A wide range of substances possessing an aromatic ring bearing hydroxyl substituent are called phenolic substances. They are common constituents of many plants and are known to participate in a number of physiological processes which are essential for growth and development. Phenolic compounds include flavonoids, phenolic quinones, lignones, xanthones, espidones, lignins, melanins, tannins, glycosides, sugar esters of phenolic acids, esters of hydroxy cinnamic acids and coumarin derivatives. Some phenolics inhibit the production of fungal enzymes and inactivate the enzymes produced by the pathogens. In many cases, total phenolics may suppress toxin production of the pathogen or destroy the toxins produced by them (Kosuge, 1969; Vidyashekaran, 1988; Weiguangma *et al.*, 1995). These substances may be responsible for the delay and decline in number of germinations, appressoria, penetrations and colonization at the onset of infection (Angra, 1989).

The importance of phenolics in disease resistance was identified quite early in 1930s. From research on resistance of onion to *Colletotricum circinans* (Link *et al.*, 1929; Angell *et al.*, 1930; Link and Walker, 1933; Walker and Stahmann, 1955) evidence was assembled to indicate that the phenolic compounds, viz., catechol and protocatechuic acid present in the dead outer scales of red or yellow onion cultivars were responsible for resistance.

Lee and Le Tourneau (1958) found that resistance of potato to *Verticillium* wilt was positively correlated with the concentration of chlorogenic acid in root tissues as the potato plants developed and matured, the phenol concentration decreased more rapidly and to a lower level in susceptible varieties than in resistant ones. Higher concentration of chlorogenic acid in vascular tissue of resistant cultivars to *Verticillium* wilt compared to susceptible cultivars was reported by McLean *et al.*(1961) and Patil *et al.*(1966) in potato and Sheppard and Peterson (1976) in tobacco.

2.3.1.1 Role of phenolics for disease resistance in finger millet

Vidyashekaran (1974a) assessed the factors responsible for resistance against *Helminthosporium nodulosum* which causes leaf blight in finger millet. The leaves of resistant (K1) and susceptible (Co 4) varieties were analyzed at different periods of inoculation for their phenolic content. Phenolics increased due to infection, the increase was gradual and found to be maintained in the susceptible leaves infected by the highly virulent isolate upto 15 days of inoculation. In the less virulent and avirulent isolate infected leaves of both varieties there was an initial increase in the phenolics but subsequently returned to a nearly normal level. In the avirulent isolate infected leaves, the initial burst of phenolics disappeared sooner than in those infected by less virulent isolate. These results suggested the accumulation of phenolics, but the speed with which phenolics accumulate may be related to the disease resistance.

Vidyashekaran (1975) observed that the phenolics did not inhibit spore germination of *H.nodulosum* and the growth of the pathogen was inhibited significantly only at 1000 ppm of the phenolics. But the oxidised phenolics inhibited spore germination and growth of the pathogen markedly even at 100 ppm. Phenoloxidase activity in leaves of resistant varieties was greater.

There was an attempt to increase the phenolic content of finger millet leaves for inducing resistance against *H.tetramara*, the leaf spot pathogen by spraying different concentrations of catechol (Vidyashekaran, 1974b). But it proved to be phytotoxic. However, glucose sprayed at 5 and 10 per cent concentration significantly increased the phenolic content of leaves of both resistant and susceptible varieties and decreased the disease incidence markedly. Since, the phenolics are synthesised through the Shikimic acid pathway from sugar, it is likely that the spraying glucose would have increased the synthesis of phenolics. Vidyashekaran (1974a) also attempted to increase the phenolics of leaves by application of potassium. Application of potassium at 30 kg/ha increased Phenolic content and decreased the helminthosporiose.

Seetharam and Ravikumar (1993) reported that, the brown seeded types have significantly higher quantity of total phenols than whites. Brown grain types were found to be resistant to blast disease than whites, as endogenic levels of phenols do influence the level of blast resistance.

Ravikumar *et al.*(1995) reported significantly higher level of total phenols in resistant cultivars compared to susceptible lines. The correlation studies between blast disease and phenols indicated strong negative association.

2.3.1.2 Role of phenolics for disease resistance in other crops

Increasing emphasis is being placed on phenolic compounds in disease resistance mechanism in plants. It is known that certain phenolic compounds and their oxidation products play an important role in inducing resistance against further invasion of the pathogen (Kosuge, 1969) or with their direct influence on other metabolic processes. The increase in concentration of phenolic compounds after infection has been recognized by many workers (Farkas and Kiraly, 1962; Mahadevan, 1973; Chattopadhyay and Bera, 1980; Abdul Galit *et al.*, 1981; Sathiyanathan and Vidyashekaran, 1981; Valluvaparidasan and Mariappan, 1983; Harms and Tarbea, 1984; Southerton and Deverall, 1990; Cahill and McComb, 1992; Sharma *et al.*, 1992; Velazhahan and Ramabhadran, 1993). These studies indicated that phenolics formed after infection are playing important role in disease resistance.

Harrison *et al.*(1961) attributed the differences in cultivar susceptibility to *Cercospora* leaf spot in sugar beet to differing concentration of phenolic substances. Similar results were also been obtained by Reddy (1971) who found higher concentration of total phenols in blast resistant variety of rice.

In 24 rice varieties with resistant or susceptible reaction to *Helminthosporium oryzae,* resistance was directly related to total phenolic content of the healthy leaves (Chattopadhyay and Bera, 1978). A similar association was also observed by Sathiyanathan and Vidyashekaran (1981) and Valluvaparidasan and Mariappan (1983) in rice cultivars resistant to *H.oryzae* and *Pyricularia oryzae*, respectively.

Prabhu *et al.*(1984) found that the callus obtained from downy mildew resistant sorghum cultivar contained higher amounts of phenols than that of a susceptible cultivars. Similarly, higher amounts of phenols in resistant cultivars was reported by Bhuller *et al.*(1972) and Narain and Mahapatra (1973) in chillies; Anahosur *et al.*(1985) in sorghum; Dhawan *et al.*(1981), Gupta *et al.*(1984) and Yadav *et al.*(1996) in Indian mustard; Cahill *et al.*(1993) in eucalyptus; Chaurasia *et al.*(1993) in pigeon pea and Angra-Sharma and Sharma (1994) in maize.

Mayama *et al.*(1981) reported that the amount of total phenols was greater in plants infected by less virulent races than by more virulent races of crown rust in oats. Similarly, Baker *et al.*(1989) reported that accumulation of phenolic compounds depended upon both the host and the race of the pathogen, while inducing resistance in interactions involving *Medicago sativa* and *Colletotricum trifoli.*

The levels of total phenols in cowpea leaves of resistant and susceptible cultivars to powdery mildew was determined by Satyanarayana *et al.*(1992). Inherently, the resistant cultivars had higher polyphenol content compared to susceptible cultivars. Similarly, relatively high constitutive levels of phenolics in resistant lines of *Eucalyptus marginata* against *Phytopthora cinnamoni* was reported by Cahill *et al* (1993).

Somani (1992) screened 46 genotypes of sorghum against grain moulds. Higher free phenolic compounds were noticed in resistant white grained sorghums. Mathur and Bhatnagar (1994) also reported similar results in resistant genotypes of tomato infected with *Stemphylium botryosum.*

Mahabaleswar Hegde (1992) reported faster accumulation of total phenols in leaf rust resistant wheat genotypes DWR 163, DWR 174 and local Khapli as compared to other genotypes.

Biochemical changes with reference to total phenols was studied in rice leaf sheath infected with *Rhizoctonia solani* by Ayesha Siddiqua and Kashem (1993). The total phenols decreased with age and degree of pathogenesis. Resistant varieties are found to have higher amount of total phenolics. The disease incidence was found to have significant negative association with grain yield.

Performance of different cultivars associated with differing resistance to *Phytopthora capscici* showed qualitative and quantitative variation after inoculation, notably an increase in the total phenolics in the resistant and intermediate varieties (Candela *et al.*, 1995). The soluble phenolics retarded mycelial growth of *P.capsici* in culture, colonization and necrosis spread throughout the stem of susceptible cultivar whereas it was only partially invaded in resistant genotypes.

Ganguly (1995) studied the different rice cultivars along with their metabolic and biochemical changes in respect to total phenol in uninoculated and inoculated plants with *Rhizoctonia solani*. Of the susceptible cultivars, Indrasail showed the best performance for yield and components and accumulation of phenols. The resistant cultivar IR 20 had higher levels of phenols than susceptible ones.

2.3.2 Tannins

Certain dihydroxy phenols are conjugated with each other or with glucose hydroxyl groups to form polyhydroxy phenolic oligomers and polymers called tannins. The tannins are also precursors of melanin biosynthesis. Phenolic residues in the originally colourless tannin molecule may also oxidise to quinone residues. The coloured condensation products of quinones and tannins constitute the plant melanins.

The tannins have long been known for their antimicrobial activity (Bell, 1981). Race specific resistance associated with necrosis is characterized by the formation of brown to black pigments. The pigmentation is normally due to accumulation of melanins. The accumulation of melanin is more in resistant plants suggesting that melanins or their precursors contribute for resistance (Bell, 1981).

Seetharam and Ravikumar (1993) reported that white grained finger millet cultivars have significantly lower total tannins compared to browns. White grained types were found to be more susceptible to blast than browns as endogenic levels of tannins do influence the level of susceptibility.

Ravikumar *et al.* (1995) observed that resistant genotypes of finger millet had higher levels of total tannins in all the four growth stages and it was negatively correlated with blast disease.

2.3.3 Proteins

The protein and nitrogen content of plant is also known to play an important role in determining the level of resistance. McNew and Spencer (1939) and Shear and Wingard (1944) demonstrated the relationship between higher nitrogen content of plants and disease susceptibility.

2.3.3.1 Role of proteins for disease resistance in finger millet

Protein content in finger millet is highly influenced by environment, i.e., the level of nitrogen application (Marimuthu and Rajagopalan, 1995). The study revealed that the protein content need not be a selection criterion while exercising selection in segregating progenies of finger millet.

Dineshkumar (1986) evaluated twenty cultivars each of elite brown and white finger millet for their performance for yield, protein content and blast susceptibility. He reported that white grained types were low yielders but possessed high protein content and high susceptibility to blast disease, whereas brown types were high yielders, but possessed low protein and less susceptibility to blast disease.

Seetharam and Ravikumar (1993) studied the association of seed colour with seed protein content and blast susceptibility in white and brown grained cultivars. The white grained types had significantly higher level of protein than browns. The mean finger blast incidence showed that, in general, white grained types were more susceptible than the browns. The study further revealed that protein content was positively associated with finger blast.

Finger millet accessions showing high resistance and susceptibility for both neck and finger blast were studied at four different stages for protein content and its association with blast incidence (Ravikumar *et al.*, 1995). The total protein content was higher in susceptible lines compared to resistant lines. The correlation values of finger blast and neck blast with total protein were significant and positive.

2.3.3.2 Role of protein for disease resistance in other crops

The nitrogen content of blast resistant rice cultivar was reported to be lower than that in a susceptible one (Paik, 1970). The resistant plant also had higher amount of free amino acids particularly glutamine, valine, leucine and isoleucine. Similar results were also obtained by Sati and Grewal (1982).

Li *et al.*(1983) from their studies on "effect of N fertilizers on blast resistance of rice cultivars" observed that the increasing use of N fertilizers in rice resulted in heavy incidence of rice blast. This was due to increase in concentration of soluble amino acids resulting from higher N application. Shatla *et al.*(1983) also reported identical results. But, Adam and Gilly (1984) observed reduced number of necrotic lesions on barley with increasing nitrogen concentration.

Seeds of pearl millet resistant to downy mildew had less crude protein than those of the susceptible (Gupta and Gupta, 1986), while Hussain *et al.*(1983) observed high correlation between grain protein content and resistance.

Increase in protein content have also been demonstrated in certain compatible and incompatible interactions. Infection by *Helminthosporium sativum* of highly susceptible cultivars of wheat increased total amino acids and total protein contents, whereas in less susceptible cultivars there was a decrease or no change in both parameters after infection (Ismail and Michalik, 1982), whereas Chiranjeevi and Tripathi (1976) observed lower nitrogen content in diseased leaves.

Sharma *et al.*(1992) studied the relationship of proteins in resistant and susceptible cultivars with Turcicum leaf blight disease in maize. The soluble proteins were more in healthy leaves of susceptible plants and less in resistant ones; but in diseased leaves the amount increased in all the cultivars.

Malhotra (1993) also observed considerably high levels of crude protein in healthy leaves of susceptible varieties as compared to resistant ones in tomato for *Fusarium* wilt. But after infection, the position was reversed. There was marked significant increase in resistant varieties; while it decreased significantly in susceptible varieties. This decrease may be the result of nitrogen utilization by the pathogen for its growth.

Yadav *et al.*(1996) reported lower levels of protein in resistant varieties of Indian mustard compared to susceptible varieties. They reported positive correlation between disease susceptibility and protein content. These findings were in conformity with Gupta *et al.*(1984) in relation to leaf blight resistance in Indian mustard.

The investigation carried out by Satyanarayna and Saikumar (1994) in ten parents and 45 F_1 crosses of maize indicated that protein levels, both in parents and their crosses for resistant and susceptible reactions to *Turcicum* leaf blight were found to be *on par* with each other. Similar results were also found by Satyanarayana *et al.*(1995) with charcoal rot resistance in maize.

2.3.3.3 Role of proteins on grain yield

Kramer (1979) obtained considerable variation for protein content in wheat. This variation may be induced by environmental factors; but can also be attributed to genetic differences. Within the genotype, the correlation between grain yield and grain protein can be either close to zero, positive or negative depending on the fertility level. Between genotypes this correlation was strongly negative. Significant genetic variation for protein content was also observed by Hallerislambers *et al.*(1973) in rice and Ramesh and Hudda (1994) in sorghum.

Grain yield and grain protein content are often negatively associated. When grain yield increases, grain protein content decreases. Seetharam *et al.*(1993) noticed negative and highly significant association between grain yield and protein content in finger millet. Similar results were also found by Girishkumar (1995) in finger millet.

Negative association of grain yield and grain protein was reported by many workers (Bhatia, 1975; Halloran, 1981; Loffier and Busch, 1982; Guthrie *et al.*, 1984; Kibite and Evans, 1984; Loffier *et al.*, 1985; Cox *et al.*, 1985; May *et al.*, 1991; Costa and Kronstad, 1994; in wheat, Ramesh and Hudda, 1994) in sorghum.

2.4 Genetics of blast disease, biochemical compounds, yield and yield components

2.4.1 Blast disease

Once the sources of resistance were identified and the role of biochemical compounds on disease resistance was established, it is important to identify and characterize the genes controlling the resistance mechanism. such information is essential for plant breeder for a successful strategy for disease development.

Although, voluminous literature is available on blast disease resistance mechanism in rice owing to its world wide occurrence, information relating to genetics of host plant resistance in finger millet is comparatively meagre. Hence, it is felt that, this review of literature related to genetics of host plant resistance be extended to rice crop also.

Seetharam and Ravikumar (1993) worked out the genetics of blast resistance in finger millet by adopting line x tester analysis, five generation mean analysis and intergeneration correlation and regression. The line x tester analysis suggested the operation of additive gene action for finger blast. The five generation mean analysis revealed non-additive gene action for neck and finger blast. For neck blast both additive and dominance gene effects were significant with predominance of dominance gene effects. Among epistatic gene effects additive x additive gene effects were important. All the three types of gene effects-additive, dominance, additive x additive and dominance x dominance were found to be important for finger blast. In the cross GE 447 x GE 156 only additive and additive x additive gene effects were significant suggesting the possibility of early generation selection. The estimates of narrow sense heritability to neck blast was low and medium for finger blast suggesting additive gene effects are not important in the expression of these characters.

Since rice blast pathogen has specialized and innumerable races have been developed, both major genes which are race specific and polygenes which control field resistance have been found to control the inheritance of the blast disease in rice. Hence it is noticed in the literature that the blast disease has been controlled by one, two, three, four or more genes.

Dominant monogenic inheritance was reported by many workers (Shen *et al.*, 1981; Mohanty and Gangopadhyay, 1982; Buu and Huang, 1983; Salem *et al.*, 1983; Mackill *et al.*, 1985; Luo *et al.*, 1985; Xu, 1986; Yu *et al.*, 1987; Mackill and Bonman, 1992; McCouch *et al.*, 1994; Bhat *et al.*, 1994). In contrast, monogenic inheritance with recessive gene for resistance was reported by few workers (Vivekanandan *et al.*, 1987; McCouch *et al.*, 1994; Bhat *et al.*, 1994).

Digenic inheritance controlled by one dominant gene and one recessive gene was reported by Balal *et al.*(1977), Kiyosawa and Cho.chung (1980), Buu and Huang (1983), Cai (1983), Mackill *et al.*(1985), Xu (1986), Yu *et al.*(1987), Marchetti *et al.* (1987), McCouch *et al.*(1994) and Bhat *et al.*(1994). Digenic inheritance controlled by two dominant genes was reported by Mackill *et al.*(1985), McCouch *et al.* (1994) and Shi *et al.* (1994). Two independently inherited duplicate dominant inheritance was reported by Mackill and Bonman (1992).

The resistance controlled by three genes was reported by other workers (Balal *et al.*, 1977; Shen *et al.*, 1981; Mohanty and Gangopadhyay, 1982).

Phenotypic evaluation of near isogenic lines suggested that resistance was controlled by as many as four genes (Mackill and Bonman, 1992). Yakoo (1994) also reported four genes involved in resistance to blast, one of which was linked to phenol reaction genes.

Rice varieties which have true resistance to blast become susceptible within a few years of their release. Field resistance has become a more important characteristic when breeding new varieties of rice crop. The inheritance of field resistance to blast has been shown to be conditioned by multiple genes (Higashi and Saito, 1985; Lin, 1986; Roumen, 1992; Purba *et al.*, 1994; Wang *et al.*, 1994).

2.4.2 Proteins, phenols and tannins

Since no information is available on genetics of biochemical compounds in finger millet, it is imperative to review the works on genetics of biochemical compounds in other crops.

The protein content exhibit low to moderate heritability reflecting considerable variability (Hallerislambers *et al.*, 1973). They attributed this to genotype x year interactions, to an environment gradient affecting protein content in the field and to within line segregations for the early generations tested. It was suggested that selection for protein content be deferred until later generations.

Segregations for protein content in F_3 generation was continuous and without dominance. In F_4 and F_5, it was again continuous but there was partial dominance for low content (Halloran, 1981).

Sampson *et al.*(1983) estimated the heritabilities for protein content based on intergenaration correlations. It ranged from 0.25 to 0.50. These results suggest additive gene action with at least two minor genes.

Additive and non additive gene effects were found to be important in the expression of protein content studied through a 7 X 7 diallel cross of mung bean by Pathak *et al.*(1990).

Dhaliwal *et al.*(1994) studied the inheritance of protein contents of wheat progenies in different generations. They reported the ratio of 1:14:1, low:medium:high protein content in F_2 and 1:3:0 in the BC_1 generation. These figures indicate that two partially dominant genes which have an additive effect, control protein content in wheat.

Phogat *et al.*(1995) studied the genetic systems governing inheritance of protein content and grain yield in barley by applying combining ability analysis. The grain yield was controlled by non-additive genes while protein content was predominantly controlled by additive genes. Narrow sense estimate of heritabilities was relatively high for protein content and low for grain yield.

Inheritance studies of proteins and phenols in relation to white rust (*Albugo candida*) resistance in Indian mustard was reported by Yadav *et al.*(1996). The study indicated the importance of both additive and dominant components of variance, with the preponderance of later, in the genetic control of both proteins and phenols.

The genetics of tannins has been investigated in *Lotus corniculatus*. The analysis of F_1, F_2 and BC_1 of crosses between high tannin and low tannin plants showed ratios corresponding to a single gene control of this character (Dalrymple *et al.*, 1984).

A single gene control of tannin content was demonstrated in lentil which was inherited quantitatively and heritability for this character was 66.40 (Vaillencourt *et al.*, 1986). High heritability for tannin content was also reported in faba bean seed coat (Ma and Bliss, 1978).

Lee *et al.*(1989) studied the inheritance of tannin content of sorghum grains. The study revealed that the tannin content was controlled by one to two pairs of genes, and the high tannin content was partial dominant over the low tannin content. Further, the results showed the higher broad sense heritability indicating that selection for this character is effective. Similar results were also reported by Bulter (1982) and Woodruff *et al.*(1982) in sorghum.

2.4.3 Yield and yield components

The available literature on genetic parameters for yield and yield components in finger millet from 1970's is reviewed below.

High estimates of phenotypic co-efficient of variablity, heritability and genetic advance for grain yield and plant height was reported by Kempanna *et al.*(1971).

Dhagat *et al.*(1972) reported high genotypic co-efficient of variation for grain yield, ear length and productive tillers and high heritability for plant height and ear length. Grain yield recorded low heritability. Plant height recorded higher values of genetic advance compared to other characters.

Mahudeswaran and Murugesan (1973) made a study with 20 varieties and observed high genotypic co-efficient of variation for grain yield and productive tillers. The study also indicated high heritability and high genetic gain for plant height.

High estimates of heritability and genetic gain observed for grain yield by Setty *et al.*(1974) suggested additive gene action in control of this trait. Plant height, productive tillers and fingers per ear had moderate heritability.

Appadurai *et al.*(1977) have obtained high variability for grain yield and productive tillers and low for plant height, ear length and fingers per ear. Moderate to high heritability and genetic advance was estimated for grain yield, productive tillers, ear length and fingers per ear.

Goud and Lakshmi (1977) found large phenotypic and genotypic variation for tiller number and grain yield. The heritability for plant height and fingers per ear were high, whereas tiller number though had moderate heritability was associated with high genetic gain.

Mallanna *et al.*(1978) in a study comprising 1064 accessions reported considerable genetic variability for plant height, fingers per ear, tiller number, yield and blast resistance.

Swamynath (1978) studied 175 African collections and reported wide variability for all the 15 characters studied. He reported moderate heritability for yield and associated characters. However, grain yield and tiller number had high genetic gain indicating the possibility of improvement through selection.

Agalodia *et al.*(1979) reported that, variability was high for ear length; moderate for productive tillers and low for grain yield and plant height. Heritability estimates were moderate to high for yield, productive tillers and ear length. The genetic advance was low for plant height; moderate for grain yield and high for productive tillers.

The first report for studying inheritance in crosses was made by Shanthappa (1979). He reported high variability for plant height and productive tillers and also found high heritability and genetic gain for plant height and grain weight; medium for productive tillers and low for other characters.

Sarvaiya *et al.*(1982) in a study involving 40 genotypes, found high co-efficient of variability,heritability and genetic advance for grain yield, productive tillers, fingers per ear and ear length.

Shankar (1982) reported high heritability for grain yield and plat height. He also indicated the importance of epistasis, additive x additive and dominance x dominance gene action in the control of grain yield.

Goswami and Asthana (1984) evaluated 34 indigenous finger millet varieties from Sikkim along with 12 varieties of All India Co-ordinated varietal trial. They observed high genotypic co-efficient of variability for grain yield and ear length. Estimates of genetic advance indicated that direct selection for yield would be most effective followed by selection for ear length, fingers per ear and plant height.

In a study of F_4 population of three intervarietal crosses, Prabhakar and Prasad (1984) found, high phenotypic co-efficient of variability for grain and productive tillers. The gene action was mostly additive for these traits. Grain yield showed high heritability and genetic advance, while plant height and fingers per ear showed non additive gene action.

Joshi and Mehra (1989) in the variability analysis involving 27 genetic stocks found high co efficient of variability for grain yield, moderate for fingers per ear and ear length and low for plant height. Heritability estimates were high for grain yield and moderate for other characters. The genetic advance was high for grain yield, moderate for ear length and fingers per ear and low for plant height.

Tyagi and Koranne (1989) estimated the genetic parameters on 29 genotypes and reported significant variability for fingers per ear, productive tillers and grain yield. High heritability and genetic advance was observed for yield, fingers per ear, plant height and productive tillers.

Verma (1989) reported low variability for yield, plant height and ear length; moderate for productive tillers. Heritability was high for plant height, productive tillers and ear length. The genetic advance was low for most of the traits studied.

Venkatesh Bhat (1991) estimated genetic parameters in F_2 populations of two crosses. The variability was high for productive tillers and grain yield; moderate for fingers per ear and ear length and low for plant height. Heritability estimates were moderate to high for all the components studied. The genetic advance was high for grain yield; moderate to high for fingers per ear and productive tillers and low for plant height and ear length. He also reported moderate to high narrow sense heritability for grain yield and low heritability for plant height and fingers per ear.

In the 978 finger millet germplasm accessions studied, there was large variability for yield and yield components-plant height, productive tillers, ear length and fingers per ear (Purushotham Rao, 1992).

Basavaraja and Sherief (1992) estimated low narrow sense heritability for grain yield in two crosses of finger millet. Moderate estimates of heritability were observed for grain yield, productive tillers and fingers per ear. Narrow sense heritability for grain yield, plant height and fingers per ear was also reported by Ravikumar (1988) and Shanthakumar (1988).

Cauvery (1993) obtained high genotypic co-efficient of variability for productive tillers and grain yield and low for plant height. High heritability was estimated for plant height. Grain yield and productive tillers recorded moderate heritability values. Genetic advance was high for productive tillers and grain yield and moderate for plant height.

Four F_2 populations of finger millet crosses were studied to understand the nature of variation for quantitative traits in relation to yield and resistance to blast (Ravikumar and Seetharam, 1994). Moderate to high variability for components of productivity and neck and finger blast was seen in all the populations. Neck and finger blast and plant height showed high heritability and genetic advance. However, productive tillers recorded moderate to high heritability with low genetic advance.

Moderate to high phenotypic and genotypic co -efficient of variability, heritability and genetic advance for plant height and productive tillers was reported by Dhanakodi (1994) and Ramaswamy *et al.*(1994).

Haider *et al.*(1995) reported high estimates of heritability and genetic advance for plant height and ear length and low estimates for productive tillers and fingers per ear.

Chunilal *et al.*(1996) reported that, grain yield, ear length, fingers per ear and productive tillers were controlled by additive gene action in a study involving 40 finger millet genotypes. Non additive gene action was important for plant height.

2.5 Character association and path co efficient analysis

The character association analysis helps to determine the nature and degree of relationship between any two measurable characters. Phenotypic correlation reflects the observed relationship, while genotypic correlations underline the true relationship among characters. Selection procedures could be varied depending upon the relative contribution of each.

The measure of correlation does not consider dependence of one variable over the other. Direct contribution of each component to any dependent variable and indirect effects they had through their association with other components cannot be differentiated from correlation studies. A statistical device called path co-efficient analysis yields direct and indirect effects. Direct effects are independent of the interrelationship between the dependent and independent variables. Indirect effects influence the dependent variable through other independent variables (Harinarayana and Gupta, 1989).

Review of literature on correlations and path co- efficient analysis for different characters in finger millet from 1970's is presented here under.

Correlation studies by Dhagat *et al.*(1972) indicated that grain yield was positively correlated with plant height and grain weight of main ear. The path analysis showed the importance of fingers per ear in the improvement of grain yield (Dhagat *et al.*, 1973). Michael Raj *et al.*(1972) showed the maximum influence of the productive tillers on grain yield in medium duration varieties.

Okiror *et al.*(1973) observed strong association of grain yield with plant height and productive tillers.

Mahudeswaran and Murugesan (1973) observed that grain yield was significantly and positively correlated with productive tillers. Path co-efficient analysis showed that both tiller number and plant height have high direct effect.

Significant and positive association of grain yield with fingers per ear and productive tillers was reported by Ranganathan *et al.*(1977) and Agalodia *et al.*(1979).

Mishra *et al.*(1980) showed that the highest yields were invariably obtained in plants having many and longer ears. They observed no relationship between resistance to blast and pigmentation of the plant.

Sarvaiya *et al.*(1983) reported strong association of grain yield with plant height and productive tillers. Prabhakar and Prasad (1983) from their study in F_3 and F_4 population, indicated that productive tillers had the strongest positive direct effect on yield.

Dineshkumar (1986) reported that grain yield was positively associated with yield attributes - productive tillers and fingers per ear. Grain protein content was negatively correlated with grain yield. Finger blast had negatively significant association with grain yield and productive tillers. Productive tillers and fingers per ear had high positive direct effect on grain yield.

Shanthakumar (1988) in a study of correlation and path analysis revealed that grain yield was positively associated with productive tillers, fingers per ear and ear length in F_2 and F_3 populations of two crosses. He observed high direct effects of productive tillers and ear weight on grain yield.

Harinarayana *et al.*(1989) reported positive correlation of grain yield with plant height, productive tillers, fingers per ear and ear length.

Venkatesh Bhat (1991) reported positive association of grain yield with most of the yield components. The association was highly significant with plant height and productive tillers; significant with ear length and fingers per ear.

Purushotham Rao (1992) reported that the yield components-plant height, productive tillers, fingers per ear and ear length were positively associated with grain yield. The productive tillers had the highest positive direct effect on grain yield.

Cauvery (1993) obtained positive and highly significant association of grain yield with productive tillers and plant height. She reported high positive direct effect of plant height and high negative indirect of productive tillers on grain yield.

The association of blast and five quantitative characters with grain yield was studied in four crosses of finger millet by Ravikumar and Seetharam (1993). The plant height, productive tillers and fingers per ear showed significant positive association with grain yield. Productive tillers had the highest positive direct effect on yield. Negative and significant association of neck and finger blast with grain yield, plant height, productive tillers and fingers per ear was noticed.

Girishkumar (1995) recorded positive but weak association of plant height and productive tillers with grain yield. The direct effect of plant height on grain yield was positive and maximum. On the contrary, productive tillers showed negative and very high direct effect on yield. Grain yield showed low and negative association with protein.

Chunilal *et al.*(1996) observed positive association of grain yield with productive tillers, fingers per ear, plant height and ear length in a study involving 40 finger millet genotypes. They observed high positive direct effects of these characters on grain yield.

Haider *et al.*(1995) reported negative association of grain yield with productive tillers and ear length.

Ramakrishna *et al.*(1996) in an exhaustive study involving 4000 finger millet germplasm observed significant and negative association between blast disease and plant height; weak associations for productive tillers, fingers per ear and ear length with blast. They also reported positive association of grain yield with fingers per ear, ear length, plant height and productive tillers.

MATERIAL AND METHODS

III MATERIAL AND METHODS

The present investigation was undertaken at Gandhi Krishi Vignana Kendra (GKVK), University of Agricultural Sciences, Bangalore which is located at the latitude of 12°58' North; longitude of 77°35' East and altitude of 930 meters above MSL.

3.1 Material

The experimental material for the present study comprised of F_2 and F_3 populations of two finger millet crosses, viz., WR 13 x GE 1409 (Cross I) and WR 13 x GE 1546 (Cross II) involving three cultivars, WR 13, GE 1409 and GE 1546. These cultivars were chosen based on their reaction to blast pathogen. Among these, white grained cultivar WR 13 was susceptible and the other two are brown grained and recorded field resistance to both neck and finger blast (Ravikumar *et al.*, 1991). All the resistant cultivars selected were purple pigmented, while WR 13 was green type.

3.2 Methods

3.2.1 Hybridization

The three parents were grown in field as well as in pots during *kharif* 1992. The female parent was sown at staggered intervals to achieve flowering synchrony. Contact method was followed to hybridize and obtain crossed seeds which were harvested from female parent at maturity.

The seeds from female parent after contact with male were sown in nursery during summer 1993 and true F_1 plants showing purple pigmentation (marker gene) were identified. The true hybrids were transplanted in the main field. The seeds from F_1 plants were harvested at maturity and sun dried.

3.2.2 F_2 generation

About 1000 F_2 plants from each of the two crosses were grown separately during *kharif* 1993 along with their parents with a inter and intra row spacing of 22.5 and 10.0 cm, respectively. All along the borders and after every ten rows, the susceptible check WR 13 was planted to provide blast inoculum.

Two hundred fifty F_2 plants from each cross having two tillers and above, and ten plants at random from each of the parents were selected for recording observations. Among the selected 250 F_2 plants from each cross (population I), 230 plants were purple pigmented and brown seeded (population II), while the remaining 20 plants were green pigmented and white seeded (Population III).

3.2.3 F_3 generation

One hundred F_3 progenies were raised during *kharif* 1994 along with their parents in a single row of 3.0 M length using Randomized Complete Block Design with two replications. A spacing of 22.0 cm between and 10.0 cm within rows was adopted. Among the selected 100 plants (population I), 80 plants were purple and brown seeded (population II) while the remaining 20 plants were green and white seeded (population III). All along the borders and after every ten rows the susceptible check WR 13 was sown to provide inoculum for blast disease.

3.2.4 Crop management

The crop in F_2 and F_3 generations was provided all necessary agronomic inputs as per the package of practices recommended for finger millet. The material was evaluated for blast under field conditions. Obviously, the disease incidence in the test material was influenced by the weather conditions prevailing during the season. However, adequate inoculum for the test material was provided by raising the susceptible check all along the borders and after every ten rows. The mean monthly maximum and minimum temperature, relative humidity (%), total rainfall and number of rainy days during crop growth period are given in Appendix-I.

The peak flowering of the crop was in October. The conditions during October was conducive for blast disease incidence with adequate rainfall, more rainy days and high relative humidity during morning and evening hours.

3.2.5 Recording of data

In F_2 population, 250 plants from each cross having two tillers and above and random five plants from each family of F_3 were tagged for recording the observations on the following traits.

3.2.5.1 Estimation of biochemical compounds

Ears at dough stage of each selected F_2 and F_3 plants from both the crosses and parents were harvested for analyzing the biochemical compounds. The ears were first dried and made into flour using a mixer grinder. The required samples of flour was taken for estimating the proteins, phenols and tannins.

a) Estimation of total proteins

Total protein content was estimated by following the standard micro Kjeldahl distillation method (A.O.A.C., 1970). Total nitrogen in the ear sample obtained after titration was multiplied with the factor 6.25 to arrive at crude protein content and expressed in percentage.

b) Estimation of total phenols and tannins

One gram sample of the plant material was extracted in 50 ml of one per cent HCl in methanol for 24 hours at room temperature with occasional stirring.

Total phenols were estimated in aliquots of the extracts using the Folin-Denis reagent as per the procedure of Swain and Hills (1959). Chlorogenic acid was used as the reference standard for the total phenols.

Total tannin content was estimated in the extract by the Vanillin-HCl procedure according to Burns (1971) using Catechol as the standard.

Total phenols and tannins were expressed as mg per g of plant material.

3.2.5.2 Yield and yield attributes

a) Fingers per ear

The number of fingers on main ear were counted at harvest.

b) Ear length

The length of main ear was measured at maturity in cm.

c) Productive tillers per plant

The number of tillers bearing well developed ears were counted at harvest.

d) Plant height

The plant height was measured in cm from the base of the plant to top of the ear.

3.2.5.3 Percentage of finger blast

The number of blast infected and total fingers were counted in each plant at the time of physiological maturity and the percentage of finger blast was calculated using formula

$$\text{Finger blast (\%)} = \frac{\text{No.of blast infected fingers per plant}}{\text{Total No.of fingers per plant}} \times 100$$

3.2.5.4 Percentage of neck blast

The number of tillers infected with blast disease at neck region and the total number of productive tillers in each plant were counted and the percentage of neck blast was computed using the formula

$$\text{Neck blast (\%)} = \frac{\text{No. of tillers with neck blast per plant}}{\text{Total No. of productive tillers per plant}} \times 100$$

3.2.5.5 Grain yield per plant

The grain yield per plant was recorded in g by weighing the grains collected from all the ears of each plant. The grains were dried to constant moisture before weighment.

3.3 Statistical analysis

Data recorded on individual plant basis for F_2 generation and on five plant mean value basis for F_3 generation were subjected to statistical analysis. In case of percentage values of finger and neck blast, data were transformed using angular transformation (Snedecor and Cochran, 1967).

In F_2 generation, phenotypic correlation co-efficient and path co-efficient were estimated. In F_3 generation, both phenotypic and genotypic correlations and path co-efficient were estimated.

3.3.1 Estimation of genetic parameters

3.3.1.1 Phenotypic and genotypic co-efficient of variation (PCV and GCV)

The phenotypic and genotypic co-efficients of variation were computed according to Burton and Devane (1953).

$$\text{PCV (\%)} = \frac{\text{Phenotypic standard deviation}}{\text{General mean}} \times 100$$

$$\text{GCV (\%)} = \frac{\text{Genotypic standard deviation}}{\text{General mean}} \times 100$$

PCV and GCV were classified as suggested by Sivasubramanian and Menon (1973) and are given below:

0-10% : Low
10-20% : Moderate
20% and above : High

3.3.1.2 Heritability (Broad sense)

Heritability in broad sense was estimated by using the following formula of Hanson *et al.*(1956).

$$h^2 \text{ (Broad sense)} = \frac{\sigma_g^2}{\sigma_p^2} \times 100$$

where σ_g^2 = Genotypic Variance

σ_p^2 = Phenotypic Variance

3.3.1.3 Heritability (Narrow sense)

Heritability in narrow sense was estimated by using the following formula of Smith and Kinman (1965).

$h^2 (F_2.F_3) = 2/3\ b\ (F_3.F_2)$

where $h^2 (F_2.F_3)$ = Heritability in narrow sense using $F_2.F_3$ regression

$b (F_3.F_2)$ = Regression of F_3 progeny means on F_2 parent

The heritability percentage was categorized as suggested by Robinson *et al.*(1949) as mentioned below.

0-30%	: Low
30-60%	: Moderate
60% and above	: High

3.3.1.4 Genetic advance (GA)

It was worked out as per the formula proposed by Johnson *et al.*(1955).

$GA = k.\sigma p.H$

where GA = Expected genetic advance under selection

k = Selection differential at given selection intensity

p = Phenotypic standard deviation

H = Heritability co-efficient

$$\text{Genetic advance (\% of mean)} = \frac{GA}{\text{Grand mean}} \times 100$$

The genetic advance as per cent of mean was categorized as suggested by Johnson *et al.*(1955) and the same given as below.

0-10% : Low

10-20% : Moderate

20% and above : High

3.3.2 Estimation of correlation co-efficients

The phenotypic and genotypic correlation co-efficients were estimated among all possible combination of characters in each populations as suggested by Al-Jibouri *et al.*(1958).

$$\tau XY = \frac{CoVxY}{\sqrt{VX \text{ x } VY}}$$

where τXY = Correlation co-efficients between character X and Y

CoVXY = Covariance between characters X and Y

VX = Variance of character X

VY = Variance of character Y

The significance of correlation co-efficients was tested against 't' values of Fisher and Yates (1963).

3.3.3 Estimation of path co-efficients

Path co-efficient analysis was carried out for the segregating populations to know the direct and indirect effects of the yield components on yield and blast disease as suggested by Wright (1921) and illustrated by Dewey and Lu (1959).

The path co-efficients were obtained from the solution of 'p' normal equations following the matrix method given by Singh and Choudhary (1985).

EXPERIMENTAL RESULTS

IV EXPERIMENTAL RESULTS

The results are presented under the following headings for the three sub populations - Population I (mixed population of brown and white grained types), population II (brown grained types) and population III (white grained types).

1. Estimation of genetic parameters,
2. Character associations and
3. Path co-efficient analysis.

4.1 Estimation of genetic parameters

4.1.1 F_2 Generation

4.1.1.1 Cross I (WR 13 X GE 1409)

Mean, range and estimates of phenotypic co-efficient of variability (PCV) for the three sub populations are presented in Table 1. The frequency distribution for finger blast, total proteins, phenols, tannins, grain yield and fingers per ear are presented in Figures 1, 3, 5, 7, 9 and 11 for population I.

1. Finger blast

The mean incidence of finger blast was 50.7 per cent in susceptible parent (WR 13) and nil per cent in resistant parent (GE 1409). The mean finger blast incidence in F_2 was the highest in population III (32.3%) followed by population I (17.2%) and population II (15.9%). The range for this character was very wide in population I (0.0 to 50.0%) and population II (0.0 to 42.9%) and was narrow in population III (14.3 to 50.0%).

Phenotypic co-efficient of variability (PCV) was very high in population II (88.1%) and population I (83.1%), while it was moderate in population III (22.4%).

2. Total proteins

The mean total proteins per cent was 9.7 in WR 13 and 7.2 in GE 1409. The mean total proteins in F_2 was high in population III (9.4%) followed by population I (8.4%) and population II (8.3%). The protein content ranged from 6.1 to 11.1 per cent in population I and II, while population III had a range of 8.4 to 10.1 per cent.

The PCV values were moderate in population I (11.9%) and population II (11.8%), while it was low in population III (5.4%).

3. Total phenols

The resistant parent GE 1409 had a mean total phenols of 6.6 mg/g compared to 0.9 mg/g of the susceptible parent WR 13. The F_2 mean was the highest in population II (3.6 mg/g) followed by population I (3.5 mg/g), while in population III mean phenolic content was 1.8 mg/g. The F_2 mean ranged from 0.6 to 7.4 mg/g in population I and II and 0.6 to 3.2 mg/g in population III.

The PCV values were high in all the three populations and ranged from 33.6 (population II) to 40.1 per cent (population III).

4. Total tannins

The mean total tannins was 0.22 mg/g in susceptible parent (WR 13) and 3.0 mg/g in resistant parent (GE 1409). The mean total tannins in F_2 was the highest in population I and II (1.3 mg/g), while in population III it was only 0.5 mg/g. The F_2 range was very wide in population I (0.16 to 3.6 mg/g) followed by population II (0.22 to 3.6 mg/g), whereas the population III showed comparatively a narrow range of 0.16 to 1.1 mg/g.

The highest PCV was recorded in population III (62.5 per cent) while in population I and II the PCV values were 47.24 per cent and 42.6 per cent, respectively.

5. Grain yield

The susceptible (WR 13) and resistant (GE 1409) parents recorded 6.4 and 20.7 g grain yield per plant, respectively. In F_2 generation, population II recorded the highest mean grain yield (11.2 g/plant) followed by population I (11.0 g/plant) and population III (8.6 g/plant). The grain yield range was very wide in populations I and II (3.6 to 29.4 g/plant) and comparatively narrow in population III (5.4 to 16.2 g/plant).

The highest PCV was recorded in population I (40.9%) followed by population II (40.4%). In contrast, population III recorded low PCV of 36.1 per cent for grain yield.

6. Fingers per ear

Number of fingers per ear recorded in parents WR 13 and GE 1409 was 4.7 and 6.0, respectively. In F_2, a mean of 5.3 fingers per ear in populations I and II, and 5.1 in population III were recorded. Populations I and II showed a wide range of 3.0 to 10.0 fingers per ear and the range was narrow in population III (3.0 to 7.0).

Co-efficient of variability for phenotype was high in population II (24.9%) and population I (24.6%), while in population III the PCV value was 20.8 per cent.

7. Ear length

The parents WR 13 and GE 1409 had an ear length of 4.2 cm and 7.7 cm, respectively. In F_2, the mean ear length was the highest in population I (6.7 cm) followed by population III (6.5 cm) and low in population II (5.6 cm). The range was similar in all the populations.

The differences in the values of PCV in different populations were very low and ranged from 21.8 per cent in population II to 25.1 per cent in population III.

8. Plant height

The genotype WR 13 was the dwarfest with the height of 58.7 cm and the genotype GE 1409 had an height of 90.0 cm. In F_2, population III recorded the highest mean plant height of 90.3 cm, while populations I and II had the mean plant height of 88.9 and 88.7 cm, respectively. A wide range of variation was recorded in population I and II (57.0 to 119.0 cm) and narrow in population III (69.0 to 109.0 cm).

Moderate PCV was recorded in all the three populations and ranged from 10.7 per cent in population III to 13.1 per cent in population II.

Table 1: Estimates of mean, range and phenotypic co-efficient of variability (PCV) in sub populations of F_2 generation of the cross WR 13 X GE 1409

Character	Parental means		Population I				Population II				Population III			
	P1	P2	Mean	Range Min.	Range Max.	PCV (%)	Mean	Range Min.	Range Max.	PCV (%)	Mean	Range Min.	Range Max.	PCV (%)
Finger blast(%)	50.7	0.0	17.2	0.0	50.0	83.1	15.9	0.0	42.9	88.1	32.3	14.3	50.0	22.4
Protein (%)	9.7	7.2	8.4	6.1	11.1	11.9	8.3	6.1	11.1	11.8	9.4	8.4	10.1	5.4
Phenol (mg/g)	0.9	6.6	3.5	0.6	7.4	36.9	3.6	0.6	7.4	33.6	1.8	0.6	3.2	40.1
Tannin (mg/g)	0.22	3.0	1.3	0.16	3.6	47.2	1.3	0.22	3.6	42.6	0.5	0.16	1.1	62.5
Yield/plant(g)	6.4	20.7	11.0	3.6	29.4	40.9	11.2	3.6	29.4	40.4	8.6	5.4	16.2	36.1
Fingers/ear	4.7	6.0	5.3	3.0	10.0	24.6	5.3	3.0	10.0	24.9	5.1	3.0	7.0	20.8
Ear length	4.2	7.7	6.7	3.0	11.0	22.9	5.6	3.0	11.0	21.8	6.5	3.0	10.0	25.1
Plant height	58.7	90.0	88.9	57.0	119.0	12.9	88.7	57.0	119.0	13.1	90.3	69.0	109.0	10.7

P1 = WR 13, P2 = GE 1409

4.1.1.2 Cross II (WR 13 X GE 1546)

The estimates of mean, range and PCV for all the three sub populations are presented characterwise in Table 2. The frequency distribution for finger blast, protein. total phenols, tannin, grain yield and fingers per ear are presented in Figures 2, 4, 6. 8. 10 and 12 for population I.

1. Finger blast

WR 13 showed the highest incidence of finger blast of 50.7 per cent compared to 0.5 per cent incidence in GE 1546. In F_2, the population III had the highest mean of 33.6 per cent, while it was 15.4 per cent and 15.8 per cent in population I and II, respectively. The range of blast incidence was wide in population I and III (0.0 to 60.0%) and comparatively narrow in population II (0.0 to 42.9%).

The PCV was very high in population I (92.2%) and population II (91.4%), while in population III it was high (30.5%).

2. Total proteins

The susceptible parents WR 13 had a mean total proteins of 9.7 per cent compared to 7.4 per cent of the resistant GE 1546. The F_2 had the highest mean total proteins of 9.7 per cent in population III followed by 8.1 per cent in population I and 8.0 per cent in population II. The total proteins ranged from 5.8 to 10.8 per cent in population I, 5.8 to 12.0 per cent in population II and 8.2 to 10.8 per cent in Population III.

The PCV was moderate in population I (12.9%) and population II (12.0%), while in population III it was low (6.3%)

3. Total phenols

The mean total phenols recorded in parents was 0.9 mg/g and 6.8 mg/g in WR 13 and GE 1546, respectively. The F_2 had the highest mean total phenols in population II (4.3 mg/g) followed by population I (4.1 mg/g) and was lowest in population III (1.8 mg/g). The range was wide in population I (0.6 to 8.1 mg/g) followed by population II (0.9 to 8.1 mg/g) and narrow in population III (0.6 to 2.9 mg/g).

The PCV was high in all the three populations and ranged from 27.7 per cent in population II to 35.4 per cent in population III.

4. Total tannins

The resistant parent GE 1546 had a mean total tannins of 3.8 mg/g while, the susceptible parent WR 13 had 0.2 mg/g of total tannins. The mean of F_2 was the highest in population II (1.7 mg/g) followed by population I (1.6 mg/g); population III had a very low total tannins (0.5 mg/g). The range was wide in population I (0.16 to 3.8 mg/g) and population II (0.3 to 3.8 mg/g) and narrow in population III (0.16 to 1.0 mg/g).

Co-efficient of variability for phenotype was high in all the three populations and ranged from 41.0 per cent in population II to 46.9 per cent in population III.

5. Grain yield

The highest grain yield of 21.1 g/plant was recorded in the resistant parent GE 1546, while it was 6.4 g/plant in the susceptible parent, WR 13. In F_2, the populations I and II had mean grain yield of 11.5 and 11.7 g/plant, respectively and the population III had a mean grain yield of 9.0 g/plant. The character showed wide range in population I (4.2 to 26.5 g/plant) and population II (4.2 to 22.5 g/plant) and the range was narrow in population III (5.2 to 18.3 g/plant).

High PCV values were recorded in all the three populations and ranged from 35.1 per cent in population III to 37.7 per cent in population I.

6. Fingers per ear

The parent WR 13 recorded minimum finger number per ear (4.7) while GE 1546 had the maximum (7.4). The mean finger number in F_2 was similar in population I and II (5.5), while the population III had a mean finger number of 5.2. Similar range was recorded in populations I and II (3.0 to 9.0), while it ranged from 3.0 to 7.0 in population III.

Table 2: Estimates of mean, range and phenotypic co-efficient of variability (PCV) in sub populations of F_2 generation of the cross WR 13 X GE 1546

Character	Parental means		Population I				Population II				Population III			
			Mean	Range		PCV	Mean	Range		PCV	Mean	Range		PCV
	P1	P2		Min.	Max.	(%)		Min.	Max.	(%)		Min.	Max.	(%)
Finger blast(%)	50.7	0.5	15.4	0.0	60.0	92.2	15.8	0.0	42.9	91.4	33.6	0.0	60.0	30.5
Protein (%)	9.7	7.4	8.1	5.8	10.8	12.9	8.0	5.8	12.0	12.0	9.7	8.2	10.8	6.3
Phenol (mg/g)	0.9	6.8	4.1	0.6	8.1	32.5	4.3	0.9	8.1	27.7	1.8	0.6	2.9	35.4
Tannin (mg/g)	0.2	3.8	1.6	0.16	3.8	46.5	1.7	0.3	3.8	41.0	0.5	0.16	1.0	46.9
Yield/plant (g)	6.4	21.1	11.5	4.2	26.5	37.7	11.7	4.2	22.5	37.2	9.0	5.2	18.3	35.1
Fingers/ ear	4.7	7.4	5.5	3.0	9.0	24.5	5.5	3.0	9.0	24.8	5.2	3.0	7.0	20.4
Ear length	4.2	7.3	5.4	2.5	8.5	17.5	5.4	2.5	8.5	17.5	5.2	4.0	7.5	18.5
Plant height	58.7	99.9	88.4	44.0	131.0	14.8	87.9	44.0	131.0	14.9	93.3	66.0	109.0	12.1

P1 = WR 13, P2 = GE 1546

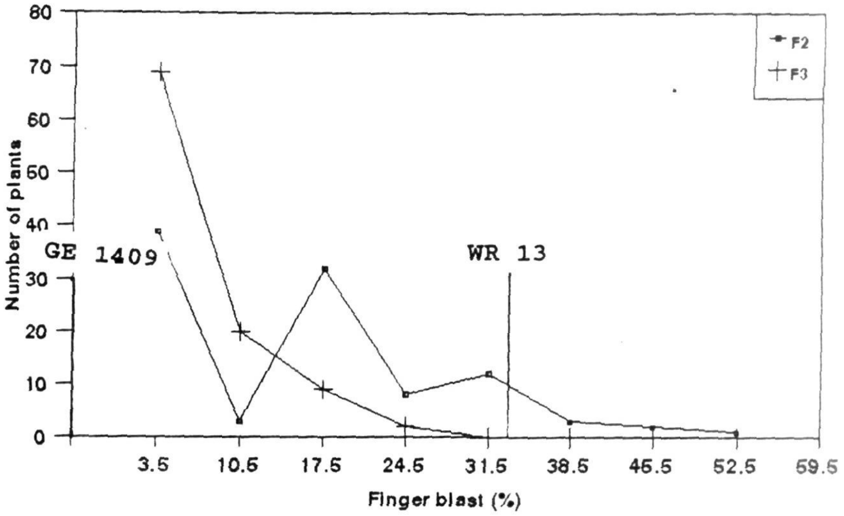

Fig.1: Frequency distribution for finger blast in F_2 and F_3 generations of the cross WR 13 X GE 1409

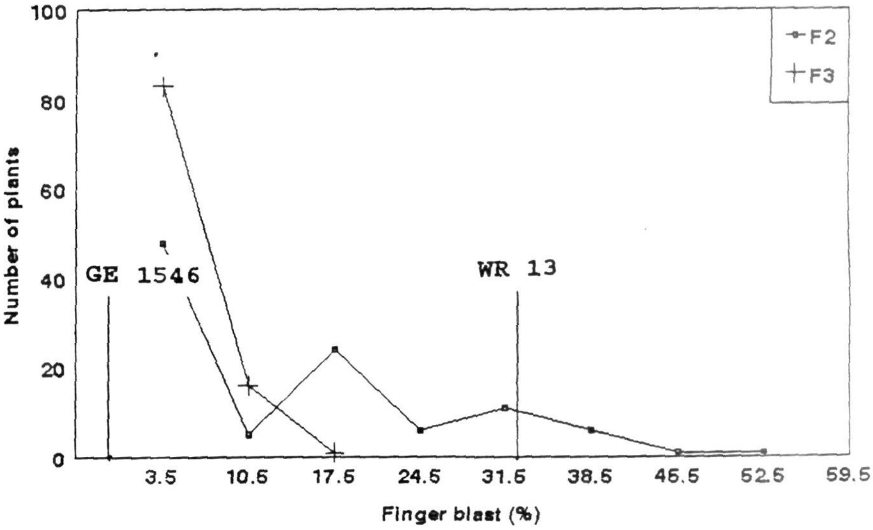

Fig.2: Frequency distribution for finger blast in F_2 and F_3 generations of the cross WR 13 X GE 1546

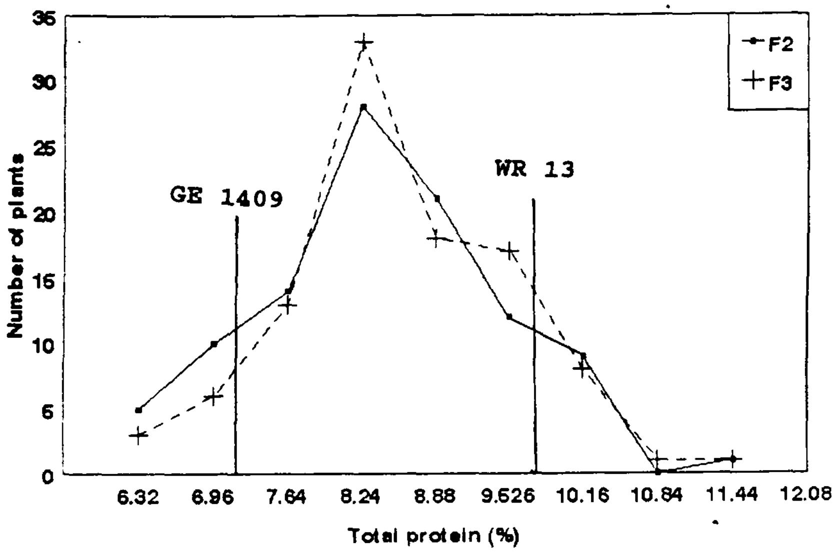

Fig.3: Frequency distribution for total protein in F_2 and F_3 generations of the cross WR 13 X GE 1409

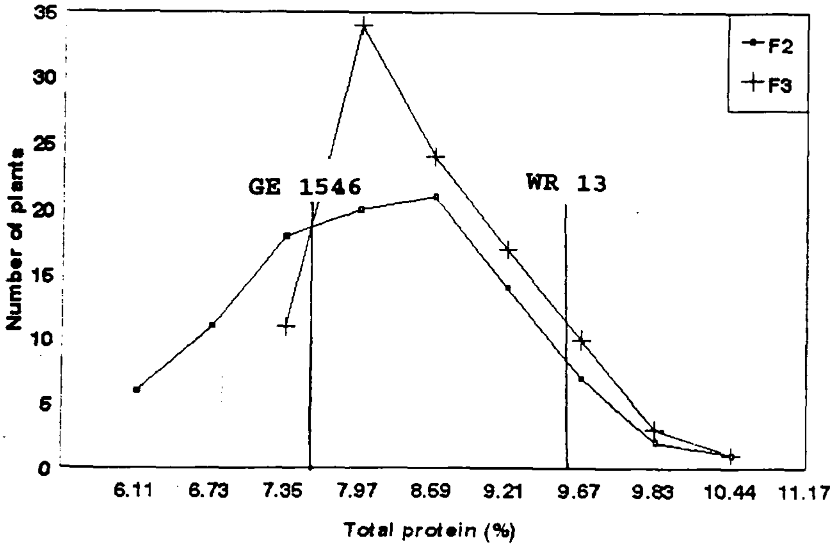

Fig.:4 Frequency distribution for total protein in F_2 and F_3 generations of the cross WR 13 X GE 1546

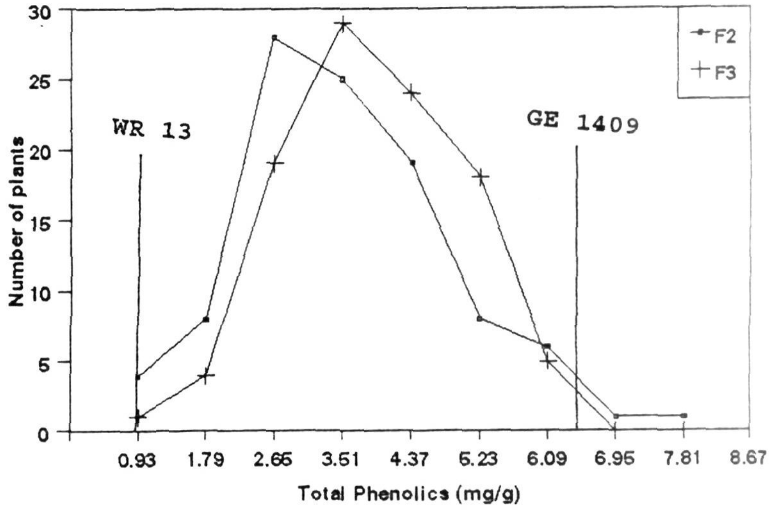

Fig.5: Frequency distribution for total phenolics in F_2 and F_3 generations of the cross WR 13 X GE 1409

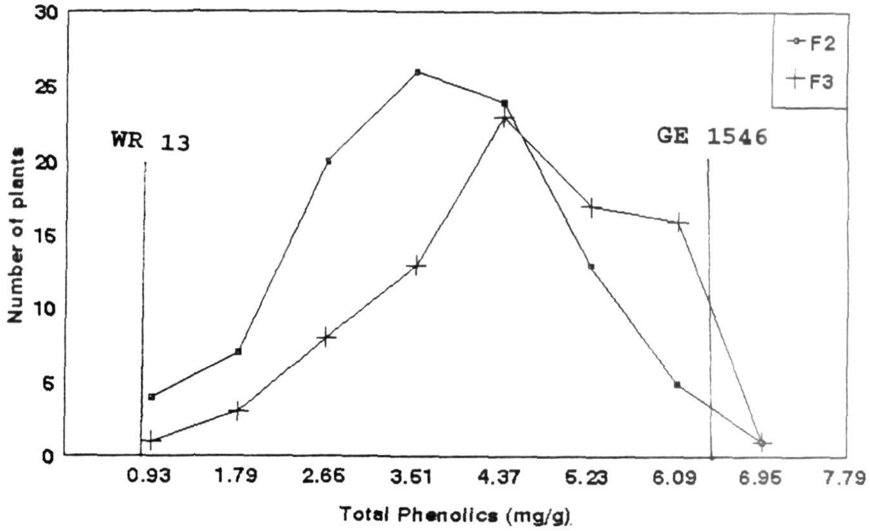

Fig.6: Frequency distribution for total phenolics in F_2 and F_3 generations of the cross WR 13 X GE 1546

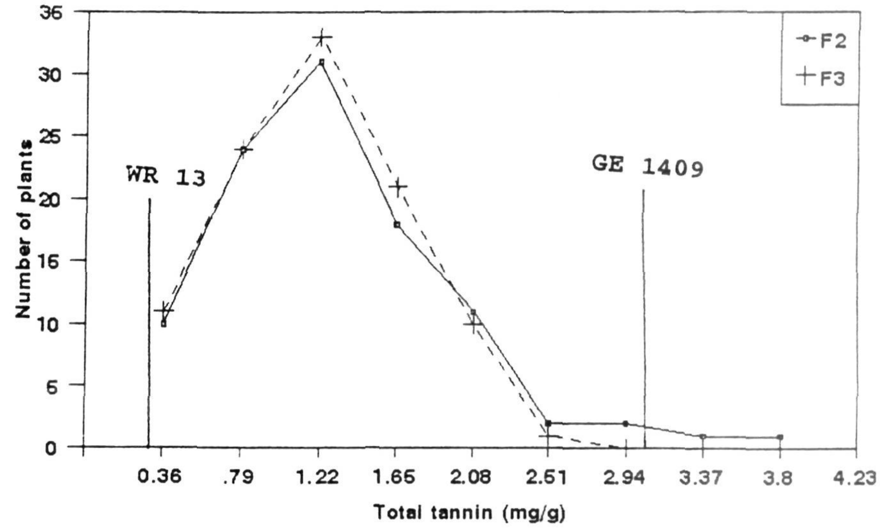

Fig.7: Frequency distribution for total tannin in F_2 and F_3 generations of the cross WR 13 X GE 1409

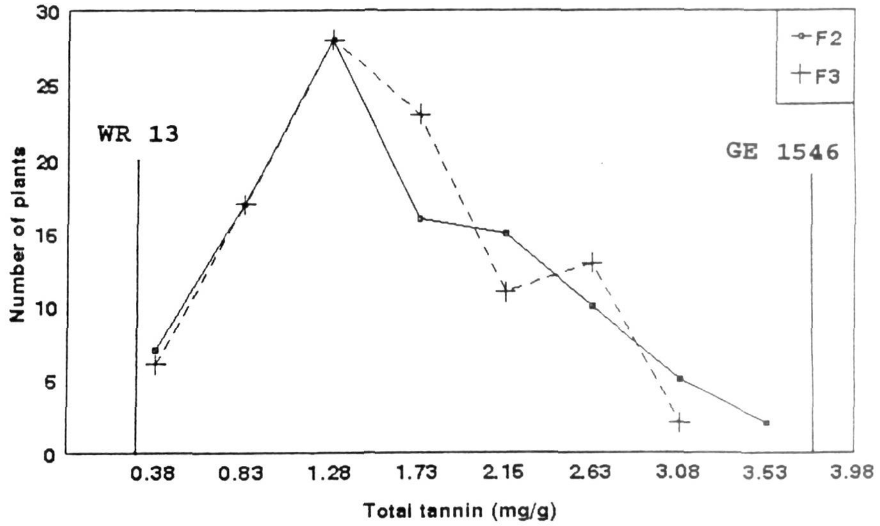

Fig.8: Frequency distribution for total tannin in F_2 and F_3 generations of the cross WR 13 X GE 1546

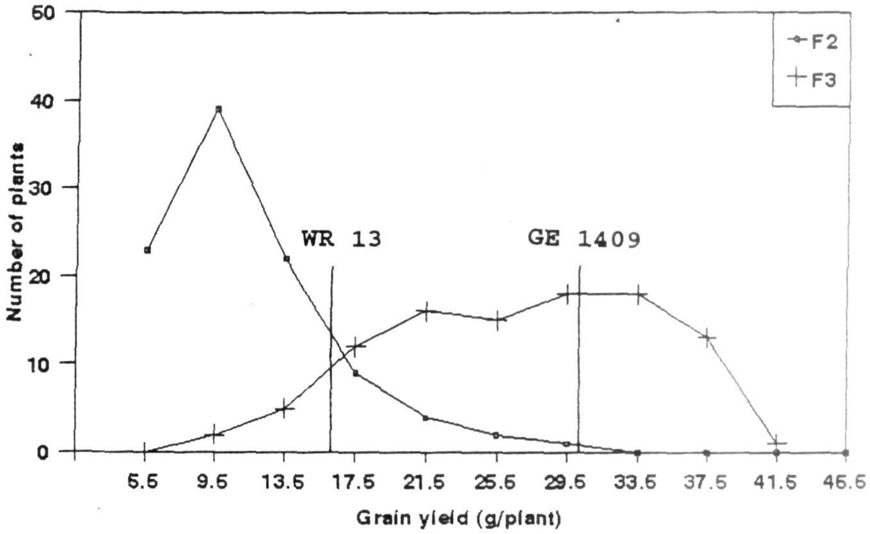

Fig.9: Frequency distribution for grain yield in F_2 and F_3 generations of the cross WR 13 X GE 1409

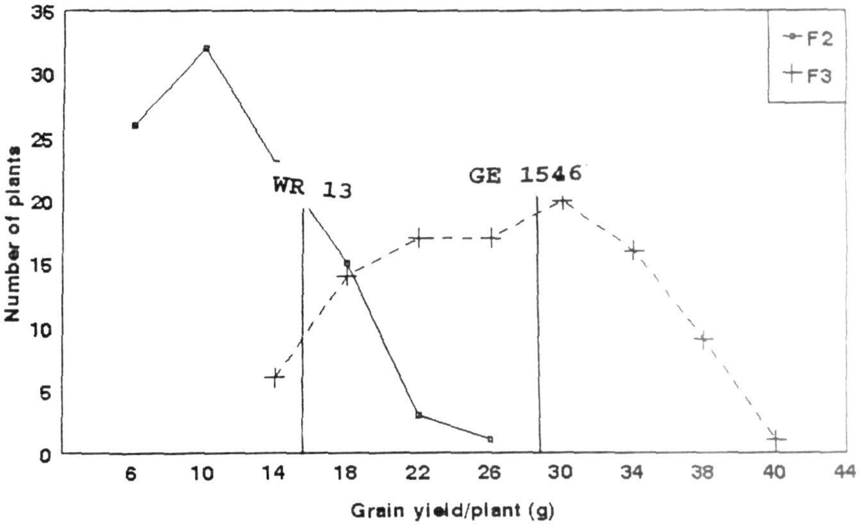

Fig.10: Frequency distribution for grain yield in F_2 and F_3 generations of the cross WR 13 X GE 1546

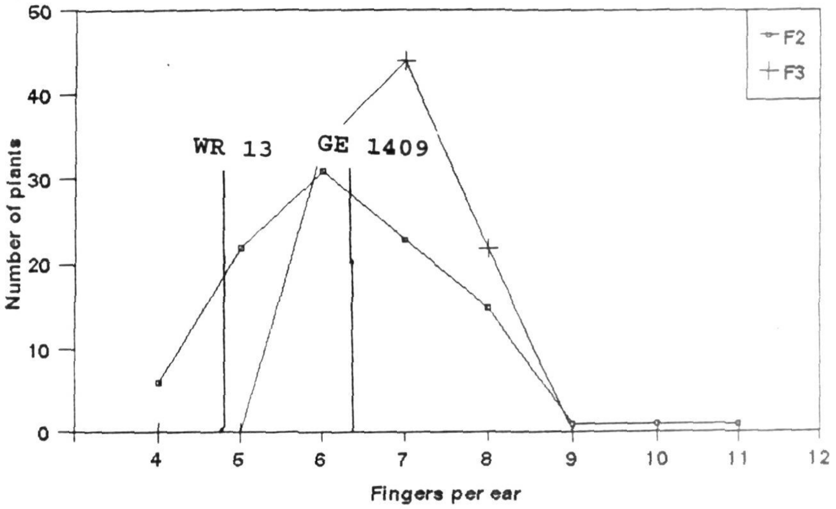

Fig.11: Frequency distribution for fingers per ear in F_2 and F_3 generations of the cross WR 13 X GE 1409

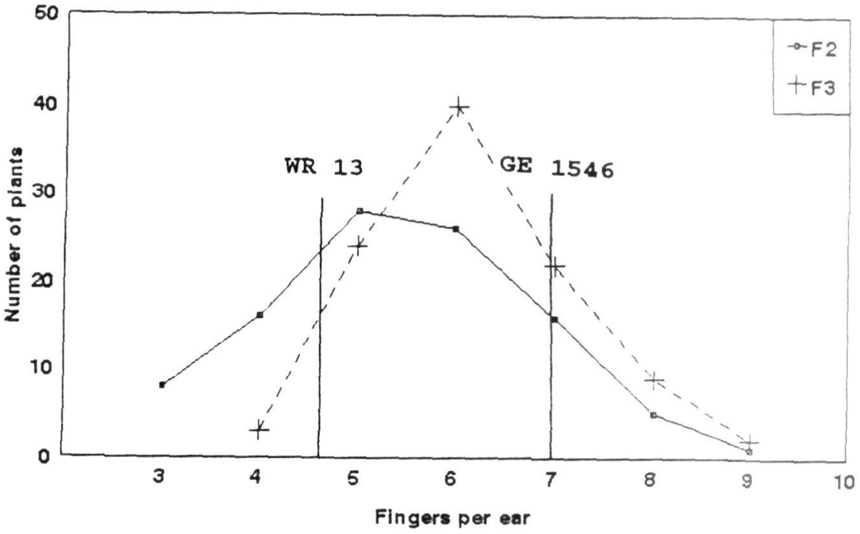

Fig.12: Frequency distribution for fingers per ear in F_2 and F_3 generations of the cross WR 13 X GE 1546

PCV values were high in all the three populations and ranged from 20.4 per cent in population III to 24.8 per cent in population II.

7. Ear length

The longest ear of 7.3 cm was found in the resistant parent GE 1546. The parent WR 13 had an ear length of 4.2 cm. In F_2, the populations I and II had a mean ear length of 5.4 cm, while the population III had an ear length of 5.2 cm. The same range of 2.5 to 8.5 cm was observed in populations I and II, and the population III had a narrow range of 4.0 to 7.5 cm.

All the three populations showed moderate estimates of PCV and ranged from 17.5 per cent in population I to 18.5 per cent in population III.

8. Plant height

The genotype GE 1546 recorded the maximum plant height of 99.9 cm, while the genotype WR 13 had an height of 58.7 cm. In F_2, population III had the highest mean plant height (93.3 cm) followed by population I (88.4 cm) and population II (87.9 cm). The range was wide in population I and II (44.0 to 131.0 cm) and narrow in population III (66.0 to 109.0 cm).

All the three populations showed moderate estimates of PCV from 12.1 (population III) to 14.9 per cent (population II).

4.1.2 F_3 generation

4.1.2.1 Cross I (WR 13 X GE 1409)

Mean, range and estimates of PCV and GCV, heritabilities in both broad and narrow sense, and genetic advance as per cent of mean are indicated characterwise in Tables 3 to 5. The frequency distribution for finger blast, protein, total phenols, tannin, yield and fingers per ear are presented in Figures 1, 3, 5, 7, 9 and 11 for population I.

1. Finger blast

The susceptible parent WR 13 had a mean finger blast incidence of 13.78 per cent and the resistant parent GE 1409 did not show any incidence. The mean finger blast in F_3, was the highest in population III (13.16%) followed by population I (6.38%) and population II (5.08%). The range was wide in population I (0.00 to 27.91%) followed by population II (0.00 to 25.89%), while in population III the range was comparatively narrow (5.50 to 27.91%).

PCV and GCV values were high for all the three populations and the differences between PCV and GCV values were very narrow. Broad sense heritability was very high in all the three populations and it ranged from 91.50 per cent in population III to 94.70 per cent in population I. The estimates of narrow sense heritability was low in population I (20.87%) and population II (18.40%) and least in population III (7.60%). Very high values of genetic advance was estimated in population II (99.07%) followed by population I (95.07%) and comparatively moderate in population III (42.41%).

2. Neck blast

The neck blast incidence in susceptible parent WR 13 was 20.27 per cent and resistant parent GE 1409 had nil incidence. In F_3, the mean incidence was maximum in population III (13.52%) followed by population I (9.32%) and population II (8.34%). Similar range of neck blast incidence was observed in population I and II (0.00 to 35.20%), while in population III, the range was 2.45 to 33.62 per cent.

High PCV and GCV values were recorded in populations I and II as compared to population III. Very high estimates of broad sense heritability was found for all the three populations. The heritability ranged from 94.60 per cent in population III to 95.40 per cent in population I. The highest genetic advance was estimated in population II (101.96 %) followed by population I (94.70%) and population III (61.13%).

3. Total proteins

The variety WR 13 had a mean total proteins of 9.74 per cent and the genotype GE 1409 had a mean total proteins of 7.20 per cent. In F_3, the population III had the highest mean total proteins of 9.47 per cent followed by population I (8.72%) and population II (8.53%). The range was wide and values were same in population I and II (6.10 to 10.90%) and a narrow range was recorded in population III (8.69 to 10.43%).

Total proteins exhibited low PCV and GCV values in all the three populations. Broad sense heritability estimates were very high in population I (78.00%) followed by population II (76.10%) and moderate in population III (45.70%). In contrast, narrow sense heritability was moderate in population I (46.60%) and population II (41.54%) and was low in population III (24.74%). The genetic advance was moderate in population I (17.89%) and population II (17.82%) and very low in population III (5.29%).

4. Total phenols

The mean total phenols in parent GE 1409 was 6.62 mg/g and the parent WR 13 had 0.90 mg/g of total phenols. In F_3, the mean total phenols was the highest in population II (3.81 mg/g) followed by population I (3.47 mg/g), and least in population III (2.12 mg/g). The range was wide in population I (0.99 to 6.20 mg/g) followed by population II (1.41 to 6.20 mg/g) and narrow in population III (0.99 to 3.61 mg/g).

High PCV and GCV values were observed in all the three populations. Very high estimates of broad sense heritability were observed in all the populations and ranged from 90.40 per cent in population II to 93.90 per cent in population III. Narrow sense heritabilities were moderate and ranged from 38.67 per cent in population III to 51.45 per cent in population I. The genetic advance was highest in population I (68.30%) followed by population III (67.45%) and population II (53.28%).

5. Total tannins

The mean total tannins of the parents was 0.23 mg/g in WR 13 and 3.02 mg/g in GE 1409. In F_3, mean total tannins content was the highest in population II (1.16 mg/g) followed by population I (1.02 mg/g) and least in population III (0.48 mg/g). The range was very wide in population I (0.15 to 2.28 mg/g) followed by population II (0.26 to 2.28 mg/g) and narrow in population III (0.15 to 1.05 mg/g).

PCV and GCV values were high in all the three populations. The highest broad sense heritability value of 97.80 per cent was observed in population I followed by population II (97.20%) and population III (95.30%). The narrow sense estimates of heritability were high in population I (64.14%), moderate in population II (57.54%) and population III (50.80%). The highest genetic advance was recorded in population III (114.58%) followed by population I (106.86%) and population II (87.93%).

6. Grain yield

The highest grain yield of 41.00 g/plant was recorded in the resistant parent GE 1409, while the susceptible parent WR 13 yielded 20.00 g/plant. Grain yield in F_3 was the highest in population II (26.27 g/plant) followed by population I (23.32 g/plant) and population III (21.55 g/plant). The range was wide and same for populations I and II (11.50 to 39.00 g/plant) and narrow in population III (11.50 to 30.50 g/plant).

High PCV and GCV values were estimated for grain yield for all the three populations. Broad sense heritabilities were also high in all the three populations. They were 93.40 per cent in population III, 92.00 per cent in population I and 91.40 per cent in population II. The narrow sense heritability was high in population II (74.94%), followed by population I (73.54%) and moderate in population III (45.74%). The highest genetic advance was recorded in population I (59.78%) followed by population II (54.27%) and population I (44.41%).

7. Productive tillers

The maximum number of productive tillers of 5.08 was recorded in WR 13 and minimum being 2.28 in GE 1409. The F_3 mean was the highest in population II (2.56) followed by population I (2.53) and population III (2.43). The range was wide and same in population I and II (1.50 to 4.30) and narrow in population III (1.55 to 2.95).

High PCV and moderate GCV values were observed in population I and II, while in population III both PCV and GCV values were moderate. Broad sense heritability was moderate in all the three populations. The heritability values were 57.20 per cent in population III, 53.40 per cent in population II and 52.30 per cent in population I. The

Table 3: Estimates of genetic parameters in brown and white grained F_3 (population I) of the cross WR 13 X GE 1409

Character	Parental means P1	P2	Mean	Range Min.	Max.	PCV (%)	GCV (%)	Heritability BS (%)	NS (%)	Genetic advance (% of mean)
Finger blast (%)	13.78	0.00	6.38	0.00	27.91	48.73	47.43	94.70	20.87	95.07
Neck blast (%)	20.27	0.00	9.32	0.00	35.20	48.20	47.07	95.40	-	94.70
Total protein (%)	9.74	7.20	8.72	6.10	10.90	11.65	9.85	78.00	46.60	17.89
Total phenol (mg/g)	0.90	6.62	3.47	0.99	6.20	35.36	34.21	93.60	51.45	68.30
Total tannin (mg/g)	0.23	3.02	1.02	0.15	2.28	53.08	52.49	97.80	64.14	106.86
Grain yield/plant(g)	20.00	41.00	23.32	11.50	39.00	29.06	27.87	92.00	73.54	59.78
Prod.tillers/plant	5.08	2.28	2.53	1.50	4.30	22.20	16.07	52.30	-	24.11
Fingers per ear	4.95	6.25	6.21	4.60	7.65	12.46	7.70	38.10	11.80	9.82

P1 = WR 13, P2 = GE 1409

Table 4: Estimates of genetic parameters in brown grained F_3 (population II) of the cross WR 13 X GE 1409

Character	Mean	Range		PCV	GCV	Heritability		Genetic advance
		Min.	Max.	(%)	(%)	BS (%)	NS (%)	(% of mean)
Finger blast (%)	5.08	0.00	25.89	51.43	49.73	93.50	18.40	99.07
Neck blast (%)	8.34	0.00	35.20	51.95	50.71	95.30	-	101.96
Total protein (%)	8.53	6.10	10.90	11.35	9.91	76.10	41.54	17.82
Total phenol (mg/g)	3.81	1.41	6.20	28.53	27.13	90.40	47.87	53.28
Total tannin (mg/g)	1.16	0.26	2.28	43.75	43.14	97.20	57.54	87.93
Grain yield/plant(g)	26.27	11.50	39.00	28.84	27.57	91.40	74.94	54.27
Prod. tillers/plant	2.56	1.50	4.30	23.28	17.02	53.40	-	27.78
Fingers per ear	6.22	4.60	7.65	12.67	7.75	37.40	10.80	9.81

Table 5: Estimates of genetic parameters in white grained F_3 (population III) of the cross WR 13 X GE 1409

Character	Mean	Range		PCV (%)	GCV (%)	Heritability		Genetic advance
		Min.	Max.			BS (%)	NS (%)	(% of mean)
Finger blast (%)	13.16	5.50	27.91	22.49	21.52	91.50	7.60	42.41
Neck blast (%)	13.52	2.45	33.62	31.08	30.51	94.60	-	61.13
Total protein (%)	9.47	8.69	10.43	5.59	3.78	45.70	24.74	5.29
Total phenol (mg/g)	2.12	0.99	3.61	34.83	33.75	93.90	38.67	67.45
Total tannin (mg/g)	0.48	0.15	1.05	58.54	57.15	95.30	50.80	114.58
Grain yield/ plant(g)	21.55	11.50	30.50	23.09	22.32	93.40	45.74	44.41
Prod. tillers/plant	2.43	1.55	2.95	15.31	11.58	57.20	-	18.11
Fingers per ear	6.18	5.15	7.35	11.91	7.65	41.30	6.67	10.19

genetic advance was high in population I (24.11%) and population II (27.78%) and moderate in population III (18.11%).

8. Fingers per ear

The maximum number of fingers of 6.25 was recorded in GE 1409 while WR 13 had the minimum number of fingers per ear (4.95). Similar means in F_3 were recorded in all the three population with the values of 6.21, 6.22 and 6.18 in I, II and III populations, respectively. The range was same in populations I and II (4.60 to 7.65), while the population III had a range of 5.15 to 7.35 fingers per ear.

Moderate PCV and low GCV values were estimated in all the three populations. The broad sense heritability was moderate in all the three populations. The highest heritability was observed in population III (41.30%) followed by population I (38.10%) and population II (37.40%). In contrast, the narrow sense heritability estimates were very low, ranging from 6.67 per cent in population III to 11.80 per cent in population I. Low genetic advance was exhibited in all the three populations. The genetic advance ranged from 9.81 per cent in population II to 10.19 per cent in population III.

4.1.2.2. Cross II (WR 13 X GE 1546)

The estimates of mean, range, PCV and GCV heritabilities in both broad and narrow sense and genetic advance as per cent of mean are indicated characterwise in Tables 6 to 8. The frequency distribution for finger blast, total proteins, phenol, tannin, grain yield and fingers per ear are presented in Figures 2, 4, 6, 8, 10 and 12 for population I.

1. Finger blast

The mean incidence of finger blast was 13.98 per cent in susceptible parent (WR 13) and 2.52 per cent in resistant parent (GE 1546). The F_3 had the highest incidence in population III (11.71%) followed by population I (6.13%) and population II (4.95%). Population I and II recorded the same range (0.00 to 22.02 per cent) of finger blast incidence, while the population III had a range of 2.66 to 29.58 per cent.

Population I and II recorded high PCV and GCV values compared to population III. Broad sense heritability was very high in all the three populations; population I recorded the highest value (94.50%) followed by population II (93.40%) and population III (92.80%). In contrast narrow sense heritability was low in all the three populations. The heritability values ranged from 17.60 per cent (population II) to 22.47 per cent (population III). Population II recorded the highest genetic advance (94.80%) followed by population I (90.92%) and population III (44.78%).

2. Neck blast

The neck blast incidence was highest in susceptible parent, WR 13 (20.27%) while the resistant parent, GE 1546 had an incidence of 1.27 per cent. In F_3, the mean neck blast incidence was the highest in population III (16.01%) followed by population I (9.75%) and population II (8.41%). The range was wide in population I and II (0.00 to 39.80%) and narrow in population III (2.78 to 36.83%).

High estimates of PCV and GCV were found in population I and population II compared to population III. Broad sense heritability was very high in all the three populations and ranged from 92.10 per cent (population III) to 93.80 per cent (population I). The highest genetic advance was estimated in population II (96.92%) followed by population I (90.72%) and population III (52.27%).

3. Total proteins

The susceptible parent WR 13 had the highest mean total proteins (9.74%) and the resistant parent, GE 1546 had 7.52 per cent total proteins. In F_3, the highest mean was present in population III (9.73%) followed by population I (8.87%) and population II (8.66%). The range for this character was same in population I and II (6.93 to 10.84%) while the population III had a range of 8.64 to 10.59 per cent.

The estimates of phenotypic and genotypic co-efficient of variability were low in all the three populations. The broad sense heritability estimates were high in population I (87.30%) and II (87.70%) and moderate in population III (44.70%). The narrow sense heritability was moderate in all the three populations. Heritability ranged from 45.80 per cent in population I to 49.54 per cent in population III. The genetic advance values were moderate in population I (18.60%) and population II (18.13%), and low in population III (5.34%).

4. Total phenols

The resistant parent GE 1546 had the highest mean total phenols (6.99 mg/g) compared to 0.90 mg/g of the susceptible parent WR 13. In F_3, total phenols was highest in population II (4.45 mg/g) followed by population I (3.95 mg/g) and low in population III (1.93 mg/g). The range was wide in population I (0.73 to 7.23 mg/g) and population II (1.48 to 7.23 mg/g) and narrow range in population III (0.73 to 2.80 mg/g).

PCV and GCV values were high in all the three populations. Very high estimates of broad sense heritability were observed in all the three populations. The heritability estimates ranged from 89.80 per cent in population II to 93.90 per cent in population I. Narrow sense heritability was high in population I (63.87%) and in population II (68.67%) and moderate in population III (47.20%). The genetic advance values were very high in all the three populations and were ranging from 56.63 (population II) to 78.73 per cent over mean (population I).

5. Total tannins

The mean total tannins in parents was 0.23 mg/g in WR 13 and 4.05 mg/g in GE 1546. In F_3, mean total tannins was the highest in population II (1.49 mg/g) followed by population I (1.30 mg/g) and least in population III (0.54 mg/g). The mean for the character ranged from 0.19 to 2.82 mg/g in population I, 0.23 to 2.82 mg/g in population II and 0.19 to 1.09 mg/g in population III.

High PCV and GCV values were observed in all the three populations. Broad sense heritability estimates were very high in all the three populations. The heritability values ranged from 92.60 per cent in population III to 98.00 per cent in population I. The estimates of narrow sense heritability was high in population III (68.34%) and population I (64.14%) and moderate in population II (56.07%). Highest genetic advance was estimated in population I (108.46%) followed by population III (92.59%) and population II (86.58%).

6. Grain yield

The highest grain yield of 36.00 g/plant was recorded in the resistant variety GE 1546. The susceptible parent (WR 13) yielded 20.00 g of grain/plant. In F_3, the highest mean grain yield was recorded in population II (24.93 g) followed by population I (24.18 g) and least in population III (21.18 g). The range for this character was same in populations I and II (12.00 to 39.00 g), while in population III the range was from 13.00 to 27.00 g per plant.

Estimates of PCV and GCV were high in population I and II and were moderate in population III. Broad sense heritability was very high in all the three populations; maximum heritability was in population II (93.10%) followed by population I (92.90%) and population III (86.50%). The narrow sense heritability was high in population II (77.40%) and population I (72.54%) and moderate in population III (44.14%). The genetic advance was the highest in population II (53.47%), followed by population I (52.44%) and population III (33.38%).

7. Productive tillers

The maximum number of productive tillers of 5.08 was recorded in the susceptible parent (WR 13) and the resistant parent (GE 1546) had productive tillers of 2.15. In F_3, almost similar means were recorded in all the three populations and they varied from 2.21 in population II to 2.25 in population III. The range was wide in population I and II (1.25 to 3.70) and narrow in population III (1.55 to 2.85).

Moderate estimates of PCV and GCV were observed in all the three populations. Broad sense heritability values were high in population II (70.30%) and population I (67.70%) and moderate in population III (51.70%). The estimates of genetic advance was high in all the three populations and ranged from 21.78 per cent (population III) to 37.56 per cent (population II).

8. Fingers per ear

The highest number of fingers of 7.57 was recorded in GE 1546, while WR 13 had minimum number of fingers per ear (4.95). In F_3, population II recorded the highest

Table 6: Estimates of genetic parameters in brown and white grained F_3 (population I) of the cross WR 13 X GE 1546

Character	Parental means P1	P2	Mean	Range Min.	Max.	PCV (%)	GCV (%)	Heritability BS (%)	NS (%)	Genetic advance (% of mean)
Finger blast (%)	13.98	2.52	6.13	0.00	22.02	46.70	45.40	94.50	19.87	90.92
Neck blast (%)	20.27	1.27	9.75	0.00	39.80	46.99	45.50	93.80	-	90.72
Total Protein (%)	9.74	7.52	8.87	6.93	10.84	10.36	9.68	87.30	45.80	18.60
Total phenol(mg/g)	0.90	6.99	3.95	0.73	7.23	40.73	39.47	93.90	63.87	78.73
Total tannin (mg/g)	0.23	4.05	1.30	0.19	2.82	53.82	53.27	98.00	64.14	108.46
Grain yield/plant(g)	20.00	36.00	24.18	12.00	39.00	27.41	26.42	92.90	72.54	52.44
Prod. tillers/plant	5.08	2.15	2.22	1.25	3.70	24.75	20.37	67.70	-	34.69
Fingers per ear	4.95	7.57	6.42	4.80	8.50	14.70	10.61	52.10	11.53	15.73

P1 = WR 13, P2 = GE 1546

Table 7: Estimates of genetic parameters in brown grained F_3 (population II) of the cross WR 13 X GE 1546

Character	Mean	Range		PCV (%)	GCV (%)	Heritability		Genetc *advance* (%of mean)
		Min.	Max.			*BS* (%)	*NS* (%)	
Finger blast (%)	4.95	0.00	22.02	49.29	47.64	93.40	17.60	94.80
Neck blast (%)	8.41	0.00	39.80	50.45	48.72	93.30	-	96.92
Total protein (%)	8.66	6.93	10.84	10.01	9.38	87.70	47.14	18.13
Total phenol (mg/g)	4.45	1.48	7.23	30.56	28.96	89.80	68.67	56.63
Total tannin (mg/g)	1.49	0.23	2.82	43.24	42.65	97.30	56.07	86.58
Grain yield/plant(g)	24.93	12.00	39.00	27.90	26.91	93.10	77.40	53.47
Prod. tillers/plant	2.21	1.25	3.70	25.88	21.70	70.30	-	37.56
Fingers per ear	6.56	5.00	8.50	13.85	9.00	42.20	8.00	12.04

Table 8: Estimates of genetic parameters in white grained F_3 (population III) of the cross WR 13 X GE 1546

Character	Mean	Range		PCV (%)	GCV (%)	Heritability		Genetic advance (% of mean)
		Min.	Max.			BS (%)	NS (%)	
Finger blast (%)	11.71	2.66	29.68	23.45	22.58	92.80	22.47	44.78
Neck blast (%)	16.01	2.78	36.83	27.56	20.44	92.10	-	52.27
Total protein(%)	9.73	8.64	10.59	5.84	3.91	44.70	49.54	5.34
Total phenol(mg/g)	1.93	0.73	2.80	32.71	31.21	91.00	47.20	61.14
Total tannin (mg/g)	0.54	0.19	1.09	48.07	46.26	92.60	68.34	92.59
Grain yield/plant(g)	21.18	13.00	27.00	18.75	17.43	86.50	44.14	33.38
Prod. tillers/plant	2.25	1.55	2.85	20.23	14.55	51.70	-	21.78
Fingers per ear	5.87	4.80	7.65	14.74	13.39	82.50	13.67	25.04

number of fingers per ear of 6.56 followed by population I (6.42) and population III (5.87). The range was wide in population I (4.80 to 8.50) and population II (5.0 to 8.50) and narrow in population III (4.80 to 7.65).

Moderate estimates of PCV and GCV values were observed for all the three populations. Broad sense heritability was high in population III (82.50%), moderate in population I (52.10%) and population II (42.20%). In contrast, the estimates of narrow sense heritability were very low in all the three populations. The narrow sense heritability was highest in population III (13.67%) followed by population I (11.53%) and population II (8.00%). The genetic advance was high in population III (25.04%) and moderate in population I (15.73%) and population II (12.04%).

4.2 Character associations

The correlation co-efficients estimated for blast disease, biochemical parameters grain yield and yield components in F_2 and F_3 generations of cross I and II for the three sub populations are presented below:

4.2.1 F_2 Generation

4.2.1.1 Cross I (WR 13 X GE 1409)

The phenotypic correlation co-efficients among all character combinations are presented in Tables 9 to 11.

1 Finger blast with biochemical compounds

Finger blast exhibited positive and highly significant correlation with total proteins in population I (0.677) and population II (0.655); while, though the association was positive but non-significant in population III (0.117). Highly significant negative association was found between finger blast and total phenols in population I (-0.650) and population II (-0.610). Finger blast and total phenols showed non-significant negative association in population III (-0.346). Similar negative association between tannin and finger blast was recorded in all the three populations wherein the association was highly significant in population I and II and non-significant in population III. The highest negative 'r' value between finger blast and total tannins was observed in population I (-0.637) followed by population II (-0.595) and population III (-0.347).

2. Finger blast with yield and yield components

In general, finger blast manifested negative association with grain yield in all the three populations. A negative and highly significant association was seen in population I (-0.517) and population II (-0.503) while it was negative and non-significant in population III (-0.365).

Fingers per ear and ear length did not show significant association with finger blast in all the three populations. Though, 'r' values indicated negative association between finger blast and plant height in all the three populations, the association was significant only in population III (-0.538).

3. Grain yield with biochemical compounds

In general, grain yield exhibited negative relationship with total proteins and positive association with total phenols and total tannins in all the three populations. A highly significant negative association was observed between grain yield and total proteins in population I (-0.413) and population II (-0.396), while the association was non-significant in population III (0.113). In contrast, total phenols was found to be highly significant and positively associated with grain yield with 'r' values of 0.410 in population I and 0.389 in population II; while in population III, it was positive and non-significant (0.194). Similarly, a highly significant positive association was indicated between grain yield and total tannins with correlation values of 0.393 and 0.377 for population I and population II, respectively. However, the association was positive and non-significant in population III (0.033).

4. Association among and between biochemical compounds, yield and yield components

As expected, a strong significant positive association was found between total phenols and tannin in all the three populations, with highest 'r' value of 0.869 in population I, followed by 0.864 in population III and 0.846 in population II. Between total proteins and total phenols highly significant negative association was recorded in population I (-0.715) and population II (-0.685), but the association was negative and significant in population III (-0.450). Similarly, a negative and highly significant association was suggestive between total proteins and total tannins in population I and population II with correlation values of -0.651 and -0.610, respectively. The population III showed significant negative association (-0.405) between total proteins and total tannins. Among the yield components, only ear length expressed significant positive association with total phenols (0.135) in population II, while fingers per ear and plant height showed non-significant associations with total proteins, phenols and tannin in all the three populations.

Grain yield exhibited highly significant and positive association with fingers per ear in population I (0.424) and population II (0.416), whereas the association was positively significant in population III (0.538) because of its small population size. The association between ear length and grain yield though positive, the strength of association varied with the populations. It was highly significant in population II (0.200), significant in population I (0.156) and non-significant in population III (0.113). Plant height showed highly significant positive association with grain yield in population I (0.220) and population II (0.225) while the association was positively non-significant (0.308) in population III because of its small population size.

Fingers per ear expressed highly significant positive association with ear length (0.192) and plant height (0.209) in population I, while the relationships were much stronger in population II with 'r' values of 0.222 between fingers per ear and ear length and 0.211 between fingers per ear and plant height. Compared to populations I and II, in population III, fingers per ear showed non-significant association with ear length (0.047) and plant height (0.222). Between ear length and plant height highly significant positive association was found in population I (0.425) and in population II (0.432). Though the correlation value between ear length and plant height was high (0.400) in population III, the association was non-significant due to small population size.

Table 9: Phenotypic correlation co-efficients among yield, blast and related attributes in brown and white grained F_2 (population I) of the cross WR 13 X GE 1409

Character	Grain yield	Total protein	Total phenol	Total tannin	Fingers /ear	Ear length	Plant height
Total protein	-0.413**						
Total phenol	0.410**	-0.715**					
Total tannin	0.393**	-0.651**	0.869**				
Fingers/ear	0.424**	-0.105	0.109	0.107			
Ear length	0.156*	-0.040	0.027	-0.009	0.192**		
Plant height	0.220**	-0.043	0.039	0.032	0.209**	0.425**	
Finger blast	-0.517**	0.677**	-0.650**	-0.637**	-0.100	0.011	-0.057

* Significant at 5% level, ** Significant at 1% level

Table 10: Phenotypic correlation co-efficients among yield, blast and related attributes in brown grained F_2 (population II) of the cross WR 13 X GE 1409

Character	Grain yield	Total protein	Total phenol	Total tannin	Fingers /ear	Ear length	Plant height
Total protein	-0.396**						
Total phenol	0.389**	-0.685**					
Total tannin	0.377**	-0.610**	0.846**				
Fingers/ear	0.416**	-0.100	0.099	0.094			
Ear length	0.200**	-0.120	0.135*	0.092	0.222**		
Plant height	0.225**	0.056	0.057	0.049	0.211**	0.432**	
Finger blast	-0.503**	0.655**	-0.610**	-0.595**	-0.086	-0.033	-0.056

* Significant at 5% level, ** Significant at 1% level

Table 11: Phenotypic correlation co-efficients among yield, blast and related attributes in white grained F_2 (population III) of the cross WR 13 X GE 1409

Character	Grain yield	Total protein	Total phenol	Total tannin	Fingers /ear	Ear length	Plant height
Total protein	-0.113						
Total phenol	0.194	-0.450*					
Total tannin	0.033	-0.405*	0.864**				
Fingers/ear	0.538*	0.090	-0.007	0.096			
Ear length	0.113	0.139	-0.243	-0.295	0.047		
Plant height	0.308	-0.113	0.091	0.075	0.222	0.400	
Finger blast	-0.365	0.117	-0.346	-0.347	-0.178	-0.377	-0.538*

* Significant at 5% level, ** Significant at 1% level

4.2.1.1 Cross II (WR 13 X GE 1546)

The data on correlation co-efficients among all pairs of characters is presented in Tables 12 to 14.

1. Finger blast with biochemical compounds

Finger blast exhibited high and significant positive association with protein in population I (0.690) and population II (0.652), whereas the population III recorded non-significant positive association (0.185). Highly significant negative association was found between finger blast and total phenols in population I (-0.674) and in population II (-0.637). But the association between finger blast and total phenols was positive but non-significant in population III (0.186). Similar to total phenols, total tannins also exhibited high and significant negative association with finger blast in population I (-0.682) and in population II (-0.637), while it was negative and non-significant in population III (-0.286).

2. Finger blast with yield and yield components

In general, finger blast showed a very strong negative association with grain yield. The highest negative 'r' value between finger blast and grain yield was observed in population III (-0.713) followed by population I (-0.595) and population II (-0.574).

The yield components - fingers per ear, ear length and plant height had no association with finger blast in all the three populations. Fingers per ear and plant height showed negative association with finger blast in all the three populations, while ear length did not show any consistency in its association with finger blast; in population I it was negative while it was positive in population II and population III.

3. Grain yield with biochemical compounds

In general, grain yield exhibited negative association with total proteins and positive association with total phenols and total tannins in population I and II. Grain yield expressed negative and highly significant association with total proteins in population I (-0.392) and population II (-0.359). The association between grain yield and protein was negative and non-significant (-0.322) in population III. A highly significant and positive correlation between grain yield and total phenols was observed in population I (0.448) and population II (0.449). However, population III recorded non-significant negative association between grain yield and total phenols (-0.290). Similar to total phenols, tannin also exhibited high and significant association with grain yield in population I (0.433) and in population II (0.413), but the association between grain yield and total tannins (0.108), was positive and non-significant in population III.

4. *Association among and between biochemical compounds, grain yield and yield components*

In general, strong positive and significant association between total phenols and total tannins was observed in all the three populations. The highest 'r' value of 0.835 between total tannins and total phenols was observed in population I followed by population II (0.796) and population III (0.622). Total proteins and total phenols were found to be highly significant and negatively associated in population I (-0.721) and in population II (-0.667), while it was positive and non-significant in population III (0.273). Similarly, total proteins depicted highly significant and negative association with total tannins in population I (-0.739) and in population II (-0.697), whereas the population III recorded positive and non-significant association between total proteins and total tannins (0.353). Among the yield components, only plant height expressed significant positive association with total phenols (0.158) in population II, while fingers per ear and ear length showed non-significant association with total proteins, phenols and tannin in all the three populations.

Grain yield expressed positive and highly significant association with fingers per ear (0.434), ear length (0.244) and plant height (0.264) in population I. Similarly, in population II, grain yield showed a highly significant and positive association with yield components. The correlation 'r' values were 0.306 with fingers per ear, 0.238 with ear length and 0.425 with plant height. However, in population III, only fingers per ear had highly significant and positive association with grain yield (0.547). The associations were non-significant for grain yield with ear length and plant height.

Table 12: Phenotypic correlation co-efficients among yield, blast and related attributes in brown and white grained F_2 (population I) of the cross WR 13 X GE 1546

Character	Grain yield	Total protein	Total phenol	Total tannin	Fingers /ear	Ear length	Plant height
Total protein	*-0.392***						
Total phenol	0.448**	-0.721**					
Total tannin	0.433**	-0.739**	0.835**				
Fingers/ear	0.434**	-0.063	0.097	0.041			
Ear length	0.244**	-0.012	0.052	-0.021	0.338**		
Plant height	0.264**	-0.008	0.079	0.059	0.280**	0.400**	
Finger blast	-0.595**	0.690**	-0.674**	-0.682**	-0.094	-0.001	-0.072

* Significant at 5% level, ** Significant at 1% level

Table 13: Phenotypic correlation co-efficients among yield, blast and related attributes in brown grained F_2 (population II) of the cross WR 13 X GE 1546

Character	Grain yield	Total protein	Total phenol	Total tannin	Fingers /ear	Ear length	Plant height
Total protein	-0.359**						
Total phenol	0.449**	-0.667**					
Total tannin	0.413**	-0.697**	0.796**				
Fingers/ear	0.425**	0.031	0.087	0.024			
Ear length	0.238**	0.029	0.005	-0.068	0.339**		
Plant height	0.306**	-0.075	0.158*	0.122	0.299**	0.433**	
Finger blast	-0.574**	0.652**	-0.637**	-0.637**	-0.072	0.015	-0.121

* Significant at 5% level, ** Significant at 1% level

Table 14: Phenotypic correlation co-efficients among yield, blast and related attributes in white grained F_2 (population III) of the cross WR 13 X GE 1546

Character	Grain yield	Total protein	Total phenol	Total tannin	Fingers /ear	Ear length	Plant height
Total protein	-0.322						
Total phenol	-0.290	0.273					
Total tannin	0.108	0.353	0.622**				
Fingers/ear	0.547**	-0.280	-0.084	-0.277			
Ear length	0.187	0.023	0.169	0.062	0.284		
Plant height	-0.049	0.135	0.186	0.068	0.101	0.134	
Finger blast	-0.713**	0.185	0.186	-0.286	-0.225	0.293	-0.111

* Significant at 5% level, ** Significant at 1% level

Among the yield components, fingers per ear showed positive and highly significant association with ear length (0.338) and plant height (0.280) in population I. Similar results of stronger associations were obtained for fingers per ear with ear length (0.339) and plant height (0.299) in population II. However, the associations were positive and non-significant for fingers per ear with ear length and plant height in population II. The association between ear length and plant height was highly significant and positive in population I (0.400) and population II (0.433), while it was positive but non-significant in population III (0.134).

4.2.2 F_3 Generation

4.2.2.1 Cross I (WR 13 X GE 1409)

The phenotypic and genotypic correlation co-efficients among all character combinations are presented in Tables 15 - 17. In general, the correlation co-efficients at genotypic level are at a higher magnitude than the phenotypic correlation co-efficients.

1. Blast disease with biochemical compounds

Finger blast exhibited positive and highly significant correlations with total proteins at both phenotypic and genotypic levels in population I (0.672/0.786) and population II (0.669/0.796), whereas the association between finger blast and total proteins was non-significant and negative in population III. Highly significant and negative associations were seen between finger blast and total phenols in population I at both phenotypic level (-0.675) and genotypic level (-0.723). Similar associations were also encountered in population II (-0.614/-0.617), but finger blast had no association with total phenols in population III. Total tannins also showed negative and highly significant association with finger blast at both phenotypic and genotypic levels in population I (-0.669/-0.696) and population II (-0.620/-0.652). However, the association in population III was non-significant and negative at both levels.

Neck blast also exhibited high and significant correlations with biochemical parameters in population I and II, and non-significant associations in population III at both phenotypic and genotypic levels. High positive correlation values were found with total proteins in population II (0.724/0.839) and population I (0.678/0.781), and the values were non-significant positive in population III. A negative correlation was found between neck blast and total phenols in all the three populations; it was highly significant in population I (-0.578/-0.607) and population II (-0.613/-0.652) and non-significant in population III. Similarly, highly significant negative associations between neck blast and total tannins were found in population I (-0.575/-0.592) and population II (-0.620/-0.637), while the association was positive and non-significant in population III.

2. Blast disease with yield and yield components

In general, finger blast expressed negative association with grain yield in all the three populations. Correlations were highly significant at both phenotypic and genotypic levels in population I (-0.694/-0.747) and in population II (-0.726/-0.790) while in population III, it was non-significant at both the levels. The finger blast showed non-significant associations with productive tillers and fingers per ear in all the three combinations, both at phenotypic and genotypic levels.

Neck blast had stronger negative correlations with grain yield in all the three populations at both phenotypic and genotypic levels. The correlation values were negative and highly significant in population I (-0.758/-0.801) and population II (-0.789/-0.838), while it was negative and non-significant in population III (-0.384/-0.397). Neck blast also encountered non-significant associations with productive tillers and fingers per ear in all the three populations.

3. Grain yield with biochemical compounds

At both phenotypic and genotypic levels, grain yield exhibited highly significant associations with all the biochemical compounds in population I and II, while it was non-significant in population III. The highest negative 'r' values between grain yield and total proteins was in population II (-0.673/-0.826), followed by population I (-0.659/-0.796) and population III (-0.112/-0.225). A positive association was found between grain yield and total phenols in all the three populations with 'r' values of 0.617/0.666 in population I, 0.631/0.696 in population II and 0.200/0.211 in population III. Similarly, total tannins also showed highly positive association with grain yield in population I (0.601/0.629) and population II (0.618/0.649) and independent in population III.

Table 15: Phenotypic and genotypic correlation co-efficients among yield, blast and related attributes in brown and white grained F_3 (population I) of the cross WR 13 X GE 1409

Character		Grain yield	Total protein	Total phenol	Total tannin	Prod. tillers	Fingers /ear	Finger blast
Total protein	P	-0.659**						
	G	-0.796**						
Total phenol	P	0.617**	-0.697**					
	G	0.666**	-0.806**					
Total tannin	P	0.601**	-0.661**	0.910**				
	G	0.629**	-0.756**	0.940**				
Prod.tillers	P	-0.042	-0.014	0.067	0.013			
	G	-0.119	-0.078	0.096	-0.013			
Fingers/ear	P	-0.002	-0.061	-0.021	-0.026	-0.034		
	G	0.014	-0.020	-0.008	-0.051	-0.237*		
Finger blast	P	-0.694**	0.672**	-0.675**	-0.669**	0.096	0.048	
	G	-0.747**	0.786**	-0.723**	-0.696**	0.068	0.071	
Neck blast	P	-0.758**	0.678**	-0.578**	-0.575**	-0.014	-0.043	0.718**
	G	-0.801**	0.781**	-0.607**	-0.592**	0.018	-0.079	0.749**

* Significant at 5% level, ** Significant at 1% level, P = Phenotypic, G = Genotypic

Table 16: Phenotypic and genotypic correlation co-efficients among yield, blast and related attributes in brown grained F_3 (population II) of the cross WR 13 X GE 1409

Character		Grain yield	Total protein	Total phenol	Total tannin	Prod. tillers	Fingers /ear	Finger blast
Total protein	P	-0.673**						
	G	-0.826**						
Total phenol	P	0.631**	-0.671**					
	G	0.696**	-0.801**					
Total tannin	P	0.618**	-0.627**	0.888**				
	G	0.649**	-0.728**	0.933**				
Prod.tillers	P	-0.087	0.039	0.036	-0.027			
	G	-0.188	-0.009	0.051	-0.081			
Fingers/ear	P	0.011	-0.055	0.011	-0.049	-0.022		
	G	0.038	-0.026	-0.040	-0.096	-0.273*		
Finger blast	P	-0.726**	0.669**	-0.614**	-0.620**	0.133	0.075	
	G	-0.790**	0.796**	-0.677**	-0.652**	0.105	0.112	
Neck blast	P	-0.789**	0.724**	-0.613**	-0.620**	-0.025	-0.016	0.733**
	G	-0.838**	0.839**	-0.652**	-0.637**	0.003	-0.033	0.771**

* Significant at 5% level, ** Significant at 1% level, P = Phenotypic, G = Genotypic

Table 17: Phenotypic and genotypic correlation co-efficients among yield, blast and related attributes in White grained F_3 (population III) of the cross WR 13 X GE 1409

Character		Grain yield	Total protein	Total phenol	Total tannin	Prod. tillers	Fingers /ear	Finger blast
Total protein	P	-0.112						
	G	-0.225						
Total phenol	P	0.200	-0.158					
	G	0.211	-0.167					
Total tannin	P	-0.036	-0.011	0.780**				
	G	-0.033	-0.010	0.797**				
Prod.tillers	P	0.083	-0.160	-0.154	-0.189			
	G	0.163	-0.247	-0.205	-0.228			
Fingers/ear	P	-0.132	-0.092	0.023	0.028	-0.138		
	G	-0.197	0.171	0.025	0.069	-0.053		
Finger blast	P	-0.184	-0.076	-0.169	-0.069	0.407	-0.006	
	G	-0.206	-0.089	-0.180	-0.053	0.516	0.009	
Neck blast	P	-0.384	0.055	-0.147	0.091	0.294	-0.181	0.553*
	G	-0.397	0.149	-0.173	0.078	0.412	-0.302	0.582*

* Significant at 5% level, ** Significant at 1% level, P = Phenotypic, G = Genotypic

4. Association among and between biochemical compounds, grain yield and yield components

Total phenols exhibited very strong positive significant association with total tannins at both phenotypic and genotypic levels in all the three populations with very high 'r' values of 0.910/0.940 in population I, 0.888/0.933 in population II and 0.780/0.797 in population III. Total proteins encountered negative and highly significant association with total phenols in population I and II with 'r' values of -0.697/-0.806 and -0.671/-0.801, respectively, whereas the association was non-significant and negative in population III. Similar results were also seen between total proteins and total tannins with high significant negative 'r' values of -0.661/-0.756 in population I and -0.627/-0.728 in population II and non-significant negative 'r' values in population III. The yield components - productive tillers and fingers per ear showed non-significant associations with total proteins, phenols and total tannins in all the three populations.

As could be seen from the tables 15 to 17, in the cross I (WR 13 X GE 1409) the associations of grain yield with productive tillers and fingers per ear were non-significant. A significant negative association between productive tillers and fingers per ear was observed at genotypic level in two of the three populations studied. The correlation values were negative and significant in population I (-0.237) and population II (-0.273) and negative non-significant in population III.

4.2.2.2 Cross II (WR 13 X GE 1546)

The phenotypic and genotypic correlation values worked out for different pairs of characters are presented in Tables 18 to 20. The genotypic correlation co-efficients in general were higher than the phenotypic correlation co-efficients.

1. Blast disease with biochemical compounds

At both phenotypic and genotypic levels, finger blast had significant positive associations with total proteins in populations I and II with 'r' values (0.711/0.771) in population I and (0.689/0.766) in population II while it was non-significant in population III (0.208/0.189). In contrast, the associations between finger blast and total phenols was negative in all the populations. It was highly significant in population I (-0.728/-0.774) and population II (-0.694/-0.762), and non-significant in population III (-0.200/-0.216). Similarly, finger blast exhibited highly significant negative association with total tannins in population I (-0.764/-0.797) and population II (-0.726/-0.766) and the association was significant and negative in population III (-0.464/-0.494).

Neck blast also exhibited highly significant and positive association with total proteins in population I and population II at both phenotypic and genotypic levels. But the association was non-significant in population III. The high correlation values of (0.739/0.821) in population II and 0.688/0.764 in population I were found between neck blast and total proteins. Neck blast encountered negative and highly significant association with total phenols in population I (-0.672/-0.720) and population II (-0.672/-0.739), but the association was non-significant in population III. Neck blast also exhibited highly significant negative association with total tannins in population I (-0.664/-0.691) and in population II (-0.638/-0.669) and the association was negative and significant in population III (-0.473/-0.483).

2. Blast disease with yield and yield components

In general, finger blast showed negative association with grain yield in all the three populations at both phenotypic and genotypic levels. The association was highly significant in population I (-0.662/-0.698) and population II (-0.682/-0.723) and non-significant in population III (-0.265/-0.277). The productive tillers showed highly significant and negative association with finger blast at genotypic level in population I (-0.288) and population II (-0.348), while at phenotypic level the association was significant and negative with 'r' values of -0.216 in population I and -0.261 in population II. In population III the association was negative and non-significant. Fingers per ear did not show consistent association with finger blast, in population I; it was significant and negative at phenotypic level (-0.207) and highly significant negative at genotypic level (-0.291), while in population I and II, the association was though negative, but non-significant.

Compared to finger blast, neck blast had stronger negative association with grain yield in all three populations at both the genotypic and phenotypic levels. The correlation values were highly significant in population I (-0.717/-0.764) and population II (-0.737/-0.788) and was non-significant in population III (-0.360/-0.380). Between productive tillers and neck blast, the association was negative and highly significant in population I (-0.269/-0.330); and population II (-0.341/-0.410) while in population III the association was non-significant. At phenotypic level, fingers per ear expressed significant negative association with neck blast in population I (-0.224) while the population II and III it had non-significant association. But at genotypic level, population I (-0.325) and population II (-0.309) had highly significant negative association; the association was non-significant in population III.

3. Grain yield with biochemical compounds

At both phenotypic and genotypic levels, grain yield showed highly significant association with biochemical parameters in populations I and II, while it was non-significant in population III. The association between grain yield and total proteins was negative and highly significant with 'r' values of -0.660/-0.745 in population I, -0.685/-0.780 in population II, while it was non-significant and negative population III. Between grain yield and total phenols, positive and highly significant association was found in population I (0.637/0.680) and in population II (0.698/0.760), while in population III, the association was negatively non-significant. Similarly, grain yield expressed positive association with total tannins in all the three populations, but the association was highly significant in population I (0.661/0.690) and population II (0.683/0.715), while in population III, the association was independent.

4. Association among and between biochemical compounds, yield and yield components

Total phenols exhibited very strong positive association with total tannins at both phenotypic and genotypic levels in all the three populations with very high correlation values of 0.906/0.933 in population I, 0.877/0.919 in population II and 0.598/0.645 in population III. Total proteins showed negative and highly significant association with total phenols in population I and II with 'r' values of -0.708/-0.781 in population I and -0.670/-0.752 in population II, but the association between total proteins and total phenols in population III was positively significant at genotypic level (0.423) and non-significant at phenotypic level. The association between total proteins and total tannins was highly significant and negative at both phenotypic and genotypic levels in population I (-0.685/-0.739) and in population II (-0.625/-0.680), while in population III the association was positive and non-significant.

The productive tillers expressed highly significant negative association with total proteins at genotypic level with 'r' values of -0.277 in population I and -0.356 in population II, while at phenotypic level, it was significantly negative with 'r' values of -0.197 in population I and -0.282 in population II. The association was independent in population III at both phenotypic and genotypic levels. Fingers per ear expressed highly significant association with total proteins at both phenotypic and genotypic levels in population I (-0.253/-0.359), but in population II the association was significantly negative only at genotypic level (-0.242). In population III, the association was non-significant. Between productive tillers and total phenols, the association was significantly positive in population I (0.211) and significant and negative in population III (-0.457) at genotypic level. The association was positive and highly significant in population II (0.301/0.372) at both phenotypic and genotypic levels. The association between fingers per ear and total phenols was highly significant and positive at both phenotypic and genotypic levels in population I (0.308/0.440) but in population II, the association was positive and significant (0.271) at genotypic level only. The association was non-significant in population III. The association between productive tillers and total tannins was high and significantly positive in population II (0.330/0.400) at both phenotypic and genotypic levels. In population I it was high and significantly positive at genotypic level (0.301) and significantly positive at phenotypic level (0.243). The association was non-significant positive in population III. Between fingers per ear and total tannins, in population I, the association was highly significant and positive at genotypic level (0.333) and, significant and positive at phenotypic level (0.233), while in population II and III, the association was independent at both the levels.

Grain yield exhibited highly significant and positive association with productive tillers both at phenotypic and genotypic levels in population I (0.359/0.464) and population II (0.422/0.540) and it was non-significant in population III. Between grain

Table 18: Phenotypic and genotypic correlation co-efficients among yield, blast and related attributes in brown and White grained F_3 (population I) of the cross WR 13 X GE 1546

Character		Grain yield	Total protein	Total phenol	Total tannin	Prod. tillers	Fingers /ear	Finger blast
Total protein	P	-0.660**						
	G	-0.745**						
Total phenol	P	0.637**	-0.708**					
	G	0.680**	-0.781**					
Total tannin	P	0.661**	-0.685**	0.906**				
	G	0.690**	-0.739**	0.933**				
Prod.tillers	P	0.359**	-0.197*	0.173	0.243*			
	G	0.464**	-0.277**	0.211*	0.301**			
Fingers/ear	P	0.246*	-0.253**	0.308**	0.233*	-0.033		
	G	0.302**	-0.389**	0.440**	0.333**	-0.083		
Finger blast	P	-0.662**	0.711**	-0.728**	-0.764**	-0.216*	-0.207*	
	G	-0.698**	0.777**	-0.774**	-0.797**	-0.288**	-0.291**	
Neck blast	P	-0.717**	0.688**	-0.672**	-0.664**	-0.269**	-0.224*	0.706**
	G	-0.764**	0.764**	-0.720**	-0.691**	-0.330**	-0.325**	0.750**

* Significant at 5% level, ** Significant at 1% level, P = Phenotypic, G = Genotypic

Table 19: Phenotypic and genotypic correlation co-efficients among yield, blast and related attributes in brown grained F_3 (population II) of the cross WR 13 X GE 1546

Character		Grain yield	Total protein	Total phenol	Total tannin	Prod. tillers	Fingers /ear	Finger blast
Total protein	P	-0.685**						
	G	-0.780**						
Total phenol	P	0.698**	-0.670**					
	G	0.760**	-0.752**					
Total tannin	P	0.683**	-0.625**	0.877**				
	G	0.715**	-0.680**	0.919**				
Prod.tillers	P	0.422**	-0.282*	0.301**	0.330*			
	G	0.540**	-0.356**	0.372**	0.400**			
Fingers/ear	P	0.196	-0.141	0.163	0.089	0.039		
	G	0.245*	-0.242*	0.271*	0.149	0.084		
Finger blast	P	-0.682**	0.689**	-0.694**	-0.726**	-0.261*	-0.108	
	G	-0.723**	0.766**	-0.762**	-0.766**	-0.348**	-0.152	
Neck blast	P	-0.737**	0.739**	-0.672**	-0.638**	-0.341**	-0.184	0.680**
	G	-0.788**	0.821**	-0.739**	-0.669**	-0.410**	-0.309**	0.725**

* Significant at 5% level, ** Significant at 1% level, P = Phenotypic, G = Genotypic

Table 20: Phenotypic and genotypic correlation co-efficients among yield, blast and related attributes in White grained F_3 (population III) of the cross WR 13 X GE 1546

Character		Grain yield	Total protein	Total phenol	Total tannin	Prod. tillers	Fingers /ear	Finger blast
Total protein	P	-0.192						
	G	-0.196						
Total phenol	P	-0.039	0.277					
	G	-0.036	0.423*					
Total tannin	P	0.251	0.049	0.598**				
	G	0.259	0.200	0.645**				
Prod.tillers	P	-0.017	0.090	-0.278	0.128			
	G	-0.067	-0.196	-0.457*	0.246			
Fingers/ear	P	0.181	-0.115	0.036	0.133	-0.395		
	G	0.232	-0.262	0.186	0.152	-0.771**		
Finger blast	P	-0.265	0.208	-0.200	-0.464*	-0.212	-0.025	
	G	-0.277	0.189	-0.216	-0.494*	-0.271	-0.046	
Neck blast	P	-0.360	-0.141	-0.366	-0.473*	0.019	0.088	0.567**
	G	-0.380	-0.211	-0.402	-0.483*	0.010	0.111	0.631**

* Significant at 5% level, ** Significant at 1% level, P = Phenotypic, G = Genotypic

yield and fingers per ear, the association was positively significant at phenotypic level and highly significant at genotypic level in population I (0.246/0.302), and population II (0.245), the association was significantly positive only at genotypic level. In population III, the association was non-significant at both phenotypic and genotypic levels. At genotypic level the productive tillers encountered highly significant and negative association with fingers per ear in population III (-0.771), but in population I and II the association was non-significant at both phenotypic and genotypic levels.

4.3 Path co-efficient analysis

Path co-efficient analysis was not carried out for population III, since the correlation values were non significant for most of the characters mainly because of low population size and variability. Path co-efficient values for the other two populations (I and II) are presented here under.

4.3.1 F_2 Generation

4.3.1.1 Cross I (WR 13 X GE 1409)

The direct and indirect effects of different characters on blast disease and grain yield for two sub populations are presented in Tables 21 to 24.

1. Direct and indirect effects of biochemical compounds, yield and yield components on finger blast

a. Population I

Total proteins showed maximum positive direct effect (0.359), while grain yield (-0.286) showed maximum negative direct effect followed by total tannins (-0.205) and total phenols (-0.108) on finger blast (Table 21).

Proteins contributed mainly through its positive direct effect, though its indirect effects via total tannins (0.133) and grain yield (0.118) was substantial and positive. The indirect effects of phenols was negative and high via total proteins (-0.257), total tannins (-0.178) and grain yield (-0.117). Similarly, total tannins had negative and high indirect effects through total proteins (-0.233), grain yield (-0.113) and total phenols (-0.094). Grain yield showed high negative indirect effects via total proteins (-0.148) and total

Table 21: Direct and indirect phenotypic effects of **seven** attributes on **Finger blast in brown** and white grained F_2 (population I) of the **cross** WR 13 X GE 1409

Character	Total protein	Total phenol	Total tannin	Fingers /ear	Ear length	Plant height	Grain yield	Phenotypic Corrl. with finger blast
Total protein	**0.359**	0.077	0.133	-0.009	-0.002	-0.001	0.118	0.677
Total phenol	-0.257	**-0.108**	-0.178	0.009	0.002	-0.000	-0.117	-0.650
Total tannin	-0.233	-0.094	**-0.205**	0.009	-0.001	-0.000	-0.113	-0.637
Fingers/ear	-0.038	-0.012	-0.022	**0.083**	0.012	-0.000	-0.121	-0.100
Ear length	-0.014	-0.003	0.002	0.016	**0.060**	-0.005	-0.045	0.011
Plant height	-0.016	-0.004	-0.007	0.017	0.025	**-0.011**	-0.063	-0.057
Grain yield	-0.148	-0.044	-0.081	0.035	0.009	-0.002	**-0.286**	-0.517

Diagonal figures in bold indicate direct effects.

Residual effect: 0.4153

total tannins (-0.081); other indirect effects were negligible. The direct and indirect effects of fingers per ear, ear length and plant height on finger blast were of a very low magnitude, thereby accounting for the non-significant correlation with finger blast.

a. Population II

Total proteins exhibited the highest positive direct effects of 0.372 followed by ear length (0.087) and fingers per ear (0.086). The highest negative direct effect of -0.297 was contributed by grain yield followed by total tannins (-0.184) and total phenols (-0.104) (Table 22).

Total proteins not only contributed directly for finger blast, but also contributed indirectly through grain yield (0.118) and total tannins (0.112). The indirect effects of total phenols through total proteins was the highest (-0.251) followed by total tannins (-0.156) and grain yield (-0.116). The negative indirect effects of total tannins through total proteins was the highest (-0.227) followed by grain yield (-0.111); and indirect effects through other characters were negligible. Grain yield had the maximum direct negative effect (-0.297) and the indirect effects of this character were negligible except the effect of grain yield through total proteins (-0.147). As in the case of population I, direct and indirect effects of fingers per ear, ear length and plant height were very low, which resulted in non-significant association with finger blast.

2. Direct and indirect effects of biochemical compounds, finger blast and yield components on grain yield

a. Population I

Finger blast exhibited maximum negative direct effect (-0.393) on grain yield, while fingers per ear (0.340) and plant height (0.101) recorded high positive direct effects. Total phenols (0.058), protein (-0.050), tannin (0.021) and ear length (0.049) had low direct effects (Table 23).

The indirect effects of total proteins through finger blast (-0.266) alone was maximum, while through all other characters it was low and negative. The indirect contributions of total phenols (0.256) and tannin (0.250) through finger blast were high

Table 22: Direct and indirect phenotypic effects of seven attributes on Finger blast in brown grained F_2 (population II) of the cross WR 13 X GE 1409

Character	Total protein	Total phenol	Total tannin	Fingers /ear	Ear length	Plant height	Grain yield	Phenotypic Corrl. with finger blast
Total protein	**0.372**	0.071	0.112	-0.009	-0.010	0.001	0.118	0.655
Total phenol	-0.251	**-0.104**	-0.156	0.009	0.012	-0.001	-0.116	-0.610
Total tannin	-0.227	-0.088	**-0.184**	0.008	0.008	-0.000	-0.111	-0.595
Fingers/ear	-0.037	-0.010	-0.017	**0.086**	0.019	-0.002	-0.124	-0.086
Ear length	-0.044	-0.014	-0.017	0.019	**0.087**	-0.004	-0.060	-0.033
Plant height	-0.021	-0.006	-0.009	0.018	0.038	**-0.009**	-0.067	-0.056
Grain yield	-0.147	-0.041	-0.069	0.036	0.018	-0.002	**-0.297**	-0.503

Diagonal figures in bold indicate direct effects

Residual effect: 0.4438

Table 23: Direct and indirect phenotypic effects of seven attributes on grain yield in brown and white grained F_2 (population I) of the cross WR 13 X GE 1409

Character	Total protein	Total phenol	Total tannin	Fingers /ear	Ear length	Plant height	Finger blast	Phenotypic corrl. with grain yield
Total protein	**-0.050**	-0.042	-0.013	-0.036	-0.002	-0.004	-0.266	-0.413
Total phenol	0.036	**0.058**	0.018	0.037	0.001	0.004	0.256	0.410
Total tannin	0.033	0.051	**0.021**	0.036	-0.001	0.003	0.250	0.393
Fingers/ear	0.005	0.006	0.002	**0.340**	0.009	0.021	0.039	0.424
Ear length	0.002	0.002	-0.000	0.065	**0.049**	0.043	-0.004	0.156
Plant height	0.002	0.002	0.001	0.071	0.021	**0.101**	0.023	0.220
Finger blast	-0.034	-0.038	-0.013	-0.034	0.001	-0.006	**-0.393**	-0.517

Diagonal figures in bold indicate direct effects

Residual effect: 0.5701

Table 24: Direct and indirect phenotypic effects of seven attributes on grain yield in brown grained F_2 (population II) of the cross WR 13 X GE 1409

Character	Total protein	Total phenol	Total tannin	Fingers /ear	Ear length	Plant height	Finger blast	Phenotypic corrl. with grain yield
Total protein	**-0.043**	-0.027	-0.025	-0.034	-0.007	-0.006	-0.255	-0.396
Total phenol	0.029	**0.040**	0.035	0.034	0.007	0.006	0.238	0.389
Total tannin	0.026	0.034	**0.041**	0.032	0.005	0.005	0.232	0.377
Fingers/ear	0.004	0.004	0.004	**0.337**	0.012	0.022	0.033	0.416
Ear length	0.005	0.005	0.004	0.075	**0.054**	0.044	0.013	0.200
Plant height	0.002	0.002	0.002	0.071	0.023	**0.102**	0.022	0.225
Finger blast	-0.028	-0.024	-0.024	-0.029	-0.002	-0.006	**-0.390**	-0.503

Diagonal figure in bold indicate direct effects

Residual effect: 0.5817

and positive; the indirect effects through other characters were negligible. Finger blast showed a large direct effect (-0.393), but low indirect effects through other characters. Similarly, fingers per ear contributed largely through their direct effects; indirect effects through other traits being of very low magnitude. Ear length did not contribute much either through its direct effect or through its indirect effects via other characters. The indirect effects of plant height on grain yield through other characters were also very low.

b. Population II

Maximum direct negative effect on grain yield was through finger blast (-0.390). The direct positive effect was high from fingers per ear (0.337), followed by and plant height (0.102). Total proteins (-0.043), phenols (0.040) and tannin (0.041) and ear length (0.054) had low direct effects Table 24).

Total proteins contributed to grain yield mainly through its indirect negative effect via finger blast (-0.255) and its indirect effects through other characters were negligible. On the other hand, contributions of total phenols (0.238) and total tannins (0.232) through finger blast were positive and substantial. Finger blast showed a large direct effect (-0.390), but small indirect effects through other characters. Fingers per ear contributed mainly through their direct effect, and the indirect effects of this character through all other characters were low and positive. The indirect effects of ear length and plant height through other characters were also negligible.

4.3.1.2 Cross II (WR 13 X GE 1546)

The direct and indirect effects of different characters on blast disease and grain yield for two sub populations are presented in Tables 25 - 28.

1. Direct and indirect effects of biochemical compounds, yield and yield components on finger blast

a. Population I

Total proteins showed the highest positive direct effect (0.322) on finger blast whereas grain yield recorded the highest negative direct effect (-0.394) followed by total phenols (-0.157) and total tannins (-0.145). Fingers per ear (0.093) and ear length (0.072) had low direct effects on finger blast (Table 25).

Table 25: Direct and indirect phenotypic effects of seven attributes on Finger blast in brown and white grained F_2 (population I) of the cross WR 13 X GE 1546

Character	Total protein	Total phenol	Total tannin	Fingers /ear	Ear length	Plant height	Grain yield	Phenotypic corrl. with finger blast
Total protein	**0.322**	0.113	0.107	-0.006	-0.001	0.000	0.152	0.690
Total phenol	-0.232	**-0.157**	-0.121	0.009	0.004	0.000	-0.176	-0.674
Total tannin	-0.238	-0.131	**-0.145**	0.004	-0.002	0.000	-0.171	-0.682
Fingers/ear	-0.020	-0.016	-0.006	**0.093**	0.024	0.000	-0.171	-0.094
Ear length	-0.004	-0.008	0.003	0.032	**0.072**	0.000	-0.096	-0.001
Plant height	-0.003	-0.012	-0.009	0.026	0.029	**0.001**	-0.104	-0.072
Grain yield	-0.126	-0.070	-0.063	0.041	0.018	0.000	**-0.394**	-0.595

Diagonal figures in bold indicate direct effects

Residual effect: 0.3477

Total proteins contributed mainly through its positive direct effect (0.322) and its indirect effect through grain yield was highest (0.154) followed by total phenols (0.113) and total tannins (0.107). The negative direct effects of total phenols and total tannins on finger blast were further magnified by their high negative indirect effects via total proteins and grain yield, and also their mutual negative indirect effects. The negative association of grain yield was mainly through its direct negative effect (-0.394) and indirect negative effect via total proteins (-0.126). Fingers per ear, ear length and plant height contributed very little to finger blast through their direct and indirect effects, thereby accounting for their low associations with finger blast.

b. Population II

Total proteins contributed maximum direct positive effect (0.319) on finger blast followed by fingers per ear (0.102). Grain yield exhibited maximum negative direct effect (-0.397) followed by total phenols (-0.158) and total tannins (-0.126). Direct effects of ear length (0.053) and plant height (0.012) were negligible (Table 26).

Contribution of total proteins to finger blast was mainly through its direct effect. Among indirect effects, the effect of total proteins through grain yield (0.143) and total phenols (0.105) were high and positive. The high negative direct effects of total phenols and total tannins were further magnified their high negative indirect effects through total proteins and grain yield and their mutual negative indirect effects. Grain yield showed a very large negative direct effect (-0.397). Its indirect effects through total proteins (-0.114) was the highest, followed by total phenols (-0.071) and tannin (-0.052). Fingers per ear had moderate direct effect (0.102) and its indirect effect through grain yield (-0.169) was maximum and negative. Ear length had low direct and indirect effects on finger blast. Plant height contributed mainly through its negative indirect effect via grain yield (-0.122).

Table 26: Direct and indirect phenotypic effects of seven attributes on **Finger blast** in brown grained F_2 (population II) of the cross WR 13 X GE 1546

Character	Total protein	Total phenol	Total tannin	Fingers /ear	Ear length	Plant height	Grain yield	Phenotypic corrl. with finger blast
Total protein	**0.319**	0.105	0.088	-0.003	0.002	-0.001	0.143	0.652
Total phenol	-0.212	**-0.158**	-0.100	0.009	0.000	0.002	-0.178	-0.637
Total tannin	-0.222	-0.126	**-0.126**	0.002	-0.004	0.001	-0.164	-0.637
Fingers/ear	-0.010	-0.014	-0.003	**0.102**	0.018	0.004	-0.169	-0.072
Ear length	0.009	-0.001	0.009	0.035	**0.053**	0.005	-0.094	0.015
Plant height	-0.024	-0.025	-0.015	0.030	0.023	**0.012**	-0.122	-0.121
Grain yield	-0.114	-0.071	-0.052	0.043	0.013	0.004	**-0.397**	-0.574

Diagonal figure in bold indicate direct effects

Residual effect: 0.3918

1. Direct and indirect effects of biochemical compounds, blast disease and yield components on grain yield

a. Population I

Finger blast exhibited the highest negative direct effect (-0.538) on grain yield. Except finger blast, direct effects of all other characters were positive. Direct positive effect was more from fingers per ear (0.323) while, ear length (0.100), total tannins (0.093), total proteins (0.092) and plant height (0.088) had low direct effects (Table 27).

Total proteins registered a low positive direct effect on grain yield and its high correlation with yield was mainly due to its greater indirect negative effect through finger blast (-0.371). Similarly, total phenols and tannin showed low positive direct effects, but, their positive indirect effects through finger blast were substantial. Finger blast had a very large negative direct effect (-0.538) but negligible indirect effects through other characters. Similarly, fingers per ear had a large positive direct effect (0.323) and its indirect effects via other characters were low. Ear length and plant height contributed mainly through their direct effects and their corresponding indirect effects via fingers per ear were high.

b. Population II

Maximum negative direct effect on grain yield was through finger blast (-0.494). Fingers per ear had the highest positive direct effect (0.322) while ear length (0.099), plant height (0.091), total proteins (0.090), total phenols (0.089) and total tannins (0.078) had low positive direct effects (Table 28).

Total proteins showed a low direct effect. Indirect effect of total proteins through finger blast alone was maximum (-0.322), while through other characters it was low. Total phenols and tannin also showed low positive direct effects, but the contributions of total phenols (0.315) and total tannins (0.315) through finger blast were high and positive. Finger blast showed a very large negative direct effect (-0.494) but small indirect effects through other characters. In contrast, fingers per ear had a large positive direct effect (0.322) and its indirect effects through other characters were low. Ear length and plant height contributed mainly through their direct effects and their corresponding indirect effects via fingers per ear were moderate.

Table 27: Direct and indirect phenotypic effects of seven attributes on grain yield in brown and white grained F_2 (population I) of the cross WR 13 X GE 1546

Character	Total protein	Total phenol	Total tannin	Fingers /ear	Ear length	Plant height	Finger blast	Phenotypic corrl. with finger blast
Total protein	**0.092**	-0.021	-0.069	-0.020	-0.001	-0.001	-0.371	-0.392
Total phenol	-0.066	**0.029**	0.077	0.032	0.005	0.007	0.362	0.448
Total tannin	-0.068	0.025	**0.093**	0.013	-0.002	0.005	0.367	0.433
Fingers/ear	-0.006	0.003	0.004	**0.323**	0.034	0.025	0.051	0.433
Ear length	-0.001	0.002	-0.002	0.109	**0.100**	0.035	0.001	0.244
Plant height	-0.001	0.002	0.006	0.090	0.040	**0.088**	0.039	0.264
Finger blast	0.063	-0.020	-0.063	-0.031	0.000	-0.006	**-0.538**	-0.595

Diagonal figure in bold indicate direct effects

Residual effect: 0.4749

Table 28: Direct and indirect phenotypic effects of seven attributes on grain yield in brown grained F_2 (population II) of the cross WR 13 X GE 1546

Character	Total protein	Total phenol	Total tannin	Fingers /ear	Ear length	Plant height	Finger blast	Phenotypic corrl. with grain yield
Total protein	**0.090**	-0.059	-0.055	-0.010	0.003	-0.007	-0.322	-0.359
Total phenol	-0.060	**0.089**	0.062	0.028	0.001	0.014	0.315	0.449
Total tannin	-0.063	0.071	**0.078**	0.008	-0.007	0.011	0.315	0.413
Fingers/ear	-0.003	0.008	0.002	**0.322**	0.034	0.027	0.036	0.425
Ear length	0.003	0.000	-0.005	0.109	**0.099**	0.039	-0.008	0.238
Plant height	-0.007	0.014	0.010	0.096	0.043	**0.091**	0.060	0.306
Finger blast	0.059	-0.057	-0.050	-0.023	0.002	-0.011	**-0.494**	-0.574

Diagonal figure in bold indicate direct effects

Residual effect: 0.4882

4.3.2 F_3 generation

4.3.2.1 Cross I (WR 13 X GE 1409)

The direct and indirect effects of different characters on finger blast, neck blast and grain yield for two sub populations are presented in Tables 29 - 34.

1. Direct and indirect effects of biochemical compounds, neck blast, yield and yield components on finger blast

a. Population I

Neck blast exhibited highest positive direct effect (0.330) on finger blast followed by total proteins (0.140) productive tillers (0.113) and fingers per ear (0.075). The negative direct effect was more from total phenols (-0.190) followed by grain yield (-0.158) and total tannins (-0.119) on finger blast (Table 29).

Total proteins contributed to finger blast mainly by its positive direct effect (0.140) and by its positive indirect effects through neck blast (0.224), total phenols (0.132) and grain yield (0.104). The negative direct effects of total phenols and tannin on finger blast were further magnified by their mutual indirect effects and indirect effects through neck blast, grain yield and total proteins. Neck blast showed a large direct effect (0.330) and was further complimented by its high indirect positive effects through grain yield (0.119), total phenols (0.110) and protein (0.095). In contrast, grain yield contributed substantially through neck blast (-0.250) followed by total phenols (-0.117) and protein (-0.092); in addition to its high direct effect (-0.158). Productive tillers contributed mainly through their direct effects (0.113) and their indirect effects through other characters were low. Fingers per ear contributed very little by their direct and indirect effects, thereby accounting for their non-significant association with finger blast.

b. Population II

Neck blast had maximum positive direct effect (0.319) on finger blast followed by total proteins (0.160), productive tillers (0.115) and fingers per ear (0.091). Highest negative direct effect was from grain yield (-0.254) followed by total tannins (-0.089) and total phenols (-0.077) (Table 30).

Table 29: Direct and indirect phenotypic effects of seven attributes on Finger blast in brown and white grained F_3 (population I) of the cross WR 13 X GE 1409

Character	Total protein	Total phenol	Total tannin	Prod. tillers	Fingers /ear	Neck blast	Grain yield	Phenotypic corrl. with finger blast
Total protein	**0.140**	0.132	0.079	-0.002	-0.005	0.224	0.104	0.672
Total phenol	-0.097	**-0.190**	-0.108	0.008	0.002	-0.191	-0.097	-0.675
Total tannin	-0.092	-0.173	**-0.119**	0.001	-0.002	-0.190	-0.095	-0.669
Prod. tillers	-0.002	-0.013	-0.002	**0.113**	-0.003	-0.005	0.007	0.096
Fingers/ear	-0.009	-0.004	0.003	-0.004	**0.075**	-0.014	0.000	0.048
Neck blast	0.095	0.110	0.068	-0.002	-0.003	**0.330**	0.119	0.718
Grain yield	-0.092	-0.117	-0.071	-0.005	0.000	-0.250	**-0.158**	-0.694

Diagonal figures in bold indicate direct effects

Residual effect: 0.3374

Table 30: Direct and indirect phenotypic effects of seven attributes on **Finger** blast in brown grained F_3 (population II) of the cross WR 13 X GE 1409

Character	Total protein	Total phenol	Total tannin	Prod. tillers	Fingers /ear	Neck blast	Grain yield	Phenotypic corrl. with finger blast
Total protein	**0.160**	0.052	0.056	0.005	-0.005	0.231	0.171	0.669
Total phenol	-0.107	**-0.077**	-0.079	0.004	0.001	-0.196	-0.160	-0.614
Total tannin	-0.100	-0.068	**-0.089**	-0.003	-0.004	-0.198	-0.157	-0.620
Prod. tillers	0.006	-0.003	0.002	**0.115**	-0.002	-0.008	0.022	0.133
Fingers/ear	-0.009	-0.001	0.004	-0.002	**0.091**	-0.005	-0.003	0.075
Neck blast	0.116	0.047	0.055	-0.003	-0.001	**0.319**	0.200	0.733
Grain yield	-0.108	-0.049	-0.055	-0.010	0.001	-0.252	**-0.254**	-0.726

Diagonal figure in bold indicate direct effects

Residual effect: 0.3505

Total proteins contributed substantially through its positive indirect effects via neck blast (0.231) and grain yield (0.171); in addition to its high direct positive effect (0.160). Total phenols and total tannins contributed mainly by their negative direct effects, mutual indirect effects and indirect effects through neck blast, grain yield and total proteins. Neck blast contributed mainly through its indirect effects via grain yield (0.200) and total proteins (0.116); in addition, to its large direct effect (0.319). The contribution of grain yield was mainly by its negative direct effect (-0.254) and negative indirect effects through neck blast (-0.252) and total proteins (-0.108). Productive tillers contributed mainly through their direct effect (0.115), while fingers per ear had low contribution either from their direct effect or indirect effects.

2. Direct and indirect effects of biochemical compounds, finger blast, yield and yield components on neck blast

a. Population I

Finger blast exhibited the highest positive direct effect (0.318) on neck blast followed by total proteins (0.213) and total phenols (0.137) while the highest negative direct effect was contributed by grain yield (-0.432). The direct effects of total tannins, productive tillers and fingers per ear were -0.087, -0.070 and -0.054, respectively (Table 31).

Total proteins not only contributed directly (0.213) for neck blast but also contributes substantially by its positive indirect effects through grain yield (0.285) and finger blast (0.214). The indirect effects of total phenols were high and negative, through grain yield (-0.267), finger blast (-0.215) and total proteins (-0.148). Total tannins showed little negative direct effect (-0.087) but its indirect contributions through grain yield (-0.260), neck blast (-0.213) and total proteins (-0.141) were high and negative. Its indirect effect through total phenols (0.125) was high but positive. Finger blast showed large positive indirect effects through grain yield (0.300) and total proteins (0.143) on neck blast. In contrast, grain yield contributed to neck blast mainly by its negative direct effect (-0.432) and indirect effects through finger blast (-0.221) and total proteins (-0.140). The direct and indirect effects of productive tillers and fingers per ear were of low magnitude, thereby accounting for non-significant association with neck blast.

Table 31: Direct and indirect phenotypic effects of seven attributes on neck blast in brown and white grained F_3 (population I) of the cross WR 13 X GE 1409

Character	Total protein	Total phenol	Total tannin	Prod. tillers	Fingers /ear	Finger blast	Grain yield	Phenotypic corrl. with neck blast
Total protein	**0.213**	-0.096	0.058	0.001	0.003	0.214	0.285	0.678
Total phenol	-0.148	**0.137**	-0.079	-0.005	-0.001	-0.215	-0.267	-0.578
Total tannin	-0.141	0.125	**-0.087**	-0.001	0.001	-0.213	-0.260	-0.575
Prod. tillers	-0.003	0.009	-0.001	**-0.070**	0.002	0.031	0.018	-0.014
Fingers/ear	-0.013	0.003	0.002	0.002	**-0.054**	0.015	0.001	-0.043
Finger blast	0.143	-0.092	0.058	-0.007	-0.003	**0.318**	0.300	0.718
Grain yield	-0.140	0.085	-0.052	0.003	0.000	-0.221	**-0.432**	-0.758

Diagonal figures in bold indicate direct effects

Residual effect: 0.3252

b. Population II

Total proteins (0.262) and finger blast (0.246) had high positive direct effects on neck blast followed by total phenols (0.126). Highest direct negative effect was from grain yield (-0.427) followed by total tannins (-0.155) and productive tillers (-0.115). Fingers per ear (-0.027) had the lowest direct effect on neck blast (Table 32).

Total proteins contributed mainly by its positive direct effect (0.262) and indirect effects through grain yield (0.288), finger blast (0.165) and total tannins (0.097). Like population I, total phenols showed moderate direct effect (0.126) and its indirect effects through grain yield (-0.270), total proteins (-0.171), finger blast (-0.151) were high and negative. Total tannins showed high negative direct effect (-0.155) and its indirect effects through grain yield (-0.264), total proteins (-0.164) and finger blast (-0.153) were also high. Its indirect effects via total phenols was positive (0.112). Finger blast showed large positive direct effect (0.246) and its indirect effects through grain yield (0.310) and total proteins (0.175) were substantial. In contrast, grain yield showed large negative direct effect (-0.427) on neck blast and its indirect contributions were substantial and negative through finger blast (-0.179) and total proteins (-0.176). Productive tillers had considerable negative direct effect (-0.115), but small indirect effects trough other characters. The direct and indirect effects of fingers per year were low, which resulted in non-significant association with neck blast.

3. Direct and indirect effects of biochemical compounds, finger and neck blast and yield components on grain yield

a. Population I

Except total phenols (0.148) all other characters showed negative direct effects on grain yield. Neck blast exhibited the highest negative direct effect (-0.468) followed by finger blast (-0.164) and total proteins (-0.129). The direct effects of productive tillers and fingers per ear were -0.046 and -0.027, respectively (Table 33).

The negative direct effect of total proteins (-0.129) was further magnified by its high indirect effects through neck blast (-0.317), finger blast (-0.111) and total

Table 32: Direct and indirect phenotypic effects of seven attributes on neck blast in brown grained F_3 (population II) of the cross WR 13 **X** GE 1409

Character	Total protein	Total phenol	Total tannin	Prod. tillers	Fingers /ear	Finger blast	Grain yield	Phenotypic corrl. with neck blast
Total protein	**0.262**	-0.085	0.097	-0.004	0.001	0.165	0.288	0.724
Total phenol	-0.176	**0.126**	-0.138	-0.004	0.000	-0.151	-0.270	-0.613
Total tannin	-0.164	0.112	**-0.155**	0.003	0.001	-0.153	-0.264	-0.620
Prod. tillers	0.010	0.005	0.004	**-0.115**	0.001	0.033	0.037	-0.025
Fingers/ear	-0.014	0.001	0.008	0.002	**-0.027**	0.018	-0.005	-0.016
Finger blast	0.175	-0.077	0.096	-0.015	-0.002	**0.246**	0.310	0.733
Grain yield	-0.176	0.080	-0.096	0.010	0.000	-0.179	**-0.427**	-0.789

Diagonal figures in bold indicate direct effects

Residual effect: 0.2704

Table 33: Direct and indirect phenotypic effects of seven attributes on grain yield in brown and white grained F_3 (population I) of the cross WR 13 X GE 1409

Character	Total protein	Total phenol	Total tannin	Prod. tillers	Fingers /ear	Finger blast	Neck blast	Phenotypic corrl. with grain yield
Total protein	**-0.129**	-0.103	-0.001	0.001	0.002	-0.111	-0.317	-0.659
Total phenol	0.090	**0.148**	0.001	-0.003	-0.001	0.111	0.270	0.617
Total tannin	0.085	0.135	**0.001**	-0.001	0.001	0.110	0.269	0.601
Prod. tillers	0.002	0.010	0.000	**-0.046**	0.001	-0.016	0.007	-0.042
Fingers/ear	0.008	0.003	0.000	0.002	**-0.027**	-0.008	0.020	-0.002
Finger blast	-0.087	-0.100	-0.001	-0.004	-0.001	**-0.164**	-0.336	-0.694
Neck blast	-0.087	-0.086	-0.001	0.001	0.001	-0.118	**-0.468**	-0.758

Diagonal figures in bold indicate direct effects

Residual effect: 0.3522

phenols (-0.103). Similarly, positive direct effect of total phenols (0.148) was further magnified by its indirect positive effects through neck blast (0.270), finger blast (0.111) and total proteins (0.090). Total tannins showed lowest direct effect (0.001), but its indirect effects through neck blast (0.269) total phenols (0.135), finger blast (0.110) and total proteins (0.085) were substantial. Interestingly, the indirect effects of all other characters through total tannins were very negligible. The negative direct effects of neck and finger blast were further magnified by their mutual indirect effects and their effects through total phenols and total proteins. Productive tillers and fingers per ear had very low contributions by their direct and indirect effects. Further, indirect effects of all other characters through productive tillers and fingers per ear were very negligible.

b. Population II

Total phenols showed the highest positive direct effect (0.162) on grain yield. Neck blast showed the highest negative direct effect (-0.485) followed by finger blast (-0.222), productive tillers (-0.073) and total proteins (-0.064) on grain yield (Table 34).

Though total proteins registered low direct effect (-0.064), its contribution was substantial by its indirect effects through neck blast (-0.351), finger blast (-0.149) and total phenols (-0.109). Total phenols had a large direct effect (0.162), besides considerable indirect effects through neck blast (0.298) and finger blast (0.137). Total tannins showed very little direct effect (-0.006) but indirect contributions through neck blast (0.301), total phenols (0.144) and finger blast (0.138) were substantial and positive. The negative direct effects of neck and finger blast were further magnified by their mutual indirect effects and indirect effects through total phenols. The direct and indirect effects of productive tillers and fingers per ear were of very low magnitude, thereby accounting for the non-significant association with grain yield. Further, the indirect effects of all other characters through productive tillers and fingers per ear were very low.

Table 34: Direct and indirect phenotypic effects of seven attributes on grain yield in brown grained F_3 (population II) of the cross WR 13 X GE 1409

Character	Total protein	Total phenol	Total tannin	Prod. tillers	Fingers /ear	Finger blast	Neck blast	Phenotypic corrl. with grain yield
Total protein	**-0.064**	-0.109	0.004	-0.003	-0.001	-0.149	-0.351	-0.673
Total phenol	0.043	**0.162**	-0.006	-0.003	0.000	0.137	0.298	0.631
Total tannin	0.040	0.144	**-0.006**	0.002	-0.001	0.138	0.301	0.618
Prod.tillers	-0.003	0.006	0.000	**-0.073**	0.000	-0.030	0.012	-0.087
Fingers/ear	0.004	0.002	0.000	0.002	**0.013**	-0.017	0.008	0.011
Finger blast	-0.043	-0.100	0.004	-0.010	0.001	**-0.222**	-0.356	-0.726
Neck blast	-0.047	-0.099	0.004	0.002	0.000	-0.163	**-0.485**	-0.789

Diagonal figures in bold indicates direct effects

Residual effect: 0.3072

4.3.2.2 Cross II (WR 13 X GE 1546)

The direct and indirect effects of different characters on finger blast, neck blast and grain yield for two sub populations are presented in Tables 35 - 40.

1. Direct and indirect effects of biochemical compounds, neck blast, yield and yield components on finger blast

a. Population I

Total proteins (0.224) and neck blast (0.223) showed maximum positive direct effects on finger blast, whereas total tannins recorded the highest negative direct effect (-0.424) followed by grain yield (-0.098). The direct effects of productive tillers (0.024), total phenols (0.018) and fingers per ear (0.017) were negligible (Table 35).

Total proteins not only contributed substantial positive direct effect (0.224) on finger blast but also contributed total tannins (0.291) and neck blast (0.153). In contrast, total phenols contributed very little by its direct effect (0.018), but its indirect negative effects through total tannins (-0.385), total proteins (-0.159) and neck blast (-0.150) were substantial. The large negative direct effect of total tannins (-0.424) was further magnified by its high indirect effects through total proteins (-0.154) and neck blast (-0.148). Similarly, the large positive direct effects of neck blast (0.223) was further magnified by its high indirect positive effects through total tannins (0.282) and total proteins (0.154). Grain yield showed moderate direct effect (-0.098) but its indirect negative effects through total tannins (-0.281) neck blast (-0.160) and total proteins (-0.148) were substantial. Productive tillers and fingers per ear showed small direct effects and their indirect effects were substantial only through total tannins.

b. Population II

The highest positive direct effect was contributed by total proteins (0.237) followed by neck blast (0.162), while, total tannins (-0.394) contributed highest negative direct effect followed by grain yield (-0.173). The direct contributions from productive tillers (0.057), total phenols (0.019) and fingers per ear (0.018) were not substantial (Table 36).

Table 35: Direct and indirect phenotypic effects of seven attributes on finger blast in brown and white grained F_3 (population I) of the cross WR 13 X GE 1546

Character	Total protein	Total phenol	Total tannin	Prod. tillers	Fingers /ear	Neck blast	Grain yield	Phenotypic corrl. with finger blast
Total protein	**0.224**	-0.013	0.291	-0.005	-0.004	0.153	0.065	0.711
Total phenol	-0.159	**0.018**	-0.385	0.004	0.005	-0.150	-0.062	-0.728
Total tannin	-0.154	0.017	**-0.424**	0.006	0.004	-0.148	-0.065	-0.764
Prod. tillers	-0.044	0.003	-0.103	**0.024**	-0.001	-0.060	-0.035	-0.216
Fingers/ear	-0.057	0.006	-0.099	-0.001	**0.017**	-0.050	-0.024	-0.207
Neck blast	0.154	-0.012	0.282	-0.006	-0.004	**0.223**	0.070	0.706
Grain yield	-0.148	0.012	-0.281	0.009	0.004	-0.160	**-0.098**	-0.662

Diagonal figures in bold indicate direct effects

Residual effect: 0.3165

Table 36: Direct and indirect phenotypic effects of seven attributes on **finger blast in** brown grained F_3 (population II) of the cross WR 13 X GE 1546

Character	Total protein	Total phenol	Total tannin	Prod. tillers	Fingers /ear	Neck blast	Grain yield	Phenotypic corrl. with finger blast
Total protein	**0.237**	-0.013	0.246	-0.016	-0.003	0.119	0.118	0.689
Total phenol	-0.159	**0.019**	-0.345	0.017	0.003	-0.109	-0.121	-0.694
Total tannin	-0.148	0.017	**-0.394**	0.019	0.002	-0.103	-0.118	-0.726
Prod. tillers	-0.067	0.006	-0.130	**0.057**	0.001	-0.055	-0.073	-0.261
Fingers/ear	-0.034	0.003	-0.035	0.002	**0.018**	-0.030	-0.034	-0.108
Neck blast	0.175	-0.013	0.251	-0.019	-0.003	**0.162**	0.127	0.680
Grain yield	-0.162	0.013	-0.269	0.024	0.004	-0.119	**-0.173**	-0.682

Diagonal figures in bold indicates direct effects

Residual effect: 0.3532

The indirect effects of total proteins through total tannins (0.246) was the highest followed by neck blast (0.119) and grain yield (0.118). Total phenols showed very little direct effect but its indirect negative contributions were substantial through total tannins (-0.345), total proteins (-0.159), grain yield (-0.121) and neck blast (-0.109). It is evident from the Table 36 that, total tannins had the maximum negative direct effect (-0.394) and was further magnified by its high indirect negative effects through total proteins (-0.148), grain yield (-0.118) and neck blast (-0.103). Neck blast showed a large positive direct effect (0.162) and its indirect effects through total tannins (0.251) was the highest followed by total proteins (0.175) and grain yield (0.127). Similarly, grain yield showed a large negative direct effect (-0.173) and its indirect effects were substantial through total tannins (-0.269) followed by total proteins (-0.162) and neck blast (-0.119). Productive tillers showed considerable indirect negative effect through total tannins (-0.130); the indirect effects through other characters were negligible. Fingers per ear did not showed considerable direct or indirect effects on finger blast.

2. Direct and indirect effects of biochemical compounds, finger blast, yield and yield components on neck blast

a. Population I

Finger blast exhibited the highest positive direct effect (0.251) on neck blast followed by total proteins (0.188). Highest negative direct effect was contributed by grain yield (-0.328) followed by total phenols (-0.193). The direct contributions of total tannins (0.058), productive tillers (-0.041) and fingers per ear (0.001) were low (Table 37).

Total proteins showed a large direct effect (0.188) and its indirect effect through grain yield (0.217) was the highest followed by finger blast (0.178) and total phenols (0.137). Total phenols showed a large negative direct effect (-0.193) and its indirect effects were substantial through grain yield (-0.209), finger blast (-0.182) and total proteins (-0.133). In contrast, total tannins had a small direct effect (0.058), but its contributions to neck blast were substantial through grain yield (-0.217), finger blast (-0.191), total phenols (-0.175) and total proteins (-0.129). The high positive direct effect of finger blast (0.251) was further magnified by its substantial indirect effects through grain yield (0.217), total phenols (0.141) and total proteins (0.133). Similarly,

Table 37: Direct and indirect phenotypic effects of seven attributes on neck blast in brown and white grained F_3 (population I) of the cross WR 13 X GE 1546

Character	Total protein	Total phenol	Total tannin	Prod. tillers	Fingers /ear	Finger blast	Grain yield	Phenotypic corrl. with neck blast
Total protein	**0.188**	0.137	-0.040	0.008	0.000	0.178	0.217	0.688
Total phenol	-0.133	**-0.193**	0.053	-0.007	0.000	-0.182	-0.209	-0.672
Total tannin	-0.129	-0.175	**0.058**	-0.010	0.000	-0.191	-0.217	-0.664
Prod. tillers	-0.037	0.034	0.014	**-0.041**	0.000	-0.054	-0.118	-0.269
Fingers/ear	-0.047	-0.060	0.013	0.001	**0.001**	-0.052	-0.081	-0.224
Finger blast	0.133	0.141	-0.044	0.009	0.000	**0.251**	0.217	0.706
Grain yield	-0.124	-0.123	0.038	-0.015	0.000	-0.166	**-0.328**	-0.717

Diagonal figures in bold indicate direct effects

Residual effect: 0.3561

the large negative direct effect of grain yield (-0.328) was further magnified by its high indirect effects through finger blast (-0.166), total proteins (-0.124) and total phenols (-0.123). Among the indirect effects of productive tillers, the contribution through grain yield (-0.118) was maximum and the indirect effects through other characters were negligible. Fingers per ear had no substantial contributions either by their direct or indirect effects through other characters.

b. Population II

Total proteins showed the highest positive direct effect (0.337) on neck blast followed by finger blast (0.151), whereas grain yield showed the highest negative direct effect (-0.298) followed by total phenols (-0.126). Productive tillers (-0.046), fingers per ear (-0.041) and total tannins (0.015) showed low direct effects on neck blast (Table 38).

The positive direct effect of total proteins (0.337) was further magnified by its substantial indirect effects through grain yield (0.204), finger blast (0.104) and total phenols (0.085). Similarly, total phenols had high negative indirect effects through grain yield (-0.208), total proteins (-0.226) and finger blast (-0.105) in addition to its large direct effect (-0.126). Total tannins showed a very little direct effect (0.015), but its indirect effects were substantial through total proteins (-0.211), grain yield (-0.203), total phenols (-0.111) and finger blast (-0.110). The positive direct effect of finger blast (0.151) on neck blast was further magnified by its high indirect effects through total proteins (0.233), grain yield (0.203) and total phenols (0.088). Grain yield showed a large negative direct effect (-0.298) and its indirect effect through total proteins (-0.231) was the highest followed by finger blast (-0.103) and total phenols (-0.088). Among the indirect effects of productive tillers, the effect through grain yield (-0.126) alone was substantial. Fingers per ear had very low contributions to neck blast by their direct or indirect effects through other characters.

3. Direct and indirect effects of biochemical compounds, finger blast, neck blast and yield components on grain yield

a. Population I

Total tannins exhibited the highest positive direct effect (0.193) on grain yield followed by productive tillers (0.167) and fingers per ear (0.007). Highest negative direct effect was from neck blast (-0.344) followed by total proteins (-0.183) and finger blast (-0.115). Total phenols had low direct effect (-0.033) on grain yield (Table 39).

Table 38: Direct and indirect phenotypic effects of **seven attributes on neck** blast in brown grained F_3 (population II) of the cross **WR 13** X GE **1546**

Character	Total protein	Total phenol	Total tannin	Prod. tillers	Fingers /ear	Finger blast	Grain yield	Phenotypic corrl. with neck blast
Total protein	**0.337**	0.085	-0.010	0.013	0.006	0.104	0.204	0.739
Total phenol	-0.226	**-0.126**	0.013	-0.014	-0.007	-0.105	-0.208	-0.672
Total tannin	-0.211	-0.111	**0.015**	-0.015	-0.004	-0.110	-0.203	-0.638
Prod. tillers	-0.095	-0.038	0.005	**-0.046**	-0.002	-0.039	-0.126	-0.341
Fingers/ear	-0.048	-0.021	0.001	-0.002	**-0.041**	-0.016	-0.058	-0.184
Finger blast	0.233	0.088	-0.011	0.012	0.004	**0.151**	0.203	0.680
Grain yield	-0.231	-0.088	0.010	-0.019	-0.008	-0.103	**-0.298**	-0.737

Diagonal figures in bold indicate direct effects

Residual effect: 0.3301

Table 39: Direct and indirect phenotypic effects of seven attributes on grain yield in brown and white grained F_3 (population I) of the cross WR 13 X GE 1546

Character	Total protein	Total phenol	Total tannin	Prod. tillers	Fingers /ear	Finger blast	Neck blast	Phenotypic corrl. with grain yield
Total protein	**-0.183**	0.024	-0.132	-0.033	-0.018	-0.082	-0.236	-0.660
Total phenol	0.130	**-0.033**	0.175	0.029	0.022	0.084	0.231	0.637
Total tannin	0.125	-0.030	**0.193**	0.041	0.016	0.088	0.228	0.661
Prod. tillers	0.036	-0.006	0.047	**0.167**	-0.002	0.025	0.093	0.359
Fingers/ear	0.046	-0.010	0.045	-0.006	**0.007**	0.024	0.077	0.246
Finger blast	-0.130	0.024	-0.148	-0.036	-0.015	**-0.115**	-0.243	-0.662
Neck blast	-0.126	0.022	-0.128	-0.045	-0.016	-0.181	**-0.344**	-0.717

Diagonal figures in bold indicate direct effects

Residual effect: 0.3726

Total proteins showed a considerable negative direct effect (-0.183) and its indirect effects through neck blast (-0.236) was the highest followed by total tannins (-0.132) and finger blast (-0.082). In contrast, total phenols showed a very little direct effect (-0.033) but its indirect effects through neck blast (0.231), total tannins (0.175), total proteins (0.130) and finger blast (0.084) were positive and substantial. Total tannins had a large positive direct effect (0.193) and its indirect effects through neck blast (0.228) was the highest followed by total proteins (0.125) and finger blast (0.088). The high negative direct effects of finger blast and neck blast were further magnified by their mutual indirect effects and their indirect effects through total tannins and total proteins. Productive tillers had a considerable direct effect (0.167) and its indirect effect through neck blast (0.093) alone was high when compared to other characters. Fingers per ear had a moderate direct effect (0.070) and indirect effect through neck blast (0.077).

b. Population II

Productive tillers showed a highest positive direct effect (0.159) on grain yield followed by total phenols (0.141), total tannins (0.110) and fingers per ear (0.066). Highest negative direct effect was from neck blast (-0.293) followed by finger blast (-0.159) and total proteins (-0.140) on grain yield (Table 40).

Total proteins registered a considerable negative direct effect (-0.140) on grain yield and its indirect effect through neck blast (-0.217) was the highest followed by finger blast (-0.110) and total phenols (-0.094). The positive direct effects of total phenols and total tannins were further magnified by their mutual indirect effects and their indirect effects through neck blast, finger blast and total proteins. Similarly, the negative direct effects of finger and neck blast were further magnified by their mutual indirect effects, and their indirect effects through total proteins and total phenols. Productive tillers had a considerable direct effect (0.159) and its indirect effect through neck blast (0.100) alone was high. The direct and indirect effects of fingers per ear were of a low magnitude, thereby accounting for their low association with grain yield.

Table 40: Direct and indirect phenotypic effects of seven attributes on grain yield in brown grained F_3 (population II) of the cross WR 13 X GE 1546

Character	Total protein	Total phenol	Total tannin	Prod. tillers	Fingers /ear	Finger blast	Neck blast	Phenotypic corrl. with grain yield
Total protein	**-0.140**	-0.094	-0.069	-0.045	-0.009	-0.110	-0.217	-0.685
Total phenol	0.094	**0.141**	0.097	0.048	0.011	0.111	0.197	0.698
Total tannin	0.088	0.124	**0.110**	0.052	0.006	0.116	0.187	0.683
Prod. tillers	0.040	0.042	0.036	**0.159**	0.003	0.042	0.100	0.422
Fingers/ear	0.020	0.023	0.010	0.006	**0.066**	0.017	0.054	0.196
Finger blast	-0.097	-0.098	-0.080	-0.042	-0.007	**-0.159**	-0.200	-0.682
Neck blast	-0.104	-0.095	-0.070	-0.054	-0.012	-0.108	**-0.293**	-0.737

Diagonal figures in bold indicate direct effects

Residual effect: 0.3254

DISCUSSION

V DISCUSSION

Finger millet has evolved in a hostile environment in tropics where unreliable rainfall, depleted soils and poor management has directed the course of natural selection. As a result the traditional varieties are not productive under optimum conditions. In the recent past, development of high yielding varieties has become the primary objective and as a result an array of high yielders have been developed and released for general cultivation. However, most of these varieties lacked resistance to biotic stresses-resulting in their vulnerability for infection by many disease causing organisms. Blast caused by *Pyricularia grisea* is the most widely spread disease resulting in significant yield losses in many states. The reduction in yield varies from season to season and could be as high as 36.4 per cent in some years (Viswanath and Seetharam, 1986). The disease control measures recommended involve multiple spray schedules of costly fungicides, making it uneconomical for adoption under dry land farming situations. Under such circumstances the development of blast resistant cultivars offers the most technically sound and economically feasible means of disease control.

The interactions between host and pathogen cells involve a complex of biological influences which ultimately lead to disease expression. Pathogenesis in general and initial infection steps in particular may be viewed as a sequence of discrete critical events. Disruption of this process at any point will result in failure of the pathogen to colonize the host tissue and may disclose a new avenue for developing innovative crop protection strategies (Howard, 1994). The understanding of genetics of host plant resistance to pathogen is considered to be a major contributor to progress in breeding for resistance in crops (Meiners, 1981). It poses many important questions for plant breeders and geneticists. If levels of resistance to different pathogens are positively correlated, then improvement of resistance will be facilitated in agricultural or natural populations, whereas, negative correlations among level of resistance would hinder plant defense against pathogen attack. Strong evidence for positive genetic correlation in levels of resistance may indicate the presence of host specific resistant genes that provide defense against some fundamental characteristics of pathogen (Mitchell-olds *et al.*, 1995).

The studies so far made in different crops have demonstrated the role of several biochemical parameters in conferring resistance/susceptibility. These mechanisms either have a direct antimicrobial effect or serve to reinforce the cell wall (Ride, 1985; Nicholson and Hammerschmidt, 1992; Baron and Zambreski,1995) or induce susceptibility as in the case of protein (Goodman *et al.*,1967; Van der Plank, 1978). Limited efforts have been made so far in finger millet to study the role of biochemical compounds in imparting resistance/susceptibility to blast disease except the studies of Seetharam and Ravikumar (1993) and Ravikumar *et al.*(1995). These studies have demonstrated the role of preformed biochemical compounds-phenols, tannins and protein in pre disposing the host plant to blast pathogen infection. It appears that total phenols and tannins show negative association with blast disease, while total proteins had a positive relationship. Seetharam and Ravikumar (1993) opined that the genetic control of blast resistance to be complex and polygenically controlled. Nevertheless, till now studies on the understanding of genetic control of the production of these biochemical compounds in finger millet and their association with blast resistance and grain yield in segregating populations have not been attempted. An attempt has been made in this study to further elucidate the role of these preformed biochemical compounds in imparting resistance/susceptiblity and to study their genetics in relation to yield and yield components.

In the present study, total proteins, phenols and tannins were quantitatively estimated and their associations with blast and yield were studied in F_2 and F_3 populations of two crosses (WR 13 X GE 1409 and WR 13 X GE 1546) involving brown and white grained parents. The segregating material developed was also utilised to study genetics of some components of the grain yield. The parents involved were not only diverse with respect to disease resistance, biochemical parameters and yield, but also for other traits, viz., plant height, productive tillers, fingers per ear and ear length. The mean performance of the populations in F_2 and F_3 generation differed for various characters reflecting high variability for all the traits thus providing an opportunity for studying their association and paths of influence. The results are discussed under the following three broad headings.

1. Variability and genetics of blast disease, biochemical compounds, yield and yield components,
2. Interrelationships among the biochemical compounds, blast disease, yield and yield components,
3. Breeding strategies for combining disease resistance, yield and protein content.

5.1 Variability and genetics of blast disease, biochemical compounds, yield and yield components

The improvement of a character is very much influenced by both phenotypic and genotypic variation of the character in the population. However, breeder cannot depend solely on these parameters. Hence, co-efficients of phenotypic and genotypic variability which are both unitless and weighed with respect to their mean values are more reliable in drawing conclusions.

Effectiveness of selection for any trait depends not only on the magnitude of variability but also on the degree to which the trait is heritable. Heritability in broadsense may not be of much significance, since it includes both additive (fixable) and non-additive (non fixable) components of genetic variance. However, heritability in narrow sense which includes mainly additive component and fixable is more reliable in deciding selection programmes. In the present study, narrow sense heritability was estimated using the method suggested by Smith and Kinman (1965). They also suggested co-efficients for various parent-offspring relationships under continuous self pollination. This method provides an automatic adjustment for a known degree of inbreeding (selfing) as the consequent of genetic correlation between parent and offspring.

The heritability is a function of the trait under consideration, type of population, mode of pollination, the environment, the generation and reproductive fitness of the character (Sharma, 1994). Therefore, the breeder cannot depend on the estimates of heritability alone. Hence, heritability along with the predicted genetic advance would serve as the most efficient tool to realise better efficiency in selection. In the present study, all these aspects were considered and the results obtained are discussed characterwise to draw valid conclusions.

5.1.1 Blast disease

The parents differed distinctly for both neck and finger blast showing near immunity in accession GE 1409 to high susceptibility in WR 13. These parents were consistent in their reaction to disease over years. However, the other resistant parent, GE 1546 was less inconsistent showing 0.50 to 2.50 per cent blast incidence in different years. The mean incidence of finger and neck blast in both F_2 and F_3 generations were generally higher in white grained types compared to browns. It is evident from these results that, white grained types were more susceptible than browns. Ravikumar *et al.(1991) and* Seetharam and Ravikumar (1993) also reported higher susceptibility of white grained finger millet cultivar to blast disease compared to brown grained types.

As expected, the range for blast incidence was wide in brown grained types and mixed population and narrow in white grained types. The range in F_3 was comparatively narrower than F_2. The narrow range in white grained types in both the generations of the two crosses was obvious due to low population size of whites on one hand and higher susceptibility of white grained types to blast on the other.

Higher values of PCV for finger blast in F_2 and higher PCV and GCV values in F_3 for both finger and neck blast were observed in all the three populations. These results are in accordance with the earlier findings of Ravikumar and Seetharam (1994). They reported high variation for neck and finger blast in F_2 populations of four crosses in finger millet. The narrow differences between PCV and GCV values was an indication of negligible environmental influence and predominant genetic control on the expression of these characters.

In all the three populations, finger and neck blast exhibited high estimates of broad sense heritability. However, narrow sense heritability estimates were low for finger blast in both the crosses. These results indicated that additive genetic variance played limited role in the expression of this character. Seetharam and Ravikumar (1993) obtained low and moderate estimates of narrow sense heritabilities for neck and finger blast, respectively in finger millet.

Both finger and neck blast manifested high genetic advance as per cent of mean in all the three populations, which was due to higher magnitude of both phenotypic and genotypic co-efficient of variation and broad sense heritability. Similar results were also reported by Ravikumar and Seetharam (1994). They have reported higher values of variability, broad sense heritability and genetic advance in F_2 populations of finger millet.

5.1.2 Biochemical compounds

Disease reaction is, by and large, a chemical process which entails changes in the cell metabolism of both host and pathogen involved. Such a process continues in a given favourable physical and chemical environment in the host from the time of first contact of pathogen until the completion of its life cycle. For instance, differential production of enzymes, toxins, growth regulators and protein in the infective agent increased permeability of cell wall and membranes and increased respiration in the host may take place after infection. The pathogen develops because of several reactions caused by fungi, toxins, enzyme inhibitors, detoxification of phytotoxicity, hypersensitivity etc. (Sharma, 1994). Therefore, if the host is to resist attack it must possess some physiological, biochemical or mechanical barrier that may inhibit or delay the parasite at some stage of development, or else, the host becomes susceptible. So, it is imperative to understand the biochemical mechanisms conferring resistance to a particular disease so as to devise suitable genetic control measures for preventing the invasion or for limiting its spread in host tissue.

A single mechanism may rarely account for resistance in a given host-parasitic system and the plant defense is generally the function of a number of mechanisms operating in an integrated and co ordinated manner. Greater the number of participating resistance mechanisms in a plant, higher is the level of resistance. Taking these factors into consideration, in the present investigation total proteins, phenols and tannins were studied in the segregating populations for their association and role in the blast disease, resistance/ susceptibility in finger millet.

5.1.2.1 Total proteins

The resistant and susceptible parents differed distinctly for their total proteins content. The white grained susceptible parent WR 13 had comparatively higher total proteins than the other two parents. The mean values for protein in F_2 and F_3 were highest in white grained types followed by mixed population (both brown and whites) and brown grained types. The range was wider in mixed population and brown grained types and narrower in white grained types.

It is evident from these results that, white grain types in general have more protein than the browns. Similar results showing significantly higher total proteins and narrow range in white grained finger millet varieties compared to brown grain types was reported by Ravikumar *et al.*(1991); Seetharam and Ravikumar (1993).

Total proteins content showed low PCV and GCV values in all the three populations, suggesting limited scope for improvement through breeding. Differences between values of PCV and GCV was low indicating low environmental effect on this character.

Both brown and mixed populations manifested high and moderate broad sense and narrow sense heritability, respectively, while the white grained types showed moderate estimates of broad sense heritability and low estimates of narrow sense heritability. These results indicated that both additive and non additive gene effects played significant role in the manifestation of this character. White grained types exhibited low to moderate heritability coupled with low genetic advance as per cent mean suggesting limited scope for improving protein content in white grained types.

Similar results indicating the importance of both additive and non additive components of genetic variance in the inheritance of protein has been reported by Yadav *et al.*(1996) for white rust resistance in Indian mustard, Pathak *et al.*(1990) in mungbean and Hallerislambers *et al.*(1973) in rice. However, several other workers have indicated the role of additive genes in controlling protein content in different crops (Halloran, 1981; Sampson *et al.*, 1983 and Dhaliwal *et al.*, 1994 in wheat and Phogat *et al.*, 1995 in barley).

5.1.2.2 Total phenols

The brown grained resistant parents had significantly higher values of total phenols than the susceptible white grained parent. The mean values of F_2 and F_3 was the highest in brown grained types followed by mixed population, which included white grained types also and least in predominantly white grained types. A wider range was observed in both generations in mixed population followed by brown grained types as compared to white grained types, in which it was narrow. These results are in accordance with the findings of Ravikumar *et al.*(1991); Seetharam and Ravikumar (1993) in finger millet, who reported significantly higher phenols content with wide range in brown grained types.

All the three populations showed higher PCV and GCV values; a narrow difference between PCV and GCV values indicated low environmental influence.

Broad sense heritabilities were high in all the three populations; while the narrow sense heritability estimates were higher in mixed population and moderate in brown and white grained types. Total phenols also exhibited high genetic advance in all the three populations. These results indicated the predominant role of additive genes in the expression of this character and scope for improvement with appropriate selection procedures. However, in Indian mustard, Yadav *et al.*(1996) reported the importance of both additive and dominant genes in the control of this trait.

5.1.2.3 Total tannins

Similar to total phenols, total tannins were higher in brown grained resistant parents compared to white grained susceptible parent. In both F_2 and F_3 populations total tannins content was higher in brown grained genotypes. Like phenols, range was wide in mixed population. These results are in line with the findings of Ravikumar *et al.* (1991); Seetharam and Ravikumar (1993) in finger millet. They reported significantly higher tannins content in brown grained types, while the white grained types had relatively low tannins.

Like total phenols, total tannins manifested high estimates of PCV and GCV values with low differences between PCV and GCV; moderate to high broad sense and narrow sense heritabilities and high genetic advance indicating the predominant role of additive genes in the expression of this character, and hence, this character can be fixed in advanced generations by selection. Similar results indicating the predominance of additive gene effects were also reported by Ma and Bliss (1978) in common beans, Dalrymple *et al.*(1984) in *Lotus corniculatus*, Vaillancourt *et al.*(1986) in lentil, Bulter (1982), Woodruff *et al.*(1982) and Lee *et al.*(1989) in sorghum.

5.1.3 Grain yield and its components

5.1.3.1 Grain yield

The parents differed significantly for their grain yields. The white grained parent, WR 13 was the lowest yielder; while the brown grained parents were comparatively high yielders. In both the generations, brown grained genotypes recorded the highest grain yield, while white grained types the least. A wide range of variation was observed in both brown and mixed populations as compared to narrow range in white grained types.

It is evident from the above that, the brown grained types have higher yield potential than white grained types. Dineshkumar (1986) reported higher yield potential of brown grained types as compared to white types in a study involving 20 each of elite brown and white finger millet cultivars of similar maturity.

In F_2 generation of both the crosses, the PCV was high in all the three populations. Similarly, the F_3 generation of the cross WR 13 X GE 1409 exhibited high PCV and GCV values in all the three populations; while, in the cross WR 13 X GE 1546 brown grained types and mixed population showed high PCV and GCV values and white grained types had moderate values. These results are in agreement with the reports of Mishra *et al.*(1980), Shankar (1982), Goswami and Asthana (1984); Prabhakar and Prasad (1984), Joshi and Mehra (1989), Tyagi and Koranne (1989), Verma (1989), Venkatesh Bhat (1991), Purushotham Rao (1992), Cauvery (1993), Ravikumar and Seetharam (1994) and Chunilal *et al.*(1996) in finger millet.

Broad sense heritability estimates were high in all the three populations; while the values of narrow sense heritability were high in brown grained and mixed population and moderate in white grained population. These results are in accordance with Venkatesh Bhat (1991). The results observed in the present and also in the earlier studies indicated the role of additive gene action in the expression of this character. However, in contrast, Ravikumar (1988), Shanthakumar (1988), Basavaraja and Sherief (1992) reported low narrow sense heritability for grain yield in finger millet.

High heritability coupled with high genetic advance observed in the present study suggested, that simple selection could be effective in isolating high yielding genotypes in segregating generations. These results are in line with Mishra *et al.*(1980), Sarvaiya *et al.* (1982), Shankar (1982), Goswami and Asthana (1984), Joshi and Mehra (1989), Verma (1989), Venkatesh Bhat (1991) and Chunilal *et al.*(1996).

5.1.3.2 Yield components

In general, the white grained susceptible parent WR13 had short plant stature, small ears and low finger number compared to the resistant parents. However, it excelled the resistant parents in number of productive tillers. The differences in the mean values of these characters in different populations in both the generations were negligible in both the crosses. The range of variation for these characters was comparatively higher in brown grained types and mixed population and narrower in white grained types.

In F_2 generation, PCV values were moderate to high in all the three populations for fingers per ear, ear length and plant height. In F_3 generation, PCV and GCV values were low to moderate for fingers per ear and productive tillers. The difference between PCV and GCV values was wide for fingers per ear and productive tillers, which was an indication of higher magnitude of environmental influence on these traits. Similar observations showing low to moderate PCV and GCV values for productive tillers and fingers per ear were reported by Prabhakar and Prasad (1984), Verma (1989), Venkatesh Bhat (1991), Purushotham Rao (1992), Dhanakodi (1994) and Chunilal *et al.*(1996).

Productive tillers exhibited moderate to high broad sense heritability and high genetic advance, indicating the predominance of additive gene effects and thus providing ample scope for further improvement of this character. These results are in consonance with the findings of Mishra *et al.*(1980), Shankar (1982), Prabhakar and Prasad (1984), Venkatesh Bhat (1991), Cauvery (1993), Ravikumar and Seetharam (1994), Dhanakodi (1994) and Ramaswamy *et al.*(1994) in finger millet.

Although broad sense heritability values were moderate, the estimates of narrow sense heritability were lower for fingers per ear which could be the reason for low predicted genetic advance. This further indicated the predominant role of non additive gene action. Therefore, it could be inferred that, simple selection may not be effective in fixing this character.

From the above discussion, it could be concluded that the traits, viz., blast, total proteins, phenols, tannins and grain yield exhibited narrow differences between the PCV and GCV values, moderate to high broad sense heritability coupled with moderate to high genetic advance. Hence it could be inferred that, simple selection would be effective in the improvement of these characters.

Although, broad sense heritability values were moderate for fingers per ear, the low values of narrow sense heritability coupled with low values of genetic advance could be attributed to strong influence of environment and predominant role of non additive gene action. So, it is obvious that simple selection may not be effective in improving this character.

5.2 Interrelationships among the biochemical compounds, blast, yield and yield components

The study of correlations in segregating generation would be of special importance, since large variability is present for most characters in a diverse cross. The correlations among yield and yield components in finger millet have been studied by several workers. However, the information on association of blast disease, biochemical compounds and grain yield among themselves is rather limited. Hence the study was envisaged to investigate the relationship among blast disease, total proteins, phenols and tannins and yield and yield components.

The correlation co-efficients reflect the extent and direction of association existing between characters. A dependent character is a result of interaction product of many mutually associated component characters and change in any one component will disturb the whole net work of cause and effect system. Hence, it is desirable to employ a method of analysis which will take into account the cause and effect relation between the variables in addition to that provided by correlation studies. Path co-efficient analysis developed by Wright (1921) and demonstrated by Dewey and Lu (1959) taking into account the cause and effect relation between the variables is unique in partitioning the association into direct and indirect effects through other independent variables on yield or any dependent variable of interest. This analysis also measures the relative importance of causal factors involved. In the present study, the path analysis was done at phenotypic level for all the characters in brown grained types and mixed population which also included limited number of white grained types.

5.2.1 Association of protein with blast disease

Total proteins exhibited a significant positive association with both finger and neck blast in brown grained types and in mixed population of both the crosses. This was also reflected in the mean total proteins content of the parents wherein the susceptible parent WR 13 had higher protein content over resistant brown grained parents. Significant positive association between total proteins and blast was also observed by Seetharam and Ravikumar (1993) and Ravikumar *et al.*(1995) in finger millet. Association of protein with disease susceptibility has been reported by many workers in other crops (Paik, 1970; Sati and Grewal, 1982; Ismail and Michalik, 1982; Li *et al.*, 1983; Gupta *et al.*, 1984; Gupta and Gupta, 1986; Sharma *et al.*, 1992; Malhotra, 1993; Angra-Sharma and Sharma, 1994; Yadav *et al.*, 1996). On the contrary, the results of Satyanarayana and Saikumar (1994) and Satyanarayana *et al.*(1995) indicated that, protein had no relationship with disease resistance in maize. However, the results obtained by Chiranjeevi and Tripathi (1976), Hussain *et al.*(1983), Adam and Gilly (1984), Mathur and Bhatnagar (1994) and Ganguly (1995) are in contrast to the results of the present study. They observed higher levels of protein in resistant cultivars than susceptible ones.

Highly significant and positive association between total proteins and finger blast was mainly due to its fairly high positive direct effect as well as moderate positive indirect effects through total tannins, grain yield and neck blast. Similarly, a fairly high direct influence of total proteins on neck blast and its indirect effects via finger blast, grain yield resulted in positive and significant correlation between total proteins and neck blast.

Although several investigations have showed the association between protein and disease susceptibility, the role of total proteins has not been clearly understood. The biochemical basis of susceptibility has been postulated by Van der Plank (1978). He postulated that, in case of susceptibility, the invading pathogen secretes a protein into the host cell after the contact. In response, the host cell also produces a complementary protein. Both these protein co-polymerize, thus interfering with the autoregulation process of the host gene that codes for the host protein. Such an interference turns the said gene 'ON' for producing more protein to serve as food for the pathogen and thus causing the establishment of a compatible relationship between host and parasite.

Most investigations of protein synthesis in diseased plants revealed the enhanced protein synthesis due to pathogen itself. Generally, in fungus infected plants, the total nitrogen and protein content of the host pathogen complex increases. This protein increase is mainly due to protein synthesis of the pathogen rather than host (Staples and Ledbetter, 1958). The enzymes involved in aminoacid and amide synthesis are also activated in infected plants as a result parallel proteolysis and protein synthesis in tissues surrounding the infection center (Goodman *et al.*, 1967). A possible explanation for the parallel activity of proteolysis and protein synthesis is that the proteolytic enzymes helps to degrade the host protein and the precursors released are utilized for protein synthesis to manufacture pathogen specific protein.

Increasing emphasis is being placed on the role of protein in disease resistance mechanism in plants. It is known that protein in the host play an important role in imparting susceptibility as high protein provide adequate nitrogen source for the pathogen for its growth. Studies indicating the role of pre-formed protein with disease has been reported by Ravikumar *et al.*(1995) in finger millet and Gupta and Gupta (1986) in pearl millet. The results of the present investigation indicate that the susceptible parent and genotypes in segregating populations had higher protein content than resistant genotypes. So, it is likely that susceptible genotypes inherently have high protein content, attracting pathogen infection as organisms gets more proteinaceous food for its growth and development. This suggests that protein was a preformed one and not increased in the plant as a defense mechanism or is not a result of metabolic change resulting from pathogen infection.

5.2.2 Association of phenols with blast disease

According to a comprehensive review by Kosuge (1969), Nicholson and Hammershmidt (1992) and Baron and Zambryski (1995), phenols content and disease reaction are negatively correlated. In the present study also, total phenols manifested very strong negative correlation with blast disease in brown grained and mixed population. These results are also reflected in the mean total phenols content in the parents wherein the resistant brown grained parents had higher total phenols as compared to white grained susceptible parent. The association was more stronger with finger blast than neck blast. These results indicate the role of total phenols in imparting resistance to blast disease. These results are in accordance with the findings of Seetharam and Ravikumar (1993) and Ravikumar *et al.*(1995) in finger millet. They observed very strong negative association between total phenols and blast incidence indicating the role of phenols in imparting resistance.

A fairly high negative direct effect of total phenols on finger blast as well as its negative indirect effects through total proteins, tannins, grain yield and neck blast could be the reason for highly significant negative correlation between total phenols and finger blast in F_2 and F_3 generation of both the crosses. In F_3 generation of the cross WR 13 x GE 1409 the direct effect of total phenols on neck blast was though positive its indirect effects via total proteins, finger blast and grain yield were negative and high. However, in the other cross, WR 13 x GE 1546, total phenols showed high negative direct effect as well as high negative indirect effects through total proteins, finger blast and grain yield.

Vidyashekaran (1974a) reported increased phenols oxidase activity in resistant leaves of finger millet infested by *Helminthosporium nodulosum* and also observed faster accumulation of phenolic compounds in resistant plants. Inhibition of spore germination and growth of *H.nodulosum* due to oxidised phenolics was reported in finger millet (Vidyashekaran, 1975).

Positive association of phenols with disease resistance has been reported in several crops by many workers (In onion for *Colletotrichum circinans* by Link *et al.*, 1929; Angell *et al.*, 1930; Link and Walker, 1933; Walker and Stahmann, 1955; in potato for *Verticillium* wilt by Mclean *et al.*, 1961; Patil *et al.*, 1966; Sheppard and Peterson, 1976; in rice for blast by Reddy, 1971; for *Helminthosporium* by Chattopadhyay and Bera, 1978; Sathiyanathan and Vidyashekaran, 1981; Valluvaparidasan and Mariyappan, 1983; for leaf sheath by Ayesha siddiqua and Kashem, 1993; in wheat for leaf rust by Mahabaleswar Hegde, 1992; in sorghum for downy mildew by Prabhu *et al.*, 1984; for charcoal rot by Anahosur *et al.*, 1985; for grain moulds by Somani, 1992; in maize for *Helminthosporium maydis* by Angra-Sharma and Sharma, 1994; in pigeon pea for *Phytopthora* blight by Chaurasia *et al.*, 1993; in cowpea for powdery mildew by Satyanarayana *et al.*, 1992; in Indian mustard for white rust by Dhawan *et al.*, 1981 and Yadav *et al.*, 1996; in chilies for anthracnose by Bhuller *et al.*, 1972; for *Phytopthora capcici* by Candela *et al.*, 1995; in tomato for *Stamphyllium botryosum* by Mathur and Bhatnagar, 1994; in alfalfa for *Colletotricum trifoli* by Baker *et al.*, 1989; in eucalyptus for *Phytopthora cinnamani* by Cahill *et al.*, 1993). The role of such pre-formed phenols in disease resistance has been reported by several other workers in different crops and the voluminous literature on this aspect has been reviewed by Friend (1979), Vidyashekaran (1988) and Nicholson and Hammerschmidt (1992).

The increase in concentration of phenolic compounds after infection has also been observed by many workers (Farkas and Kiraly, 1962; Mahadevan, 1973; Chattopadhyay and Bera, 1980; Abdul Galit *et al.*, 1981; Shatla *et al.*, 1983; Southerton and Deverall, 1990; Cahill and McComb, 1992; Sharma *et al.*, 1992; Velazhahan and Ramabhadran, 1993). The above studies indicated that, post infectionally formed phenols are also playing important role in disease resistance.

A wide range of phenols and their derivatives are known to participate in a number of physiological processes which are essential for growth and development. Some phenols inhibit the production of fungal enzymes and inactivate the enzymes produced by the pathogen; in many cases total phenols may suppress toxin production by the pathogen or destroy the toxins produced inhibits production of fungal enzymes or inactivates the enzymes produced by the pathogens and inhibit spore germination and growth of pathogen (Kosuge, 1969; Vidyashekaran, 1988; Angra. 1989; Weinguangma *et al.*, 1995).

In the present investigation the resistant genotypes in the segregating populations had consistently higher phenols content and this may be regarded as constituents imparting resistance. Such higher phenolic compounds could not only act as a marker of resistance but also may be actively involved in the resistance process (Castana *et al.*, 1992; Seetharam and Ravikumar, 1993). Higher phenolic content in resistant plants, in fact, reflects the greater synthetic capacity of the phenols (Patil *et al.*, 1966) and resistant plants reach a post infection level sufficient to limit the fungal growth soon (Castana *et al.*, 1992). So, it has been suggested that disease resistance may be due to a pre-formed phenols/or infection activated phenols synthesis. In the present study resistant genotypes had higher quantity of pre-formed phenols and screening of healthy plants for phenols content may aid in the selection of resistant genotypes.

5.2.3 Association of tannins with blast disease

Comprehensive review by Bell (1981) has brought out that, tannins play an important role in inducing resistance against invading pathogen. Tannins in the present study also exhibited a very strong negative association with blast disease in brown grained types and mixed population as in the case of phenols. This was also reflected by the high mean total tannins content in resistant parents. The total tannins content was more in brown grained resistant parents compared to susceptible white grained parent. The association was non-significant in white grained types except in F_3 generation of the cross WR 13 X GE 1546, which showed significant negative association. Non-significant association in white grained types in the present study was obvious due to small population size and low variability for total tannins in white grained types. Strong negative correlation between total tannins and blast disease was also reported by Seetharam and Ravikumar (1993) and Ravikumar *et al.*(1995). These studies have indicated the role of tannins in imparting resistance in finger millet.

The strong negative association between total tannins and finger blast was due to a considerable magnitude of negative direct effect of total tannins on finger blast and its negative indirect contributions through total proteins, phenols and grain yield. In F_3 generation of both the crosses, total tannins also exerted fairly high magnitude of indirect effect on finger blast via neck blast. Similarly, considerable magnitude of negative direct effect of total tannins coupled with high negative indirect effects via total proteins, finger blast and grain yield contributed for the highly significant negative correlation between total tannins and neck blast in the F_3 generation of the cross WR 13 x GE 1409. In the other cross, WR 13 x GE 1546, although direct effect of total tannins was low, substantial indirect effects through total proteins, phenols, finger blast and grain yield have caused the high negative significant correlation between total tannins and neck blast.

Such a positive association of tannins with resistance is expected as tannins are nothing but polyphenols (Vidyashekaran, 1988) and polyphenols are known to play decisive role in disease resistance. The tannins are also known for the antimicrobial activity (Bell, 1981) and help the plant in avoiding the pathogen growth in host tissue. They are also known to interfere with infection process and inhibit the entry of the pathogen thereby conferring resistance (Cadman, 1959).

It is clear from the present study that, the resistant genotypes consistently had higher level of tannins and this may be regarded as constituents imparting resistance. Hence, screening of healthy plants for tannins may help in the selection of resistant genotypes in the absence of epiphytotics.

5.2.4 Association of yield and its components with blast disease

It is obvious that disease and yield are negatively associated. Improvement of yield together with resistance can be achieved only by understanding the association of yield and yield components with disease resistance. Hence, in the present study association of yield and its components with blast was studied.

Grain yield exhibited significant negative association with both finger and neck blast in brown and mixed grained populations. The association between finger blast and grain yield in white grained types was significantly negative only in F_2 generation of the cross WR 13 x GE 1546. Though large negative correlation values were observed for white grained types in F_2 generation of the cross WR 13 x GE 1409 and in F_3 generation of both the crosses, the association was found to be statistically non-significant because of small size of white grained population. Negative association between blast and grain yield was also reported by other workers in finger millet (Dineshkumar, 1986; Ravikumar and Seetharam, 1993).

Highly significant negative correlation between grain yield and finger blast was mainly due to substantial negative direct contribution of grain yield coupled with a moderate to high negative indirect effects through total proteins and neck blast. In addition, grain yield had a moderate indirect contributions via total phenols and tannins. However, their magnitude varied from cross to cross. Similarly, highly significant negative association between grain yield and neck blast was mainly due to high negative direct effect of grain yield as well as its high negative indirect effects through finger blast and total proteins.

When the grain yield was considered as dependent variable, the direct effects of finger blast on grain yield was large and negative. The negative indirect effects of finger blast on grain yield through neck blast was very large, while through total proteins, phenols and tannins it was moderate. Similarly, the indirect effects of neck blast on grain yield through finger blast, total proteins, phenols and tannins were moderate and negative. Ravikumar and Seetharam (1993) reported high negative direct effect of finger and neck blast on grain yield, while Dineshkumar (1986) recorded both positive and negative direct effects of finger blast on grain yield in different environments.

Ear length did not show any association with blast disease in F_2 generation of both the crosses. Similarly, plant height also showed no association with blast in all the three populations except in white grained types of the cross WR 13 x GE 1409, which recorded significant negative association. This may be a cross specific association as the susceptible parent WR 13 was dwarfer than resistant parent and need not be a general trend.

Productive tillers showed significant negative association with blast susceptibility in brown grained and mixed populations of the cross WR 13 x GE 1546, while the other cross exhibited non-significant association in all the three populations. Significant and negative correlation between productive tillers and blast in the cross WR 13 x GE 1546 could have resulted from low direct effect as well as cumulative, but small negative indirect effects of productive tillers via most of the characters. Inspite of high positive direct contribution of productive tillers on finger blast in the cross WR 13 x GE 1409, a poor correlation between these traits might have resulted from more than compensation from the cumulative negative indirect effects through most of the traits. However, the weak association between productive tillers and neck blast in the cross WR 13 x GE 1409 was due to low contribution of productive tillers either by its direct effect or indirect effects through other traits.

Fingers per ear manifested significant negative association with blast disease only in the mixed F_3 population of the cross WR 13 x GE 1546, while in the other cross and in F_2 generation of both the crosses the association was non-significant. A poor correlation of fingers per ear with finger and neck blast was predominantly due to very low either positive or negative contributions (direct and indirect) of fingers per ear on both finger and neck blast in F_2 and F_3 generations of both the crosses.

The association of blast severity with plant height, productive tillers and fingers per ear varied from cross to cross. The association that was observed in the present study was more a cross specific and need not be a general occurrence as the study was conducted under blast epiphytotics with heavy disease pressure. Such cross specific associations of blast with plant height, productive tillers and fingers per ear was reported by Ravikumar and Seetharam (1993) in F_2 populations of finger millet. Dineshkumar (1986) reported both positive and negative associations in the material grown under different soil fertility. Ramakrishna *et al.*(1996) in an exhaustive study involving 4000 finger millet accessions observed significant negative relationship between plant height and blast, and weak associations for productive tillers, finger number and ear length with blast.

The results of the present study indirectly suggests that occurrence of blast was not influenced by plant height, number of productive tillers and fingers per ear. Breeding for taller plants, increased productive tillers and fingers per ear are unlikely to increase the disease susceptibility, while they are likely to increase the grain yield as these traits are positively and significantly associated with grain yield. Hence, simultaneous selection for these traits along with resistance may likely to be more rewarding in breeding cultivars with high yield possessing higher level of resistance.

5.2.5 Association of protein with yield and its components

In general, grain yield and protein content are inversely associated, when grain yield increases grain protein concentration decreases (Frey, 1973). In the present study also the association between total proteins and grain yield was negative and highly significant in brown grained types and mixed populations, which also contains white grain types. This was also reflected in the parents, wherein low yielding genotype WR 13 had higher total proteins than high yielding brown grained parents. Negative association between grain yield and protein was reported in the studies of Dineshkumar (1986), Seetharam *et al.*(1993) and Girishkumar (1995) in finger millet. Negative association of grain yield and grain protein was also reported by several workers in other crops (Bhatia, 1975; Halloran, 1981; Loffier and Busch, 1982; Guthrie, *et al.*, 1984; Kibite and Evans, 1984; Loffier *et al.*, 1985; Cox *et al.*, 1985; May *et al.*, 1991; Costa and Kronstad, 1994; in wheat, Ramesh and Hudda, 1994 in sorghum).

The significant negative correlation observed between total proteins and grain yield was not only due to moderate to high negative direct effect of total proteins on grain yield but also due to substantial negative indirect effects through finger and neck blast. High negative direct effect of protein on grain yield was also observed by Dineshkumar (1986) in finger millet under blast endemic situation. In contrast, Girishkumar (1995) reported very large and positive direct effect of crude protein on grain yield under blast free conditions in finger millet.

Kibite and Evans (1984) suggested that inverse relationship between grain yield and grain protein was not caused by genetic factors. Environmental factors, source-sink interactions and dilution of protein by non protein compounds were the major agents that caused undesirable association between the two traits. Klepper (1975) analyzed this unfavourable association in wheat. He reasoned this to be due to the competition for energy between nitrate reduction (to produce protein) and CO_2 fixation (to produce photosynthates and yield) at the level of Ferredoxin. The consequence is a failure to develop individuals having both high yield and high protein. Thus, the selection for high protein content has been regarded as an artifact resulting from selection of types with low starch synthesis.

The association of total proteins with plant height and ear length was non-significant in all the three populations. Productive tillers and fingers per ear exhibited significant negative association with grain protein only in brown grained and mixed F_3 populations of the cross WR 13 X GE 1546, while in other cross the correlations were non-significant. Grain yield is influenced by factors not operative in grain protein synthesis. Productive tillers and fingers per ear are more closely related to yield and they may have relatively small effect on the level of protein. Since association between protein and grain yield was strongly negative, all factors showing positive association with grain yield should show negative association with protein and this is true in the present study also.

5.2.6 Association of phenols and tannins with yield and its components

The association of total phenols and tannins with grain yield was positive and highly significant in brown grained and mixed populations and non-significant in white grained types. It is obvious that in the present study, some of the brown grained resistant genotypes in the segregating populations had higher levels of total phenols and tannins and were high yielding too. So, phenols and tannins may not directly influence yield but indirectly and positively when blast incidence was very high.

The positive and significant correlation manifested between total phenols and grain yield in F_2 generation of both the crosses was predominantly due to the indirect effect of total phenols through finger blast. However, in F_3 generation, different trend was observed. The strong positive association between total phenols and grain yield in the cross WR 13 x GE 1409 could be explained on the basis of high positive direct effect of total phenols and its substantial indirect negative contributions through neck and finger blast. Similar trend was also observed in respect of the brown grained types of the cross WR 13 x GE 1546; however, in the mixed population the significant and positive association was predominantly due to high positive indirect effects via total proteins, tannins and neck blast.

Like total phenols, total tannins also had low to moderate direct effect on grain yield in F_2 generation of both the crosses. Hence, the significantly positive correlation between total tannins and grain yield seemed to be predominantly due to its very high positive indirect effect through neck blast. In F_3 generation of the cross WR 13 x GE 1409, inspite of the very low direct effect of total tannins, the significant positive association with grain yield could have resulted mainly from the positive indirect effects of total tannins via total phenols, finger and neck blast. However, in the cross WR 13 x GE 1546, the strong association was due to high positive direct effect of total tannins as well as its high positive indirect effect through neck blast.

In general, total tannins and phenols showed non-significant associations with plant height and ear length, except in the brown grain types of the cross WR 13 x GE 1546, which showed significant positive association between total phenols and plant height and of the cross WR 13 x GE 1409, which showed significant positive association between total phenols and ear length. The association of total phenols and tannins with fingers per ear was non-significant in all the three populations except in the mixed population of the cross WR 13 x GE 1546, which showed significant positive association between fingers per ear and phenols and tannins. Productive tillers exhibited significant association with total phenols and tannins in brown grained and mixed populations of the cross WR 13 x GE 1546. However, the association was non-significant in the other cross.

5.2.7 Associations among yield components, biochemical compounds and blast disease

Grain yield exhibited significantly positive association with plant height, ear length, productive tillers and fingers per ear. However, the magnitude of their association varied from cross to cross. Positive association of these traits with grain yield was the resultant of a moderate to high positive direct effects of these characters on grain yield. Positive associations with moderate to high direct effects on grain yield have been reported by many workers in finger millet (Ramalingeswara Rao, 1985; Harinarayana *et al.*,1989; Venkatesh Bhat, 1991; Basavaraja and Sherief, 1992; Purushotham Rao, 1992; Cauvery, 1993; Ravikumar and Seetharam, 1993; Girishkumar, 1995; Haider *et al.*, 1995; Chunilal *et al.*, 1996).

As expected, the correlations between finger blast and neck blast, total phenols and tannins were highly significant and positive, while the associations of total proteins with total phenols and tannins were negative and highly significant.

From the above discussions on correlation and path analysis, it could be summarized as under.

* Higher protein content in the plants resulted in increased incidence of blast, as revealed from the high positive correlation of total proteins with blast as well as its high positive direct effect on blast.

* Higher levels of total phenols and tannins in the plants prevents the incidence of blast disease. These phenolic compounds act both directly and indirectly with each other as could be seen from their high negative direct effects and their corresponding negative indirect effects.

* Grain yield exhibited highly significant negative association with both finger and neck blast. The negative correlation between grain yield and finger blast was due to high negative direct effect of grain yield on finger blast coupled with moderate to high negative indirect effect through protein and neck blast. A significant negative association between grain yield and neck blast was due to high negative direct effect of grain yield on neck blast and its high negative indirect effects through finger blast and protein.

* There appeared to be very little or no influence of yield components, viz., plant height, ear length , productive tillers and fingers per ear on blast disease as evident from their low associations and their low direct and indirect effects on blast.

* A strong negative association between total proteins and grain yield was mainly due to moderate negative direct effect of total proteins on grain yield and its very high negative indirect effect via finger and neck blast. This clearly indicated that, higher level of protein pre-disposes the plant to increased incidence of blast, thereby resulting in lower yields.

* The phenolic compounds and grain yield exhibited strong positive correlations, which could be explained mainly by the moderate to high positive direct effects of these phenolic compounds on grain yield and their very high positive indirect influences via finger and neck blast. This means that, higher levels of phenolic compounds confer resistance to blast and results in higher yields.

* In general, the yield components, viz., plant height, ear length, productive tillers and fingers per ear had positive association with grain yield, although the magnitude was low. This indicated that, selection for these traits may prove fruitful for realising higher yields.

5.3 Breeding strategies for combining blast resistance, yield and protein content

Breeders until recently were primarily concerned with yield improvement; disease resistance and grain quality received low priority. As a result, most high yielding varieties developed, although superior yielders were often inferior as far as grain quality and resistance to biotic stresses are concerned. Large chemical inputs are required in the cultivation of these varieties to ward off negative effects from these and realise higher seed yield; finger millet is no exception.

The rapid spread of these high yielding varieties helped in achieving quantum yield jumps and growth in food production in the country keeping pace or even surpassing population growth, thus ensuring the vital food and feed security. The sustenance of growth in food front has infused greater confidence in the agriculture sector in meeting internal food needs as well as in looking for new world markets for export. Nevertheless, increasing awareness about the ill-effects of extensive use of agro-chemicals on human and animal health besides the other considerations in the areas of long term ecological security and sustainability in crop production has necessitated the breeders to review the long term goals in crop improvement programmes.

Finger millet is the staple food crop for a large section of rural people in India. No doubt breeding for yield will continue to be important in this crop. Incorporating durable resistance to one or more diseases particularly blast will be crucial from the angle of long term cultivation of the variety. In addition, grain quality is important as the grain is used for human consumption. In breeding programme of this kind with multiple goals the success depends upon the balance maintained among the three components - yield, resistance and quality, as it may not be possible to have the best of all the three in one and the same variety.

The results in the present investigation have given important information having direct bearing for breeding programmes aiming at combining high yield, blast resistance and grain protein content in finger millet. The genetic control of blast resistance appears to be complex and multigenic. The availability of such resistance mechanism promises incorporation of durable resistance in the varieties bred. The positive association of blast resistance and yield is imperative in blast endemic growing regions and incorporation of resistance should not pose special problem. Nevertheless, there is a general trend of negative association between protein content of the grain and yield on one hand and protein content and blast resistance on the other hand. This implies that a selection programme aiming at higher protein content in the grain is likely to end up with lower yields and resistance for blast in the varieties bred. So, combining high seed yield, high blast resistance and protein content in a single variety might be difficult. The studies of segregating material of the two crosses provided an opportunity to see how far that these three components could be combined in a single variety. The F_3 population of both the crosses were grouped based upon protein content into three groups, viz., 1) less than 8.00 per cent, 2) 8.00 to 9.50 per cent and 3) more than 9.51 per cent. The number of brown grained plants falling in the above three categories is given in the Table 41 along with mean blast score and grain yield for each class.

From the data (Table 41) it is evident that there is an inverse relationship between protein content and grain yield, protein content and blast susceptibility and positive selection for protein content would adversely affect the other two characters. However, the data reflects this general trend of events happening but does not provide information as to the rare favourable recombinations that might take place. So, the values of individual F_3 progenies were critically compared so as to obtain a relatively better picture on the possibility of combining these characters favourably (Table 42).

The data (Table 42) point out to the possibility of identifying F_3 progenies having reasonably higher levels of grain protein accompanied with moderate to high levels of resistance and grain yield. The early detection of such F_3 progenies having multiple characters combined and further confirmation and fixation in the homozygous state should be possible through pedigree breeding up to F_5 and F_6 generations. Ravikumar *et al.*(1991) suggested biparental mating system for breeding white grained finger millets combining high protein and blast resistance. But difficulty is that, the crop is not amenable for making large number of planned crosses. If this difficulty could be overcome the situation arising may be useful in recovering useful recombinations by breaking undesirable associations.

The effectiveness of selection for multiple traits of this kind discussed here would depend very much on the genetic - environment interaction which is very difficult to deal with. The success in resistance breeding will be decided by the regularity as well as intensity with which the disease appears in a given location. Growing segregating population in a highly endemic region to blast disease is an important pre-requisite. Side by side artificial epiphytotics should be created to supplement natural incidence and ward off the problem of escapes and the resulting susceptibility in later generations. It appears that the overall solution in such a situation will have to breed for high yield while maintaining a reasonable level of resistance and grain quality.

Table 41: Grouping of F_3 progenies of brown types based upon protein content along with mean values for finger blast and grain yield

Cross	Protein content (%)	Mean values of Protein (%)	Finger blast(%)	Grain yield (g/plant)
WR13 X GE1409	< 8.00	7.50	2.20	32.83
	8.00-9.50	8.73	7.52	26.27
	> 9.51	9.94	14.79	17.71
WR13 X GE1546	< 8.00	7.66	2.06	32.00
	8.00-9.50	8.67	5.63	24.16
	> 9.51	9.87	11.41	18.47

Table 42: F_5 progenies having favourable combination of protein content, blast resistance and grain yield

Cross	Progeny Number	Protein content(%)	Finger blast(%)	Grain yield (g/plant)
WR13 X GE1409	48	9.90	4.22	23.00
	52	9.34	5.22	28.50
	38	9.19	4.95	28.50
	25	8.99	4.98	29.00
	72	8.81	2.21	32.00
	63	8.80	4.59	29.00
	86	8.70	4.70	28.50
	31	8.66	1.50	33.50
	12	8.60	4.16	31.50
WR13 X GE1546	78	9.80	3.26	22.00
	27	9.79	4.12	18.50
	7	9.74	3.16	17.50
	82	9.70	2.98	26.50
	91	9.58	3.62	20.50
	4	9.34	3.89	30.50
	88	9.11	2.89	22.50
	97	9.05	5.18	21.50
	84	8.90	4.07	26.50
	36	8.79	1.90	30.50

SUMMARY

VI SUMMARY

The present study was envisaged at studying the (i) the nature of inheritance of blast disease, proteins, phenols, tannins, yield and yield components, (ii) the role of biochemical compounds in imparting resistance/susceptibility and their effect on grain yield, (iii) the relative contribution of different traits on blast and grain yield.

Blast disease, biochemical compounds, grain yield and the components of yield, viz., fingers per ear, productive tillers, plant height and ear length were studied in F_2 and F_3 generations of two crosses, viz., WR 13 x GE 1409 and WR 13 x GE 1546, involving three finger millet cultivars. Among these, white grained cultivar WR 13 was susceptible to both finger and neck blast and the other two cultivars, GE 1409 and GE 1546, were purple pigmented with brown grains and are resistant to both finger and neck blast. Estimates of co-efficient of variability were determined for each character. Heritability estimates in broad sense for each character were obtained in F_3 generation. Heritability in narrow sense was estimated for six characters in the F_3 generation through regression of F_3 on F_2 generations. To realize better efficiency in selection programmes, the genetic advance as per cent of mean was estimated for each character in F_3 generation.

To investigate the relationship among blast disease, proteins, phenols, tannins, yield and yield components, the correlation co-efficients were computed in both F_2 and F_3 generations. Path analysis was made at phenotypic level for all the characters to take into account the cause and effect relationship by partitioning the association into direct and indirect effects through other independent variables on blast and grain yield. The following observations and conclusions were made.

1. The phenotypic and genotypic co-efficient of variation was large for finger and neck blast, total phenols, tannins and grain yield; low to moderate for productive tillers, fingers per ear and total proteins.

2. Finger blast, total proteins, phenols, tannins and grain yield exhibited narrow differences between PCV and GCV, indicating low environmental effect on these characters. Productive tillers and fingers per ear showed wide differences between PCV and GCV, which was an indicator of high magnitude of environmental influence on these two characters.

3. Both additive and non-additive gene effects played significant role in the expression of blast disease and total proteins.

4. Total phenols, tannins and grain yield were highly heritable indicating the predominant role of additive gene effects in controlling these characters.

5. Productive tillers comparatively had high heritability than fingers per ear.

6. Blast disease, total phenols, tannins, grain yield and productive tillers manifested high genetic advance suggesting the scope for improvement of these characters with simple selection.

7. Total proteins and fingers per ear showed low to moderate genetic advance as per cent of mean indicating that, simple selection may not be effective in fixing these characters.

8. Higher protein content in the plants resulted in increased incidence of blast, as revealed from the high positive correlation of total proteins with blast as well as its high positive direct effect on blast.

9. Higher level of total phenols and tannins in the plants prevented the incidence of blast disease, as revealed from their high negative association with blast. These phenolic compounds act both directly and indirectly with each other as could be seen from their high negative direct effects and their corresponding negative indirect effects.

10. Grain yield exhibited highly significant negative association with both finger and neck blast. The negative correlation between grain yield and finger blast was mainly due to substantial negative direct effect of grain yield on finger blast coupled with a moderate to high negative indirect effects through total proteins and neck blast. Similarly, highly significant negative association between grain yield and neck blast was mainly due to high negative direct effect of grain yield on neck blast as well as its high negative indirect effects through finger blast and total proteins.

Furthermore, when the grain yield was considered as dependent variable, the direct effect of finger blast on grain yield was large and negative. The negative indirect effect of finger blast on grain yield through neck blast was very large, while through total phenols and tannins was moderate. Similarly, neck blast had high negative direct effect on grain yield and the indirect effects of neck blast on grain yield through finger blast, total proteins, phenols and tannins were moderate and negative. Hence, it is obvious that, the increased incidence of blast disease resulted in lower yields.

11. None of the yield components, viz., plant height, ear length, productive tillers and fingers per ear had strong association with blast disease as evident from their low associations and their low direct and indirect effects on blast.

12. A strong negative association between total proteins and grain yield was mainly due to moderate negative direct effect of total proteins on grain yield and its very high negative indirect effect via both finger and neck blast.

13. The phenolic compounds - total phenols and tannins exhibited very strong positive correlation with grain yield, which could be due to their moderate to high positive direct effects and their indirect effects on grain yield. The indirect effects of total phenols on yield were positive and high through total proteins, tannins, neck and finger blast, while total tannins had high and positive indirect effects on yield via total phenols, neck and finger blast.

14. In general, the yield components, viz., plant height, ear length, productive tillers and fingers per ear had positive association with grain yield, although the magnitude was low. Number of productive tillers and fingers per ear had high direct influences on yield and hence are to be given weightage while breeding varieties for high yield.

15. The study has also brought out information on the strategies to be adopted in breeding programmes aiming at combining grain yield, blast resistance and high protein content. The genetic control of blast resistance in general appears to be complex and polygenic. However, incorporation of durable resistance in the cultivars should not be difficult.

The finding that the association between protein content and grain yield as well as blast resistance is negative; implying selection for higher protein is likely to influenced other two parameters negatively. A critical analysis of values of protein content, blast score and grain yield in F_2 and F_3 populations have indicated the possibility of combining all the three to some extent favourably, although it may not be possible to have the best of all the three in one and the same genotype. The ultimate solution may lie in breeding for high yield while at the same time maintaining reasonable level of resistance and protein content.

REFERENCES

VII REFERENCES

*Abdul Galit,S.A., Assay, A.A. and Ghanim,S.A., 1981, Phenol and carbohydrate changes in leaves of 8 wheat varieties with different rust reactions. *Egyptian J. Agron.*, **4(1)**:133-134.

Adam,A. and Gilly,A., 1984, Effect of nitrogen supply on the resistance of barley to *Heleminthosporium sativum. Kingaw Boke Noven Yve'delm.* **20(9)**:385-390.

Agalodia,A.V., Desai,K.B. and Tikka,S.B.S., 1979, Analysis of the parameters of variability and interrelationship of yield attributes in finger millet. *Indian J. Agric. Sci.*, **49(12)**:924-928.

AL-Jibouri,H.A., Miller,P.A. and Robinson,H.F., 1958, Genotypic and environmental variances in upland cotton crops of interspecific origin. *Agron. J.*, **50**:633-637.

A.O.A.C., 1970, Official Methods of Analysis. W.Startwitzled (Ed.). A.O.A.C., Washington, DC, USA.

Anahosur,K.H., Patil,S.H. and Hegde,R.K., 1985, Relationship of stalk sugars and phenols with charcoal rot of sorghum. *Indian Phytopath.*, **38(2)**:335-337.

Angell,H.R., Walker,J.C. and Link,K.P., 1930, The relation of protocatechuic acid to disease resistance in the onion. *Phyto Path.*, **20(1)**:431-438.

*Angra, 1989, Studies on some factors affecting pathogenesis of some cereal hosts by *Helminthosporium* spp. Ph.D. thesis Punjab University, Ludhiana, India.

Angra-Sharma,R. and sharma,D.K., 1994, Biochemical and histological studies on the susceptible and resistant maize leaves infected by *Helminthosporium maydis., Plant Pathology*, **43**:972-978.

Anonymous, 1996, Annual Report for 1995-96. All India co-ordinated small millets improvement project. UAS-ICAR, Bangalore.

Appadurai,R., Thangam,M.S., Raveendran,T.S. and Natarajan,V.S., 1977, Genotypic association, heritability and path analysis in ragi (*Eleusine coracana* G.). *Madras Agric. J.*, **64(1)**:18-21.

Ayesha Siddiqua and Kashem,M.A., 1993, Total phenol and soluble sugar in rice leaf sheaths in relation to resistance to sheath blight pathogen. *Indian J.Agric.Res.*,**27(2)**:57-63.

Baker,C.J., O'Neill,N.R. and Tomerlin,R.J., 1989, Accumalation of phenolic compounds in incompatible clone/rice interaction of *Medicago sativa* and *Colletotrichum trifoli. Mol. Pl. Pathology*, **35**:231-241.

*Balal,M.S., Salim,A.K., Hassanein,S.H. and Maximas,M.A., 1977, Inheritance of resistance to leaf and neck blast in rice. *Egyptian J. Genet. Cytol.*, **6(2)**:332-341.

Baron,C. and Zambryski, 1995, The plant response in pathogenesis, symbiosis and wounding; variations on a common theme? *Ann. Rev. Genetics*. **29**:107-129.

Basavaraja,C.T. and Sherief,R.A., 1992, Formulation of selection indices in finger millet (*Eleusine coracana* G.). *Indian J. Genet.*, **52(2)**:199-202.

Bell,A.A., 1981, Biochemical mechasnisms of disease resistance. *Ann. Rev. Pl. Physiol.*, **32**:21-81.

Bhatia,C.R., 1975, Criteria for early generation in wheat breeding programmes for improving protein productivity. *Euphytica*, **24**:787-794.

Bhat,J.C., Singh,R.A., Mani,S.C. and Jagshoran, 1994, Inheritance of blast resistance in rice. *Indian J. Genet.*, **54(2)**:142-148.

Bhuller, B.S., Bajaj,K.L. and Bhatia,I.S., 1972, Studies on the phenols of resistant and susceptible varieties of chillies in relation to anthracnose disease. *Plant Pathology.*, **75**:236-240.

Bulter,L.G., 1982, Relative degree of polymerization of sorghum tannins during seed development and maturation. *J. Agric. Food Chem.***30**:1090-1094.

Burns,R.E., 1971, Method for estimation of tannins in grain sorghum. *Agron. J.*, **63**:511.

Burton,G.W. and Devane,E.M., 1953, Estimating heritability in tall fescue (*Festuca arundanacea*) from replicated clonal material. *Agron. J.*, **45**:478-481.

Buu,R.H. and Huang,C.S., 1983, Studies on the improvemennt of blast disease resistance in the Japonica rice variety Taichung 67. *J. Agric. Res. china*, **32(3)**:201-208.

Cadman,C.H., 1959, Some properties of an inhibitor of virus infection from leaves of raspberry. *J.Gen. Microbiol.*, **20**:113-128.

Cahill,D.M. and McComb,J.A., 1992, A comparison of changes in phenyl alanine-ammonialyose activity, lignin and phenolic synthesis in roots of *Eucalyptus calophylla* (field resistant) and *E.marginata* (susceptible) when infected with *Phytopthora cinnamoni. Physiol. Mol. Pl. Path.*, **40**:315-332.

Cahill,D.M., Benett,I.J. and McComb,J.A., 1993, Mechanisms of resistance to *Phytopthora cinnamoni* in clonal micropropagated *Eucalyptus marginata. Plant Pathology*, **42**:865-872.

*Cai,G.H., 1983, Genetic analysis of blast resistance in indica rice cultivars. *Zhejiang Agric. Sci.*, 1:16-18.

Candela,M.E., Alcazar,M.O., Espin,A., Egea,C. and Almela,L., 1995, Soluble phenolic acids in *Capsicum annuum* stems infected with *Phytopthora capsici*. *Plant Pathology* **44**:116-123.

Castana,F.M.C., Hemery-Tardin,D., Tour Vielle De Labrouthe and Vear,F., 1992, The inheritance and biochemistry of resistance to *Sclerotiana sclerotionum* leaf infections in sun flower. *Euphytica* **58**:209-210.

Cauvery,M.B., 1993, Variability for fodder yield, its components and grain yield in Indian and African collections of finger millet (*Eleusine coracana* G). M.Sc. (Agri.) thesis, UAS, Bangalore.

Chattopadhyay,S.B. and Bera,A.K., 1978, Phenol content a possible biochemical parameter for resistance and susceptibility in rice plant to *Helminthosporium oryzae. Int. Rice Res. Newslett.*, **3(4)**:7.

Chattopadhyay,S.B. and Bera,A.K., 1980, Phenols and polyphenol oxidase activity in rice leaves infected with *Helminthosporium oryzae. Phyto Path.Z.*, **98(1)**:59-63.

Chaurasia,S., Rathi,Y.P.S., Srivasthava,A., Sand,N.K. and, Gupta,K.C., 1993, Role of phenolic acids in phytopthora blight resistance. *Pigeonpea Newsletter.*, **17**:29-31.

Chiranjeevi,V. and Tripathi,R.K., 1976, Changes in chemical constituents of anthracnose infected sorghum leaves. *Indian J. Mycol. Pl. Path.*, **6(2)**:171-172.

Chunilal, Tashidawa, Plaha,P. and Sharma,S.K., 1996, Studies on genetic variability and component analysis in ragi (*Eleusine coracana G). Indian J. Genet.*,**56(2)**:121-228.

Costa,J.M. and Kronstad,W.E., 1994, Association of grain protein concentration and selected grain traits in hard red winter wheat populations in the Pacific North west. *Crop Sci.* **34(5)**:1234-1239.

Cox,M.C., Qualset,C.O. and Rains,W., 1985, Genetic variation for nitrogen assimilation and translocation in wheat. Nitrogen assimilation in relation to grain yield and protein. *Crop. Sci.*, **25**:435-440.

Dalrymple,E.J., Goplen,B.P. and Howorth,R.E., 1984, Inheritance of tannins in birds foot trefail (*Lotus corniculatus*). *Crop Sci.*24:921.

Dev,V.P.S. and Mary,C.A., 1983, Varietal resistance to leaf blast and sheath blight at Pattambi, India. *Intl. Rice Res. Newslett.*,8(5):5-6.

Dewey,D.R. and Lu,K.H., 1959, A correlation and path co-efficient analysis of components of crested wheat grass seed production. *Agron.J.*, 51:515-518.

Dhagat,N.K., Patidar,G.L., Srivastava,P.S. and Joshi,R.C., 1972, Correlation and genetic variability study in ragi (*Eleusine corocana* G.). *JNKVV Res. J.* 6(2):121-124.

Dhagat,N.K., Patidar,G.L., Srivastava,P.S. and Joshi,R.C., 1973, Path analysis and selection indices in finger millet. *JNKVV Res. J.* 7(4):214-215.

Dhaliwal,L.S., Harjit Singh, Nanda,G.S. and Dhaliwal,H.S., 1994, Inheritance of grain protein content in two high protein lines of wheat. *Rachis*,13(1/2):34-37.

/Dhanakodi,C.V., 1994, Variability studies in fodder ragi (*Eleusine corocana* G.). *Madras Agric. J.*, 81(3):147-148.

Dhawan,K., Yadava,T.P., Kaushik,C.D. and Thakral,S.K., 1981, Changes in phenolic compounds and sugars in relation to white rust in Indian mustard. *Crop Improv.* 8:141-144.

Dineshkumar,S.P., 1986, Variation for protein content, its stability and association with yield and other characters in white and brown finger millet (*Eleusine corocana* G.). M.Sc. (Agri.) thesis, UAS, Bangalore.

Farkas,C.L. and Kiraly,Z., 1962, Role of phenolic compounds in the physiology of plant diseases and disease resistance. *Phytopath.*, 2(44):8-150.

Fisher,R.A. and Yates,F., 1963, Statistical tables for Biological, Agricultural and Medical Research. Oliver and Boyd, Edinburgh.

Frey,K.J., 1973, Improvement of quantity and quality of cereal grain protein. **In**:Alternative Sources of Protein for Animal Production.*National Acad. Sci.*, ISBN.0-309-2114-6, Washigton, D.C.

Friend,J., 1979, Phenolic substances and plant disease. **In**: Recent advances in Phytochemistry, Biochemistry of plant phenolics,12:557-558.

Ganguly,L.K., 1995, Biochemical alterations in respect of total phenols, sugar and protein contents in *Rhizoctonia solani*.K., inoculated rice plants. *J. Mycopatho. Res.*, 33(1):53-58.

Girishkumar,K., 1995, Performance of 14 finger millet genotypes over seasons for grain yield, fodder yield and quality characteristics and character association. M.Sc.(Agri.) thesis, UAS, Bangalore.

Goodman,R.N., Kiraly,Z. and Xaitlin,M., 1967. The biochemistry and physiology of infectious plant disease. D. Van Nostrand Company Inc.

Goswami,P. and Asthana,A.N., 1984, Genetic variability in indigenous varieties of finger millet in Sikkim. *Indian J. Agric. sci.*, **54(1)**:959-961.

Goud,J.V. and Lakshmi,P.V., 1977, Morphological and genetic variabilities for qualitative characters in ragi (*Eleusine coracana* G). *Mysore J. Agric. Sci.*, 11:438-443.

Gupta,S.K., Kumar,P., Yadava,T.P. and Sahran,G.S., 1984, Changes in phenolic compounds, sugars and total nitrogen in relation to *Alternaria* leaf blight in Indian mustard. *Haryana Agric. J. Res.*, **14**:535-537.

Gupta,G.K. and Gupta,A., 1986, Biochemical components of pearl millet varieties in relation to downy mildew infection. *Annals Arid Zone*, **23(3)**:269-274.

Guthrie,D.A., Smith,E.L. and McNew,R.W., 1984, Selection for high and low grain protein in six winter wheat crosses. *Crop. Sci.*,**24**:1097-1100.

Haider,Z.A., Jaylal Mahto, Binod Kumar and Ganguly,D.K., 1995, Genetic variability in finger millet (*Eleusine coracana* G). *J. of Res. Bir. Agric. Univ.*, **7(1)**:43-47.

Hallerislambers,D., Rutgor,J.N., Qualset,C.O. and Wiser, 1973, Genetic and environmental variation in protein content of rice. *Euphytica* **22**:264-273.

Halloran,G.M., 1981, Grain yield and protein relationship in wheat crosses. *Crop Sci.*, **21**:679-701.

*Hansford,C.G., 1943, Contributions towards the fungus flora of Uganda. V. Fungi imperfecti. *Proc. Linn. Soc.*, London, **1**:34-67.

Hanson,C.H., Robinson,H.F. and Comstock,R.E., 1956, Biometrical studies of yield in segregating populations of Korean Lespedeza. *Agron. J.*, **48**:268-272.

Harinarayana,C. and Gupta,V.P., 1989, Biometrical approaches to finger millet genetics and breeding. **In**: Finger millet Genetics and Breeding in India. Proceedings of National Seminar. 1983, pp. 1-7.

Harinarayana,C., Shewale,T.T., Gaikwad,A.C. and Harer,P.N., 1989, Variability for components of yield in Maharastra, Sikkim and Malawi collections of finger millet. **In**: Finger millet collections and breeding in India. Proc. Nat. Seminar. 1983, pp. 119-123.

Harrison,M., Payne,M.G. and Gaskill,J.U., 1961, Some chemical aspects of resistance to *Cercospora* leaf spot in sugar beets. *J. am. soc. Sugar beet Technol.*, **11**:457-468.

Harms,H. and Tarbea,M., 1984, Metabolism of phenolic compounds in healthy and brown rust infected barley and wheat varieties. *Phytopath. Z.*, **111(3)**:283-296.

*Higashi,T. and Saito,S., 1985, Linkage of field resistance genes of upland rice variety 'Sensho' to leaf blast caused by *Pyricularia oryzae. Japanese J. Breed.*, **35**:438-448.

*Hirano,T., 1994, Studies on the field resistance of rice vaieties to blast disease. *Bull. Akita Prefectul. Coll. Agric.*, **20**:1-41.

Howard,R.J., 1994, Cell biology of pathogenesis. In:Rice blast disease.(Eds. Zeigler,R.S., Leong,S.A. and Teng,P.S.), CAB International, Wallingford, U.K., pp.3-22.

*Hussain,H.A.S, Morsi,L.R. and Mustafa, K.A.L., 1983, Diallel analysis for powdery mildew resistance and protein content in barley. *Egyptian J. Genet. Cytol.*, **12(1)**:187-206.

*Ismail,M.K. and Michalik,I., 1982, Proteins and aminoacids in shoots and roots of some wheat cultivars before and after infection with *Helminthosporium sativum. Egyptian J. Bot.*, **23(3)**:145-162.

Jain,K., Gupta,J.C., Yadava,H.S. and Tikle,A.N., 1994, Assessment of stable resistance to blast in finger millet. *Adv. Pl. Sci.*, **7(2)**:330-334.

Jena,B.C. and Patnaik,H.B., 1987, Screening of ragi varieties against leaf blast. *Millets News Letter*, **6**:44-45.

Johnson,H.W., Robinson,H.F. and Comstock,R.E., 1955, Estimation of genetic and environmental variability in soybean. *Agron. J.*, **47**:314-318.

Joshi,H.C. and Mehra,H.S., 1989, Investigations on variability and genetic advance in ragi germplasm of Uttar Pradesh hills. **In**: Finger millet Genetics and Breeding in India. Proceedings of the National Seminar. 1983, UAS, Bangalore.

Kempanna,C., Vijayamma,R. and Setty,M.V.N., 1971, The impact of genotypic environmental interaction on the determination of the components of variation and other genetic parameters in *Eleusine coracana. Mysore J. Agric. Sci.*, **5(3)**:295-301.

Kibite,S. and Evans,L.E., 1984, Causes of negative correlations between grain yield and grain protein concentration in common wheat. *Euphytica*, **33**:801-810.

*Kiyosawa,S. and Cho.Chung,I.K., 1980, Identification of blast resistance genes in Korean vaiety Tangil. *Jap. J. Bread.*, **30**:73-82.

Klepper,L.A.S., 1975, Nitrate assimilation and seed protein content in wheat. *Poc. II Int. Wheat Conf.*,Zagreb.

Kosuge,T., 1969, The role of phenolics in host response to infection. *Ann. Rev. Phytopathol.*, **7**:195-222.

Kramer,T., 1979, Environmental and genetic variation for protein content in winter wheat (*T.aestivum*). *Euphytica*, **28**:209-218.

Lee,T.S., Chang,L.Z. and Kao,T.C., 1989, Genetic studies on tannin content and various characters in grain sorghum. **In**:**VI International Congress of SABRAO, breeding research: The key to the survival of the earth.** (Eds. Iyama.S. and Takada,G.). pp. 413-416.

Lee,S. and Le Tourneau.D.J., 1958, Chlorogenic acid content and *Verticillium* wilt resistance of potatoes. *Phytopathol.*, **48**:268.

*Li,X.K., Zhong,X.J., Mu,Y.S. and Xu.Z.Z, 1983, Effect of N-fertilizers on blast resistance on cultivars.*Ningixia Agric. Sur. Tech.*, **5**:10-13.

Lin,S.C., 1986, Genetic analysis of minor gene resistance to blast in Japonica rice. **In**:Rice Genetics, IRRI, Los Banos, The Phillippines, pp. 451-469.

*Link,P.K., Dickson,A.D. and Walker,J.C., 1929, Further observations on the occurrence of protocatechuic acid in pigmented onion scales and its reaction to disease resistance in the onion. *J. Biol. Chem.*, **84**:719-725.

*Link,P.K. and Walker,J.C., 1933, The isolation of catechol from pigmented onion scales and its significance in relation to disease resistance in onions. *J. Biol. Chem.*, **100**:379-383.

Loffier,C.M. and Busch.R.H., 1982, Selection for grain protein, grain yield and nitrogen partitioning efficiency in hard red spring wheat. *Crop Sci.*, **22**:591-595.

Loffier,C.M., Rauch,T.L. and Busch,R.H., 1985, Grain and plant protein relationships in hard red spring wheat. *Crop Sci.*, **25**:529.

Luo,K., Huang,S.Y., Wang,G.P. and Wan,W.J., 1985, Genetic analysis of the resistance of the rice cultivars zhenbong 13 and Zaiyaging 8 to *P.oryzae*. *Acta Phytopath Sinica*, **15(2)**:115-119.

Ma,Y. and Bliss,F.A., 1978, Tannin content and inheritance in common beans. *Crop Sci.* **18**:159.

Mackill,O.J., Bonman,J.M., Suh.,H.S. and Srilingam,R., 1985, genes for resistance to the Philippine isolates of the rice blast pathogen. *Rice Genetics Newsletter*, **2**:80-81.

Mackill,O.J. and Bonman,J.M., 1992, Inheritance of blast resistance in near isogenic lines of rice. *Phytopath.*, **82**:746-749.

Mahabaleswar Hegde, 1992, Physiological, biochemical and histological aspects of leaf rust (*Puccinia recondita* F. spp. *tritici*) in wheat genotypes. M.Sc.(agri.) thesis, UAS, Dharwad, India.

*Mahadevan,A., 1973, Theoretical concepts of disease resistance. *Acta Phytopath. Hung.* **8**:391-423.

Mahudeswaran,K. and Murugesan,M., 1973, Correlation and path analysis in *Eleusine coracana* G. *Madras Agric. J.*, **60(9)**:1287-1291.

Malhotra,S.K., 1993, Biochemical components of tomato genotypes in relation to *Fusarium* wilt. *Indian J. Micol. Pl. Pathol.*, **23(3)**:302-304.

Mallanna,K.N., Aradhya,K.M., Gowda,K.C.B. and Umashankar,R., 1978, A study of variability in a world collection of *Eleusina.* Paper presented in national Symposium in Genetic Research, IARI, New Delhi.

Marchetti,M.A., Lai,X. and Bollich,C.N., 1987, Inheritance of resistance to *Pyricularia oryzae* in rice cultivars grown in the United states. *Phytopathol.* **77**:799-804.

Marimuthu,R. and Rajagopalan,R., 1995, Protein stability in ragi. *Madras Agric. J.*, **82(11)**:617-618.

Mathur,K. and Bhatnagar,A.C., 1994, Changes in chlorophyll, phenols, proteins and soluble sugars in leaves of three cultivars of tomato infected with *Stemphyllum botryosum* Waur., *Proc. Indian Sci., Congress.*, Jaipur.

May,L., Van Stanford,D.a., Mackown,C.T. and Cornelins,P.L. 1991, Genetic variation for nitrogen using Soft Red X Hard Winter wheat populations. *Crop sci.*, **31**:626-630.

Mayama,M., Tani,T., Matsura,Y., Uneno,T. and Fukami,H., 1981, The production of phytoalexins by oats in response to crown rust, *Puccinia cornata* f. sp. *avenae*. *Physiol. Plant Path.*, **19(2)**:217-226.

McCouch,S.R., Nelson,R.J., Tohme,J. and Zeigler,R.S., 1994, Molecular mapping of blast resistance genes in rice. **In:**Rice blast disease.(Eds. Zeigler,R.S., Leong,S.A. and Teng,P.S.) CAB International, Wellingford, UK. pp.167-186.

McLean,J.H., Le Tourneau,D.J. and Guthrie,J.W., 1961, Relation of histochemical tests for phenols to *Verticillium* wilt resistance of potatoes. *Phytopathol.*, **51**:84-89.

McNew,G.L. and Spencer,F.L., 1939, Effect of nitrogen supply of sweet corn on the wilt bacterium. *Phytopathol.*, **29**:1051-1067.

*McRae, 1922, Report of imperial Mycologist, *Agric. Res. Inst.* Pusa Scientiic Reports., 1921-22, 44-50.

Meiners,J.P., 1981, Genetics of disease resistance in edible legumes. *Ann. Rev. Phytopathol.*, **19**:189-209.

Michael Raj,S., Premsekar,S. and Mahudeswaran,K., 1972, Studies on the correlation between tillers and grain yield in white and brown ragi types. *Madras Agric. J.*, **60**:362-363.

Mishra,H.P., Patnaik,M.C. and Naik,P.K., 1980, Variation in quantitative traits in finger millet. *Indian J. Agric. Sci.*, **50(4)**:298-301.

Mitchel-Olds,T.M., James,R., Palmer,M.J. and Williams,P.H., 1995, Genetics of *Brassica rapa* (SY. *Compestris*). 2. Multiple disease resistance to three fungal pathogens *Pernospora parasitica, Albugo candida* and *Lepto sphaeria maculans. Heredity*, **75**:362-369.

Mohanty,C.R. and Gangopadhyay,S., 1982, Variation in leaf angle and incidence of rice blast disease. *J.Agric. Sci.*, **98(1)**:225-227.

Narain,A. and Mahapatra,B.N., 1973, Factors controlling resistance of chilli leaves to *Colletotrichum capsici. Indian Phytopath.*, **26**:364-365.

Nicholson,R.L. and Hammerschmidt,R., 1992, Phenolic compounds and their role in disease resistance. *Ann. Rev. Phytopathol.*, **30**:369-389.

*Okiror,M.A., Mukur,S.Z. and Zake,V.M., 1976, Influence of male sterility on yield and yield characters in finger millet (*Eleusine coracana* G) East African agriculture and Forestry Research Organisation,. *EAC Record of Research.*

Padmnabhan,S.Y., Mathur,S.C. and Mishra,R.K., 1974, Breeding for blast resistance in India. *Indian J.Genet.*, **34(A)**:424-429.

*Paik,S.P., 1970, The relationship between varietal resistance to blast and chemical composition in rice. *J.Pl. Prot. Suwan.* **9(1)**:24-30.

Pathak,A.R., Zaveri,P.P., Patel,J.A. and Kher,H.R., 1990, Inheritance of protein content in mungbean under different environments. *Indian J. Genet.*,**50(3)**:276-278.

Patil,S.S., Zucker,M. and Dimond,A.E., 1966, Biosynthesis of chlorigenic acid in potato roots resistant and susceptible to *Verticillium alboatrans.*, *Phytopathol.***56**:971-974.

*Park,M., 1937, Report., The mycological Division, Ceylon Directorate of Africulture, Ceylon. pp. 25-28.

*Paul,H.,1980, Fungal diseases of Tropical Crops. Camb. Univ. Press, Cambridge. pp. 408-413.

Phogat,D.S., Singh,D.S. and Dhaliya,Y.S., 1995, Genetics of protein content and yield in barley (*Hordeum vulgere* L). *Crop Res.*, **9(1)**:85-92.

Prabhakar and Prasad,M.N., 1983, Correlation and path analysis in segregating population of finger millet (*Eleusine coracana* G). *Madras Agric. J.*, **70**:366-371.

Prabhakar and Prasad,M.N., 1984, Variability, heritability,genetic advance and gene action studies in segregating populations of ragi (*Eleusine coracana* G). *Madras Agric. J.*, **71**:288-285.

Prabhu,M.S.C., Venkatasubbaiah,P. and Safeeulla,K.M., 1984, Changes in total phenolic contents of sorghum callus resistant and susceptible to downy mildew. *Curr. Sci.*,**61(6)**:271-273.

*Purba,D., Kiyosawa,S., Audo,I. and Furutani,T., 1994, Estimation of functional values of field resistance genes to blast disease in some rice varieties. *Breed. Sci.*, **44(3)**:285-293.

Purushotham Rao,K., 1992, Genetic divergence in germplasm accessions of finger millet (*Eleusine coracana* G.), M.Sc.(Agri.) thesis, UAS, Bangalore.

Ramakrishna,B.M., Gowda,B.T.S., Katti,M., Seetharam,A., Mantur,S.G., Viswanath,S., Chennamma,K.A.L., Krishnappa,M., Vasanth,K.R., Krishnamurthi,B. and Jagadeeswara,K., 1996, Evaluation of finger millet germplasm. Germplasm Catalogue 1. Small millets Project Co-ordination Unit, UAS-ICAR, Bangalore. pp 33-35.

Ramakrishnan,K.V., 1948, Studies on the morphology and parasitism of the genus *Pyricularia* in Madras. *Proc. Indian Acad. Sci.*, Sect.B., **27**:174-193.

*Ramalingeswara Rao,G., 1985, Correlation and path analysis on yield components of ragi (*Eleusine coracana* G). M.Sc.(Agri.) thesis APAU, Hyderabad India.

Ramaswamy,P., Ramalingam,A., Shanmugavalli,N. and Soundarapandian., G., 1994, Variation and character associations of green fodder yield and component traits in ragi (*Eleusine coracana* G). *Madras Agric. J.*, **81(8)**:411-413.

Ramesh,B. and Hudda,M.P.S., 1994, Study on variability and associations involving protein content, amino acids and grain yield in sorghum. *Indian J. Genet.*, **54(1)**:37-44.

Ranganathan,C.R., Sundaram.A. and Menon,U.K., 1977, Correlation and path co-efficient analysis on yield contents of ragi. *Madras Agric. J.*, **64(9)**:591-592.

Rao,A.N.S., 1982, Estimation of crop loss in finger millet (*Eleusine coracana* G.) due to blast disease (*Pyricularia grisea*). Ph.D. thesis, UAS, Bangalore.

Rao,A.N.S., 1990, Estimation of losses in finger millet due to blast disease. *Mysore J. Agric.*, 24(1):57-60.

Rath,G.C. and Mishra,D., 1975, Nature of losses due to neck blast infection in ragi. *Sci. Cult.*, 41:322.

Ravikumar,R.L., 1988, Genetic and biochemical basis of blast resistance in finger millet (*Eleusine coracana* G.). Ph.D. thesis, UAS, Bangalore.

Ravikumar,R.L., Seetharam,A. and Gowda,B.T.S., 1990, Identification of sources of stable resistance to finger millet (*Eleusine coracana* G.) blast. *SABRAO J.*, 22(2):117-121.

Ravikumar,R.L., Dineshkumar,S.P. and Seetharam,A., 1991, Association of seed colour with seed protein, phenol, tannin and blast susceptibility in finger millet (*Eleusine coracana* G.). *SABRAO J.*, 23(2):91-94.

Ravikumar,R.L. and Seetharam,A., 1993, Character association in segregating populations of finger millet (*Eleusine coracana* G.). *Indian J. Agric. Sci.*63(2):96-99.

Ravikumar,R.L. and Seetharam,A., 1994, Genetic variation in yield and its components in relation to blast disease caused by *Pyricularia grisea* in finger millet. *Indian J. Agric. Sci.*, 64(2):103-106.

Ravikumar,R.L., Seetharam,A. and Shashidhar,V.R., 1995, Preformed internal defenses in finger millet (*Eleusine coracana* G.) against blast fungus *Pyricularia grisea. Fitopatol.*, 20(1):13-19.

*Reddy,M.K., 1971, Certain chemical constituents of rice plants in relation to resistance to blast disease. *AUARA.*, 3:106-107.

*Ride,J.P., 1985, Non-host resistance to fungi. **In**: Mechanisms of resistance to Plant Diseases., Martinus Nijhoff/Dr. W.Junk. Publishers. The Netherlands, pp. 29-55.

Robinson,H.F., Comstock,R.E. and Harvey,V.H., 1949, Estimates of heritability and the degree of dominance in corn. *Agron. J.*,41:353-359.

Roumen,E.C., 1992, Small differential interactions for partial resistance in ice cultivars to virulent isolates of the blast pathogen. *Euphytica*, 64:143-148.

*Salem,A.H., Abdel Sayyed and Shatla,M.A., 1983, Gene effects and selection efficiency of leaf blast resistance in the rice cross Yabani (15) X PI(1). *Ann. Agric. Sci.*, 28(3):1575-1592.

Sampson,D.R., Flynn,D.W. and Sui,P.Y., 1983, Inheritance of kernel protein in five spring wheat crosses. *Canadian J. Genet. Cytol.*, **25**:398-402.

Sarvaiya,R.B., Desai,K.B. and Kukedia,M.V., 1982, Genetic variability in ragi. *Gujrath Agric. Univ. Res.J.*, **7**:113-117.

Sarvaiya,R.B., Desai,K.B. and Kukedia,M.V., 1983, Correlation and path co-efficient analysis in finger millet. *Indian J.Agric. Sci.*, **53**:15-18.

Sathiyanathan,S. and Vidyashekaran,P., 1981, Role of phenolics in brown spot disease resistance in rice. *Indian Phytopath.*, **34(2)**:225-227.

Sati,K.C., and Grewal,J.S., 1982, Studies on gram blight caused by *Ascochyta rabici*. IV. The relationship of soluble sugars and total nitrogen contents of gram varieties to their susceptibility to blight. *Indian J. Mycol. Plant Path.*,**12(1)**:16-20.

Satyanarayana,E., Saikumar,R. and Reddy,M.S.S., 1995, Relationship of some prime biochemical compounds with charcoal rot resistance in corn (*Zea mays* L). *Mysore J. Agric. Sci.***29(2)**:120-124.

Satyanarayana,N., Rao,A.N.S., Ramarao,S. and Anilkumar,T.B., 1992, Phenol metabolism in cow pea plants due to infection by powdery mildew. *Indian Phytopathol.*, **44**:120.

Satyanarayana,S. and Saikumar, 1994., Relationship of biochemical compounds with *Turicum* leaf blight resistance in maize. *Mysore J. Agric. Sci.*, **28**:135-140.

Seetharam,A. and Ravikumar,R.L., 1993, Blast resistance in finger millet - its inheritance and biochemical nature. In:Advances in small millets.(Eds. Riley,K.W., Gupta,S.C., Seetharam,A. and Mushanga,J.N.), Oxford and IBH Publishing Co. Pvt. Ltd. New Delhi, pp. 449-467.

Seetharam,A. and Viswanath,S., 1983, Identification of sources of resistance to ragi blast and its utilization in breeding. *Proceedings of Seminar on "Breeding crop plants for resistance to pests and diseases"*. TNAU, Coimbatore, India.

Seetharam,A., Gowda,B.T.S., Subba Rao,A. and Prabhu,V.H., 1993, Genetic parameters and relationship of characters associated with fodder yield and its quality in finger millet. **In:** "Feeding of ruminants on fibrous crop residues" (Eds. Kiran Singh and Schiers,J.B.) ICAR, New Delhi and Agricultural University, Wagenigen.

Setty,M.V.N., Govindaraj.,D.R., Vijayakumar,S. and Shetter,B.I., 1974, Variability pattern of yield and its components in finger millet (*Eleusine coracana* G.), *Madras J. Agric. Sci.*, **8**:519-524.

Shankar,T.D., 1982, Genetics of yield and yield components in finger millet following generation mean analysis. M.Sc. (Agri.) thesis, UAS, Bangalore, India.

Shanthakumar,G., 1988, Inheritance of plant pigmentation, grain colour, character association, path analysis and heritability of yield and its components in finger millet (*Eleusine coracana* G.). M.Sc. (Agri.) thesis, UAS, Bangalore, India.

Shanthappa,M.B., 1979, Inheritance studies in *Eleusine coracana* G. crosses. M.Sc. (Agri.) thesis, UAS, Bangalore, India.

Sharma,J.R., 1994, Principles and practice of plant breeding. Tata McGraw-Hill Publishing Company Limited, New Delhi.

Sharma,J.P., Mishra,B. and Krishna Jha, 1992, Biochemical relationship in resistant and susceptible cultivars with *Turricum* leaf blight disease in maize. *Indian Phytopath.*, **45**:241-245.

*Shatla,H.N., Nazim,M., Basiony,A.M., Abdet Ghar,A.I., Sehly,M.R. and El-Shennawy,Z., 1983, Effect of nitrogen fertilization on the physiology of rice plant resistance to blast. *Minufiya J. Agric. Res.*, **6**:61-74.

Shear,G.M. and Wingard,S.A., 1944, Some ways by which nitrogen may affect severity of disease in plants. *Phytopath.*,**34**:603-605.

*Shen,J.H., Ni,P.C. and Wang,J.L., 1981, Studies on inheritance of blast resistance in rice varieties. *Scientia Agricultura Sinica* 3:10-15.

Sheppard,J.W. and Peterson,J.F., 1976, Chlorogenic acid and verticillium wilt of tobacco. *Canadian J. Pl. Sci.*, **56**:157-160.

Shi,S.H., Shi,D., Sun, Tao,R.X. and Sun,S.Y., 1994, Inheritance of resistance to rice blast disease in some Japonicas. *Intl. Rice Res. Notes.* **19(2)**:12-13.

Singh,R.K. and Choudhary,B.D., 1985, Biometrical Methods in quantitative Genetics Analysis, Kalyani Publishers, Ludhiana.

Sivasubramanian,S. and Menon,M., 1973, Heterosis and inbreeding depression in rice. *Madras Agric. J.*, **60**:1139-1144.

Smith,J.D. and Kinman,M.L., 1965, The use of parent off spring regression as an estimator of heritability. *Crop Sci.*, **5**:595-596.

Snedecor,C.W. and Cochran,W.C., 1967, Statistical Methods. The IOWA State University Press, USA, pp. 593.

Somani,R.B., 1992, Studies on biochemical status of resistant and susceptible *Sorghum bicolor* cultivars against grain moulds. Ph.D. thesis Punjab Rao Krishi Vidya Peeth. Akola.

Somashekara,Y.M., Viswanath,S. and Anilkumar,T.B., 1991, Evaluation of finger millet (*Eleusine coracana* G.) cultivars for their reactions to blast (*P.grisea* Sacc.). *Trop. Agric.*, **68(3)**:231-234.

Somashekara,Y.M., Viswanath,S. and AnilKumar,T.B., 1992, Screening of finger millet (*Eleusine coracana* G.) cultivars for multiple disease resistance. *Trop. Agric.*, **69(3)**:293-295.

Southerton,S.G. and Deverall,B.J., 1990, Changes in phenolic acid levels in wheat leaves expressing resistance to *Puccinia recondit* F. sp. *tritic. Physiol. Mol. Pl. Pathol.*37:437-450.

*Sprague,R., 1950, Diseases of cereals and grasses in North America (Fungi, except smuts and rusts). Ronald Press, New York. pp. 538.

*Staples,R.C. and Ledbetter,M.C., 1958, Study of micro radiography of the distribution of tritium labelled glycine in rusted Pinto bean leaves. *Contrib. Boyce Thompson Inst.*,19:349-354.

Swain,T. and Hills,W.E., 1959, The phenolic constituents of *Prunus domestica*. I. The quantitative analysis of phenolic constituents. *J. Sci. Food Agric.*, **10**:63-68.

Swamynath, 1978, Study on the genetic diversity in the African collection of finger millet and their interaction with environments. M.Sc.(Agri.) thesis, UAS, Bangalore.

Tyagi,P.C. and Koranne,K.D., 1989, Genetic variability studies in finger millet. **In:** Finger millet Genetics and Breeding in India. Proceedings of National Seminar, 1983, UAS, Bangalore, India. pp. 79-81.

Vaillencourt,R., Sinkard,A.E. and Reichert., R.D., 1986, The inheritance of condensed tannin concentrations in lentil. *Can. J. Plant Sci.*66:241.

Valluvaparidasan,V. and Mariappan, 1983, Accumulation of phenolics in rice varieties due to infection by *Xanthomonas compestris* cv. *Oryzae. Intl. Rice Res. Newslett.*8(3):10-11.

Van der Plank,J.E., 1978, Genetic and molecular basis of plant pathogenesis. Sprenger - Verlag, Berlin, New York.

Velazhahan,R. and Ramabhadran,R., 1993, Changes in phenolic contents of rice during pathogenesis of *Sarocladium Oryzae*. *Madras Agric J.* **50-54**:50-51.

Venkatarayan,S.V., 1947, Diseases of ragi (*Eleusine coracana* G.). *Mysore Agric. J.*, **24**:50-57.

Venkatesh Bhat, 1991, Genetic investigations in early generations of finger millet (*Eleusine coracana* G.). M.Sc.(Agri.) thesis UAS, Bangalore.

Verma,V.S., 1989, Variability pattern in quantitative traits of ragi (*Eleusine coracana* G.). *Madras Agric. J.*, **76**:626-629.

Vidyashekaran,P., 1974a, Changes in phenolic content in ragi leaves due to susceptible and resistant *Heliminthosporiose* disease reactions. *Indian J. expt. Biol.*, **12**:592.

Vidyashekaran,P., 1974b, Role of phenolics in leaf spot incidence in ragi infected by *Helminthosporium tetramara. Indian Phytopathol.* **27**:583.

Vidyashekaran,P., 1975, Role of auxin phenol complex in finger millet (*Eleusine coracana* G.) resistance to Heliminthosporiose. *Phytopathol. Z.*, **82(2)**:89-99.

Vidyashekaran,P., 1988, Physiology of Disease resistance in plants., Vol.1. CRC Press, Florida, pp.49-76.

Viswanath,S. and Chennamma,L., 1988, Survey and surveillance of ragi diseases and their management in Karnataka. **In**: National Seminar on Pest Surveillance for Integrated Pest management. TNAU, Coimbatore, pp.35.

Viswanath,S., Sannegowda,S., Seetharam,A. and Gowda,B.T.S, 1986a, Evaluation of 1941 germplasm accessions of ragi for blast disease. *Millet News Letter*, **5**:31.

Viswanath,S., Sannegowda,S., Seetharam,A. and Gowda,B.T.S., 1986b, Reaction to blast disease of released and pre-released varieties of finger millet from different states. *Millet News Letter*, **5**:31

Viswanath,S. and Seetharam,A., 1986, Diseases of small millets and their management in India. **In**:**Small millets in global agriculture.** (Eds. Seetharam,A., Riley,K.W. and Harinarayana,G.) , Oxford and IBH Publishing Co. Ltd. New Delhi. pp. 237.

Vivekanandan,P., Krishnaswamy,V. and Kadambavanasundaram,M., 1987, Susceptibility of rice hybrids to blast. *Intl. Rice Res., News Lett.*, **12(1)**:6-7.

Walker,J.C. and Stahmann,M.A., 1955, Chemical nature of disease resistance in plants. *Ann. Rev. Pl. Physiol.* **6**:351-366.

*Wallace,G.B., 1950, Annual report of the plant pathologist, *Thanganyika*, Dept. Agric. Report. 1948, pp.45.

Wang,G.L., Mackill,D.J., Bonman,J.M., McCouch,S.R., Champoux,M.C. and Nelson,R.J., 1994, RFLP mapping of genes conferring complete and partial resistance to blast in a durably resistant rice cultivar. *Genetics*, **136**:1421-1434.

Weiguangma, Fuzzoti,N., Li,Q.S., Yang,C.R., Evans,H.S. and Hostettmann,K., 1995, Polyphenols form *Eriosoma tuberosum*. *Phytochemistry*, **39**:1049-1061.

Woodruff,B.J., Cantrell,R.P., Axell,J.D. and Bulter,L.G., 1982, Inheritance of tannin quantity of sorghum. *The J. Heridity*, **73**:214-218.

Wright,S., 1921, Correlation and causation. *J. Agric. Res.*, **20**:202-209.

*Xu,W.Y., 1986, Inheritance of resistance to three physiological races of *Pyricularia oyzae* in 6 Indian donors. *Fujian Agric. Sci. Techn.* **7**:16-18.

Yadav,O.P., Yadava,T.P., Kumar,P. and Gupta,S.K., 1996, Inheritance of phenols and protein in relation to white rust (*Albugo candida*) resistance in Indian mustard. *Indian J. Genet.*, **56(3)**:256-261.

*Yakoo,M., 1994, Inheritance of resistance to blast disease in upland rice Norin Mochi 4. *Bread Sci.*, **44(1)**:97-100.

Yu,Z.H., Mackill,D.J. and Bonman,J.M., 1987, Inheritance of resistance to blast in some traditional and improved rice cultivars. *Phytopathol.*, **77**:323-326.

APPENDIX

Appendix-I: Monthly weather data for the years 1993 and 1994 during crop growth period at GKVK, UAS, Bangalore.

1993					
Month	Temparature (°C)		Relative humidity (%)	Rainfall (mm)	Rainy days
	Max.	Min.			
July	27.8	19.1	72.5	58.5	6
August	27.0	18.6	73.5	150.6	9
September	27.1	18.1	76.5	328.1	9
October	26.9	18.6	77.0	273.4	10
November	26.0	17.1	75.5	21.6	2
December	24.6	14.7	69.5	65.4	2
1994					
July	26.6	18.7	76.5	92.3	11
August	27.3	13.8	72.5	96.7	10
September	28.5	18.6	68.0	113.9	5
October	27.0	18.0	76.0	212.1	12
November	25.0	15.4	71.5	21.0	2
December	25.1	13.3	64.0	3.2	-