VARIABILITY IN VEGETABLE AMARANTH (*Amaranthus dubius* Mart. ex Thell.) FOR YIELD, QUALITY AND RESISTANCE TO LEAF BLIGHT

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DECLARATION

I hereby declare that this thesis entitled "**Variability in vegetable amaranth (*Amaranthus dubius* Mart. ex Thell.) for yield, quality and resistance to leaf blight**" is a bonafide record of research work done by me during the course of research and that the thesis has not previously formed the basis for the award of any degree, diploma, associateship, fellowship or other similar title, of any other university or society.

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Certified that this thesis entitled "**Variability in vegetable amaranth (*Amaranthus dubius* Mart. ex Thell.) for yield, quality and resistance to leaf blight**" is a record of research work done independently by Ms. Sindhu. L. (2000-12-02) under my guidance and supervision and that it has not previously formed the basis for the award of any degree, fellowship or associateship to her.

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Dedicated to

Achan and Amma

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LIST OF ABBREVIATIONS

%	per cent
β	Beta
µg	Micro gram
^{0}C	Degree Celsius
Anon.	Anonymous
A.O.A.C.	Association of Official Agricultural Chemists
Ca	Calcium
cm	Centimetre
CRD	Complete Randomised Design
cv.	Cultivar
DAT	Days After Transplanting
et al.	And others
Fe	Iron
Fig.	Figure
g	Gram
GA	Genetic Advance
GCV	Genotypic coefficient of variation
h	Hour
H^2	Heritability
ha	Hectare
i.e.	That is
I.U.	International Unit
IPGRI	International Plant Genetic Resources Institute
K	Potassium
KAU	Kerala Agricultural University
kg	Kilogram
l	Litre
m	Metre
Mg	Magnesium
ml	Millilitre
mm	Millimetre

LIST OF ABBREVIATIONS Continued

NCRPIS	North Central Regional Plant Introduction Station
nm	Nanometre
No.	Number
P	Phosphorus
PCV	Phenotypic coefficient of variation
PDA	Potato Dextrose Agar
PDI	Percentage Disease Index
RBD	Randomised Block Design
sp.	Species
t	Tonnes
var.	Variety
via	Through
viz.	Namely
W.H.O.	World Health Organisation

INTRODUCTION

1. INTRODUCTION

Amaranthus is the most popular and widely grown leafy vegetable of Kerala. The general term 'protective food' applied to vegetables, is very much suited to amaranthus as it is a rich source of protein, vitamins and minerals. It contains protein 4.0 g, fibre 1.0 g, vitamin A 9200 I.U., riboflavin 0.10 mg, thiamine 0.03 mg, vitamin C 99 mg, Fe 25.5 mg and Ca 397 mg per 100 g of edible portion (Choudhury, 1996). On the other hand, farmers prefer this crop because of its short duration, high productivity and relative low incidence of pests and diseases.

Though highly esteemed as a nutritious leafy vegetable, the presence of antinutrient factors like oxalates and nitrates has always been a negative factor in its large-scale consumption (Marderosian *et al.*, 1980). The calcium oxalate formed by the binding of the free oxalates with calcium leads to oxalurea or kidney stones. The nitrate level is of concern when it is converted to nitrites and nitrosamines.

Despite the fact that amaranthus is less affected by pests and diseases, recently, the incidence of leaf blight disease caused by *Rhizoctonia solani* Kühn, in severe intensity in many parts of the state is causing considerable economic loss (Nayar *et al.*, 1996).

Amaranthus belongs to the family Amaranthaceae, spread over 65 genera and 900 species. The important vegetable types under the genus *Amaranthus* are *A. tricolor* L., *A. dubius* Mart. ex Thell. and *A. tristis* L. Among these, *A. tricolor* and *A. dubius* are grown in Kerala (Devadas and Mallika, 1991).

Almost all the species except *A. dubius* are found to be susceptible to *R. solani* (Priya, 1998). The commonly cultivated species *A. tricolor* is highly susceptible to this disease. Moreover, the antinutrient factors are less in *A. dubius* compared to *A. tricolor*. Hence, *A. dubius* was taken for

the present study. It is the only tetraploid species with a chromosome number of 2n = 4x = 64.

Assessing the variability for desirable characters is a prequisite for any crop improvement programme. So a detailed study involving a wide germplasm of *A. dubius* would enable the breeder to locate superior genotypes for yield, quality and resistance to leaf blight. The knowledge of available variability and association of attributes to yield enables the breeder to determine the method of crop improvement. The path analysis studies would facilitate effective selection for simultaneous improvement of one or more yield contributing characters.

Accounting the importance of above facts, the present study was carried out with the following objectives.

1. To assess the variability existing in the vegetable amaranth (*A. dubius*) germplasm for yield, quality and resistance to leaf blight.
2. To identify superior genotype(s).
3. To find out the direct and indirect effects of characters on yield.
4. To confirm the resistance of *A. dubius* to *R. solani* under artificial epiphytotic conditions.

REVIEW OF LITERATURE

2. REVIEW OF LITERATURE

Amaranthus, also known as poor man's spinach, is one of the most nutritious leafy vegetables of the tropics. Among the different species *Amaranthus tricolor* L. and *A. dubius* Mart. ex Thell. are the two species cultivated in Kerala. The present study is concentrated on variability in *A. dubius* for yield, quality and resistance to leaf blight. Though genetic studies specific in *A. dubius* are very meagre, the available literature in *Amaranthus* spp. is reviewed under the following subheads.

2.1 Biometric characters

2.2 Quality characters

2.2.1 Nutrient factors

2.2.2 Antinutrient factors

2.3 Biotic stress

2.3.1 Leaf blight

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2.3.3 Leaf webber

2.4 Variability, heritability and correlation

2.5 Ploidy level of *Amaranthus* spp.

2.1 BIOMETRIC CHARACTERS

Variability in biometric characters like plant height, stem girth, length of leaf lamina, leaf width, petiole length, number of branches, days to 50 per cent bolting, leaf / stem ratio and yield were studied by several workers in amaranthus.

Kamalanathan *et al.* (1973) showed that the vegetable amaranthus variety Co-1, belonging to *Amaranthus dubius* yielded 19 t ha^{-1}.

Mohideen and Rajagopal (1974) reported that 'Arakeerai' (*A. tristis*) responded favourably to clipping with 11,736 kg of green yield per ha as compared to 'Sirukeerai' (*A. blitum*) with 8680 kg ha^{-1}.

Mohideen and Rajagopal (1975) reported that transplanting delayed flowering and prolonged the total duration of vegetative phase.

A high yielding variety Co-2 (*A. tricolor*) with yields of 10,780 kg ha^{-1} at 25^{th} day and 16,200 kg ha^{-1} at 30^{th} day as compared to Co-1 with yields of 6578 kg ha^{-1} and 12,789 kg ha^{-1} respectively was reported by Rajagopal *et al.* (1977). He also reported that in direct sowing, amaranthus took 52 days to flower.

The performance of amaranthus was superior at 25^{th} day after sowing with increased leaf weight, stem weight, leaf length, leaf breadth, stem diameter and plant height (Mohideen, 1978). Hence, the optimum stage of harvest in amaranthus could be fixed at 25^{th} day after sowing. Mohideen and Muthukrishnan (1979) reported the influence of plant height, leaf breadth and stem diameter on total yield and did not account days to bolting and frequency of harvests. In the varieties, Co-1 and Co-2, the green matter yield increased from 27^{th} to 42^{nd} day after sowing (Subbiah, 1979).

A study conducted by Vijayakumar (1980) on the performance of 19 types of amaranthus belonging to *A. dubius, A. tricolor, A. blitum, A. hypochondriacus, A. cruentus, A. tristis* and *A. edulis* indicated green yield range from 0.920 kg m^{-2} to 4.700 kg m^{-2} on the 30^{th} day of harvest.

Mohideen and Muthukrishnan (1981) classified the amaranthus genotypes into high yielders, moderate yielders and low yielders. They reported that the mean yield of greens in most of the amaranthus types was high during summer season than in rainy season.

Campbell and Abbott (1982) conducted field evaluation of vegetable amaranthus (*Amaranthus* spp.) and revealed that *A. dubius* was the highest yielder, whereas *A. tricolor* had the highest leaf / stem ratio.

Devadas (1982) conducted a screening to locate non bolting types of amaranthus suited for year round planting in Kerala. The study showed that days to flowering is a genetic character indicating scope for simple selection methods to improve this character.

The ranges of yield as reported by various workers were 4.0 to 16.5 t ha^{-1} (Campbell and Abbott, 1982), 9.90 to 18.30 t ha^{-1} (Makus, 1984).

A high yielding clipping type of amaranthus Co-3 was released by Tamil Nadu Agricultural University, Coimbatore, through selection which recorded an yield of 10 – 12 t ha^{-1} (Mohideen *et al.*, 1985).

Mutation breeding studies with gamma rays on six genotypes of amaranthus was undertaken by Mohideen (1988). The study led to the selection of a number of promising mutant lines for earliness, dwarf stature, broad leaf characters, late flowering, basal branching and higher growth ability with higher green matter.

Olufolaji and Dinakin (1988) reported that grain and green yields vary with seed colour. The highest vegetable yield in amaranthus was given by the black seeded cultivars while white seeded types recorded highest seed yield.

There was no significant differences between red and green amaranthus for plant height, stem girth and petiole length at 30 days after sowing, but the leaf length, leaf width and number of branches differed significantly and higher yield and frequency of harvests were observed in red types as compared to green (Devadas *et al.*, 1993).

A study on vegetable yield of amaranthus, as influenced by species and harvesting frequency revealed that *A. hybridus, A. hypochondriacus* and *A. dubius* produced significantly higher yields than *A. flavus* and *A. hybridus* had the highest leaf / stem ratio (on a dry weight basis). Harvesting at three weeks interval significantly increased vegetable yield, but higher leaf / stem ratio was obtained from fortnightly harvesting (Norman and Sichone, 1993).

Pusa Kirti (*A. tricolor*) and Pusa Kiran (a natural cross between *A. tricolor* and *A. tristis*) recorded an yield of 50 – 55 t ha^{-1} and 35 t ha^{-1} respectively (Sirohi and Sivakami, 1995).

Allemann *et al.* (1996) evaluated six amaranthus for productivity, taste and acceptability. The highest total yield was obtained from *A. hypochondriacus* (43 t ha^{-1}) and lowest from *A. tricolor* (13 t ha^{-1}). First cutting gave highest yields which decreased progressively with subsequent harvests.

Pusa Lal Chaulai, a red pigmented vegetable amaranthus suited for both spring – summer and kharif seasons gave an average yield of 49 and 45 t ha^{-1} in spring and kharif seasons (Sirohi and Sivakami, 1997). A high yielding double coloured and dual purpose amaranthus, Co-5 was released for commercial cultivation from Tamil Nadu Agricultural University, Coimbatore. As 'mulaikeerai' in a crop duration of 30 days, it can yield 16.20 t ha^{-1} and as thandukeerai with a duration of 50 days it can yield 33.17 t ha^{-1} (Anon., 1998).

Mohanalekshmi *et al.* (1998) studied variability in relation to stages of growth in amaranthus. An overall analysis of growth pattern, yield of greens and component characters conclusively indicated the optimum harvest stage as 20 to 30 days after sowing. Optimum leaf / stem ratio of around 1 to 1.5 has to be aimed at in selection.

Priya (1998) reported significant difference among the genotypes for all the characters studied. The highest yield was obtained for Amt 193 (304.5 g plant^{-1}). The genotype A 24 belonging to *A. tricolor* recorded the highest leaf / stem ratio of 1.57. Days to 50 per cent bolting ranged from 36.38 in A 53 to 74.50 in A 41.

Hossain and Rahman (1999) carried out an investigation to assess the stem production potential of 11 amaranth genotypes and results indicated that stem portion contributed more over leaf portion towards the yield and the genotypes Aus Danta, Baromashy, Sureshsory and Red Force were found promising for stem production. Baromashy (51.50 days) and Aus Danta (51 days) were earliest while Red Force (113 days) and Sureshsory (112 days) were late to flower.

Huaixiang (2000) evaluated 229 genotypes of 20 *Amaranthus* sp. Agronomic traits including, plant height, maturity, leaf number and colour, stem colour, seed colour, branch number, 1000 grain weight, yield per plant and resistant to stresses were measured. Cultivated genotypes had higher yields.

Arka Arunima, a high yielding purple coloured multicut amaranth variety has been released at IIHR. Leaves are broad, purple and yields about 27 t ha^{-1} in three cuts (IIHR, 2000).

Shukla and Singh (2000) showed that foliage yield per plant vary between 1.18 – 3.29 kg with average of 2.25 kg. The range and mean of individual cuttings for plant height, leaves/plant and foliage yield generally increased in ascending order of cuttings and was maximum in 4th cutting, while range and mean were maximum in 3rd cutting for leaf size (38.07 ± 3.99) and branches per plant (11.9 ± 0.78).

Srinivasaiah *et al.* (2000) studied the effect of varieties and sowing dates on seed yield and quality in vegetable amaranthus (*Amaranthus* sp.), using three *A. tricolor* cultivars Arka Suguna, AG 114 and

local sown at 30 days interval from 15 July 1997 to 15 February 1998. The earliest in flowering was the August sown crop, while earliest in maturity was observed in July sown crop. Highest seed yield with fairly good seed quality was observed in November sown crop, but better seed quality was in July and February sown crops. AG 114 recorded the highest values for all yield attributes irrespective of the date of sowing.

2.2 QUALITY CHARACTERS

2.2.1 Nutrient Factors

Amaranth is a leafy vegetable, rich in protein, vitamin C, vitamin A, Fe and Ca which is a rare example of a vegetable where all these essential dietary components are combined in one (Mohideen and Subramanian, 1974).

Variation in different species of amaranthus for ascorbic acid content was reported by Grubben (1976), which ranged from 325 to 1250 mg in 100 g of drymatter. Rajagopal *et al.* (1977) reported that the amaranthus variety Co-2 contains 3.5 g protein, 1.3 g crude fibre, 39.38 mg P, 310 mg Ca and 19 mg Fe in 100 g of edible matter.

Martin and Telek (1979) reported that amaranthus leaves are a good source of vitamin A, vitamin C, Ca and Fe. Relation between yield and some nutritive constituents in amaranthus was studied by Mathai *et al.* (1980). Protein content of the leaves ranged from 21 to 28 per cent in *A. caudatus* and 18.37 to 37.19 per cent in *A. tricolor*, on the drymatter basis.

Sreeramulu (1982) studied the chemical composition of some green leafy vegetables and reported that *A. viridis*, a common weed, had the highest fibre content of 21.3 g / 100 g. Ramanathan and Subbiah (1983) reported that the crude protein was highest in amaranthus harvested 27 days after sowing.

Ezeala (1985) reported that *A. viridis* leaves contained 32.2 per cent crude protein and 11.2 per cent fibre, whereas, *A. caudatus* contained 27.2 per cent crude protein and 11.1 per cent fibre, on dry weight basis.

The nutrient content of the variety Co-3 was studied by Mohideen *et al.* (1985). It contained 12.5 per cent protein and 17.4 per cent crude fibre on dry weight basis and 11.04 mg of carotene in 100 g of fresh matter.

Singh *et al.* (1985) reported that N application decreased the crude protein content of *A. tristis* cv. Co-3.

The nutritive value of seven types of amaranthus was studied by Vijayakumar and Shanmughavelu (1985). The ascorbic acid ranged from 32.9 to 44.2 mg / 100 g, carotene content 9.9 to 10.9 mg, crude fibre 16.5 to 21.9 per cent, protein 12.5 to 14.5 per cent and Ca content 2.30 to 2.52 per cent on dry weight basis.

Castanedae *et al.* (1986) reported that the protein content of amaranthus was similar to that of spinach. Imeri *et al.* (1987) conducted a study using 25 varieties of amaranthus (*A. caudatus*) and revealed that mean protein content was 12.66 per cent.

The variability study for nutritive aspects in 30 accessions of amaranthus including *A. tricolor*, *A. dubius* and *A. cruentus* conducted by George *et al.* (1989) revealed that *A. cruentus* Acc 14 had the highest dry matter content (17.2 per cent), a red entry Acc 59 had the highest crude protein content (29.3 per cent) and Acc 28 contained the highest quantity of beta-carotene (36.1 mg/100 g of dry matter). Red and green-red entries had high protein and beta-carotene contents.

Amaranth protein is a valuable contribution to the diet where protein intake is marginal (Shanmugavelu, 1989).

Prakash and Pal (1991) studied 61 accessions of amaranthus and reported variation for carotenoid content from 90 to 200 mg kg^{-1} in

vegetable and from 60 to 200 mg kg^{-1} in grain types. The variation in leaf protein was 14 to 30 g kg^{-1} and 15 to 43 g kg^{-1} for vegetable and grain types respectively.

Jijiamma and Prema (1993) studied the nutritional composition and organoleptic qualities of two cultivars of amaranthus (*A. tricolor* – red and green types) during rainy and summer seasons. Leaf protein content was unaffected by seasons. The red cultivar, however, grown in the summer season had better organoleptic quality.

The contents of chlorophyll, carotenoids and betacyanin were determined in leaves picked at the flowering stage from 31 specimens representing the species, *A. tricolor*, *A. caudatus* and *A. cruentus*. The chlorophyll a and chlorophyll b contents were maximum in *A. tricolor* accessions K 49 (14.61 mg/g) and K 99 (15-12 mg/g). These two have highest carotenoid contents (4.95 and 4.23 mg/g respectively), while K 99 had the highest amaranthin content 34.2 mg/g (Kononkov *et al.*, 1995).

Trojani *et al.* (1995) studied the relation between the crude protein content and cutting height (0.1, 0.2, 0.3 m form top) of *A. mantegazzianus* Pass cv. Don Juan. Crude protein content was similar for most treatments ranging from 18 to 23 per cent for 1 m tall plants cut 30 cm from top to 23.6 per cent for 0.4 m tall plants cut 0.1 m from top. Ca, Mg, P and ash content did not vary significantly between treatments.

Cherezov *et al.* (1997) estimated content of N containing compounds and carbohydrates on developing amaranth plants (*A. cruentus*) by internal reflection spectroscopy in infra-red light and reported that high extent of coordination and seasonal rhythmicity of carbohydrate and nitrogen metabolism was found in each of the plant organs and these processes were also coordinated between different organs.

Guill *et al.* (1997) reported carotenoid content of *A. viridis* as 15.4 mg/ 100 g.

Raja *et al.* (1997) analysed eight green vegetables including amaranthus for their nutritive value and reported the levels of crude protein 1.03 – 5.23 per cent on fresh weight basis.

Analysis of 11 genotypes of local amaranthus (*A. tricolor*) was done for their nutritional and organoleptic properties by Hossain *et al.* (1999). The genotype Bone Fire had highest content of drymatter (10.07 per cent), protein (12.97 per cent), Ca (1.54 per cent), Mg (0.25 per cent) and Fe (576 ppm).

Kowsalya *et al.* (2001) reported the beta-carotene content of Araikeerai (*A. tristis*) as 19.900 mg/100g and mullakeerai (*A. spinosus*) as 13.941 mg/100g.

2.2.2 Antinutrient Factors

The major limiting factor in consumption of amaranthus is the presence of antinutrient factors like oxalates and nitrates. At high concentration, oxalates cause kidney stones and nitrates cause concern when it is converted to nitrites and nitrosamines.

Martin and Telek (1979) suggested that the amount of amaranthus in the diet should be limited as it is high in oxalic acid content.

Marderosian *et al.* (1980) reported that mean nitrate levels were 0.48 per cent in leaves and 1.72 per cent in stems on dry weight basis, oxalate levels were 5.00 per cent in leaves and 0.63 per cent in stems. The nitrates and oxalates in amaranthus were similar to those found in spinach and chard.

Adverse nutritional effects would not occur with consumption level of 100-200 g day^{-1} (Grubben and Vanaslotten, 1981). Kauffmann and Gilbert (1981) analysed the free oxalates and nitrate in the leaves

and stem of eight amaranthus species and revealed that *A. dubius* was characterized by lowest content of nitrates and oxalates.

Hill and Rawati (1982) studied the oxalic acid and nitrate content of *A. retroflexus* and found that these factors would be important only if large amounts are eaten raw.

Sanni (1983) reported that *A. hybridus* L. contained a nitrate level of 1675 ppm on dry weight basis which exceeded the limit of 500 ppm recommended by W.H.O.

Makus (1984) indicated from a study on eight accessions of *A. tricolor* that, the leaf blades contained 1.1 per cent nitrate nitrogen and 2.3 per cent soluble oxalates on dry weight basis.

Singh *et al.* (1985) studied the effect of added N on certain qualitative characters of *A. tristis* cv. Co-3 and showed that increasing levels of N increased the oxalic acid and hydrocyanic acid content of the edible matter.

A. dubius cv. Ibondwe proved to be superior among different species studied, for carotene content (15.4 mg/g fresh weight) and low oxalate content (Sealy *et al.*, 1988).

George *et al.* (1989) found that all green entries had low oxalate contents, while red and green-red entries had high oxalate contents, in a study involving leaves from 30 entries of *A. tricolor, A. dubius, A. cruentus* collected after 45 days growth in the field. Vityakon and Standal (1989) also reported high levels of oxalates in *A. tricolor* (91 g kg^{-1}) on dry weight basis.

Devadas and Mallika (1991) had reported a range from 0.94 to 1.29 per cent for oxalate content. The least oxalate content of 0.94 per cent was recorded in the variety Co-3. In general, section Blitopsis had higher content of antinutrients than in the section Amaranthus.

Prakash and Pal (1991) in their studies with 61 accessions comprising vegetable and grain amaranthus types, reported a variation in the content of nitrate from 1.8 to 9.2 g kg^{-1} and oxalate from 3.0 to 19.2 g kg^{-1} on fresh weight basis. The oxalate content increased with advance in growth period while nitrate content remained constant.

Devadas *et al.* (1993) reported that red pigmented lines had the highest content of oxalates compared to green amaranthus.

On screening 41 types, the oxalate content ranged from 0.820 to 0.921. In general the red types were observed to have higher content while the pale green types had lower oxalate content (Thamburaj *et al.*, 1994).

Ebeling *et al.* (1995) examined the wild species *A. retroflexus, A. viridis, A. palmeri* and *A. blitoides* as potential sources of vegetable green. Antinutrient factors were quantified in the flowering stage and found only nitrate 0.34 – 2.00 per cent on dry weight basis.

Guill *et al.* (1997) reported that in *A. viridis* the nitrate content was 597 mg / 100 g.

Bianco *et al.* (1998) examined 31 edible wild herbaceous species to establish the nutritional value with regard to their domestication and the enlargement of their consumption. They reported extremely high levels of soluble oxalates in *Amaranthus retroflexus*.

Oxalate was highest (2.40 per cent) in the red leaved genotype A 80 (Arun) while the green leaved genotype A 63 (*A. tristis* cv. Co-3) recorded the lowest oxalate content (0.82 per cent). In general, the red coloured genotypes had high oxalate, while the green genotypes had comparatively less oxalates (Priya and Celine, 2001).

Sukumar and Rajan (2001) studied the impact of NPK nutrition and frequency of cuttings on nitrate content in *Amaranthus tricolor* L. (var. Arun). The nitrate content increased with increase in levels of N

and K upto the highest level tried (150 and 100 kg respectively). Phosphorus has no significant influence.

2.3 BIOTIC STRESS

Diseases like leaf blight and white rust and insect pests like leaf Webbers are the major biotic stresses in amaranthus.

2.3.1 Leaf Blight

Though amaranthus is comparatively free from pests and diseases, the leaf blight caused by *Rhizoctonia solani* Kühn has become a severe problem nowadays reducing its marketability to a great extent.

Roy (1975) reported the incidence of collar rot caused by *R. solani* in amaranthus. Leaf blight caused by *R. solani* was reported in other vegetables (Khatua and Maiti, 1982 ; Bandyopathyay and Khatua, 1985) and in ornamentals (Jana *et al.*, 1990).

Nayar *et al.* (1996) found that *A. tricolor* was severely infected with *Rhizoctonia solani* during the post monsoon period of 1994 (August – September) in Kerala. The pathogen produced cream coloured spots on leaves which spread rapidly and resulted in extensive damage and economic losses.

The green amaranthus variety Co-1 released from Tamil Nadu Agricultural University, Coimbatore exhibited excellent field tolerance to leaf blight (Gokulapalan *et al.*, 1997). They also reported that raising of green and red amaranthus as a mixed crop can also help in reducing the spread and severity of this disease.

Priya (1998) reported that the tetraploid amaranth, *A. dubius* is the only species resistant to leaf blight caused by *R. solani* among the different species studied.

Krishnakumary *et al.* (2001) screened 168 accessions belonging to different *Amaranthus* sp. for leaf spot resistance and reported that 14

accessions were immune and 15 were resistant. Co-1, the popular green variety cultivated in Kerala showed a disease severity less than 10 per cent and categorized as resistant.

2.3.2 White Rust

At IIHR 98 genotypes were evaluated for yield, quality and resistance to disease and reported that 24 accessions were found to be highly resistant to white rust (IIHR, 1998). In another study using 105 genotypes, 14 were found resistant to white rust under field conditions. The variety Arka Arunima, released from IIHR is white rust resistant (IIHR, 2000).

Leaves of *A. tricolor* var *bengalensis* infected with *Albugo blitii* showed decrease in the total and reducing sugars and an increase in the phenolic compounds during the early stages of the disease. A substantial depletion of anthocyanin in plant pigments was also recorded in the infected leaves (Maiti and Mandal, 2000).

2.3.3 Leaf Webber

Leaf webbers are the most important pest attacking amaranthus. The attack of leaf webbers lead to low vegetable yield and makes the produce unsuitable for consumption.

The leaf webbers, *Psara basalis* Fab. and *Hymenia recurvalis* (F.) badly damage the leaves of vegetable amaranthus. Their caterpillars, web together the leaves of amaranthus and feed from within skeletonising the leaves completely (Bhattacharjee and Menon, 1964; Nair, 1980). *Hymenia recurvalis* was reported as an important defoliator of *A. viridis* (Pande, 1973).

Unnikrishnan (1986) studied the effectiveness of some *Bacillus thuringiensis* strains on the biological control of amaranthus pests and reported that the strain HD109 gave superior control of leaf webbers.

2.4 GENETIC VARIABILITY, HERITABILITY AND CORRELATION

Mohideen and Subramanian (1974) suggested that leaf breadth, stem length and stem diameter are reliable characters for exercising selection based on a correlation study using the variety Co-1 belonging to *A. dubius*.

Based on the results of a path coefficient analysis, Mohideen (1978) reported that weight of leaves, weight of stem, height, stem diameter and breadth of leaf contributed the highest direct and indirect positive effects on yield of greens.

The plant height has a positive and significant correlation with the green yield and the leaf / stem ratio co-exhibited a significant negative association with yield of greens (Vijayakumar, 1980).

Mohideen *et al.* (1982) studied the extent of variability in yield of greens and its components using 75 genotypes of amaranthus (*A. tricolor* L.) and reported that at the optimum harvest stage of 25^{th} day, the genotypic coefficient of variation was high for weight of stem, leaf / stem ratio, yield of greens and weight of leaves. High heritability estimates along with high genetic advance for the above characters, indicated that phenotypic selection for these traits will be more useful.

High heritability (broad sense) with high genetic advance was recorded for yield of greens, fresh weight of leaf, fresh weight of stem and number of leaves per plant. Plant height, leaf area and ascorbic acid content showed high heritability with moderate genetic advance. Considerably high heritability accompanied by low genetic advance were obtained for leaf / stem ratio, stem girth, dry weight of stem, dry weight of greens, percentage of crude protein and total chlorophyll content. Number of branches per plant showed low heritability coupled with low genetic advance (Revanappa, 1985).

Joshi (1986) observed wide variability for height, number of leaves per plant, leaf length and width, inflorescence length, number of spikelets per plant, days to maturity, 1000 seed weight, seed protein content and seed yield per plant among 20 genotypes of *A. hypochondriacus*.

Devadas *et al.* (1989) reported that leaf width, plant height on bolting day, days to 50 per cent bolting and frequency of harvests are the most important factors favouring the total vegetable yield and further suggested the usefulness of these traits in the selection programme.

In amaranthus, the height and stem girth are positively correlated with yield (Hamid *et al.*, 1989).

Das *et al.* (1991) studied the genetic variation for quantitative traits and yield components in grain amaranthus (*A. hypochondriacus* L.). Panicle weight, which had the highest estimates of heritability and genetic advance, and 1000 grain weight contributed most to grain yield.

Pan *et al.* (1991) in their studies on vegetable amaranthus (*A. tricolor*), reported that among the characters studied, days to flowering, number of clippings, duration of harvest, diameter of stem and width of leaf had high GCV values indicating the presence of greater extent of genetic variability. High heritability estimates, combined with high genetic advance as per cent of the mean were obtained for number of clippings, width of leaf, duration of harvest, total yield of greens, diameter of stem and leaf / stem ratio. They suggested that phenotypic selection for these traits would be most effective.

Genetic studies by Anuradha (1992) revealed highly significant positive genotypic as well as phenotypic association in total green yield with plant height, stem girth, number of nodes per plant, number of leaves, leaf length, fresh weight of leaves, fresh weight of stem, days to 50 per cent bolting and total crude protein.

Devadas *et al.* (1992) studied genetic divergence among 25 vegetable amaranthus accessions belonging to four botanical species and were grouped into seven clusters. Study of intracluster differences revealed that the variability in *A. tricolor* was maximum when compared to other species.

Lohithaswa (1992) reported that grain yield had significant positive correlation with plant height, inflorescence length, stem girth at collar region, fresh weight of the plant, number of rachis, fresh weight of inflorescence and dry weight of stem.

Pandey (1993) indicated significant and positive association between yield and yield contributing traits. Path coefficient analysis suggested that harvest index had maximum direct effect on yield.

High genotypic coefficient of variation was obtained for number of leaves, leaf weight, stem weight, leaf / stem ratio and yield of greens per plant. Heritability and genetic advance were also high for these five characters (Varalakshmi and Reddy, 1994).

Joshi and Rana (1995) analysed a set of 20 genetically diverse genotypes of grain amaranthus for genetic variability, correlation and path coefficient. Leaf length showed maximum direct effect on grain yield followed by number of leaves, plant height and 1000 grain weight.

Genetic variability, heritability and genetic advance for 11 characters in 144 genotypes of grain amaranthus were studied by Lohithaswa *et al.* (1996). High heritability coupled with moderate genetic advance was observed for plant height and days to 50 per cent flowering indicating that additive gene effects were operating for these characters and selection pressure could be applied on them for yield improvement.

Revanappa and Madalgeri (1997) evaluated 40 genotypes of amaranthus and reported higher PCV than GCV for all characters. PCV

and GCV were maximum for leaf / stem ratio, number of leaves and fresh weight of leaves and minimum for stem girth.

Diversity for grain yield and other morpho-physiological characters has been reported in amaranthus germplasm (Bansal and Sharma, 1998).

Reddy and Varalakshmi (1998) studied heterosis, general and specific combing ability variances for nine characters in line x tester design in vegetable amaranth (*A. tricolor* L.). The results indicated the predominance of non-additive gene action for plant height, leaf number, leaf breadth, stem girth, stem weight, leaf weight. Additive gene action was preponderant for leaf / stem ratio.

Shukla and Singh (2000) worked out coefficient of variability and genetic advance for foliage yield and its four main component traits. The heritability estimates in broad sense ranged from 33.24 to 75.00 per cent. High heritability coupled with high genetic advance noticed for foliage yield (75.00 per cent), leaf size (74.98 per cent) and leaves per plant (73.43 per cent) indicated the prevalent role of additive gene effects.

Fifteen genotypes of amaranthus were evaluated for yield, yield attributes, quality characters, oxalate and reaction to leaf blight and leaf webber. High values of PCV and GCV were obtained for most of the characters. High heritability coupled with high genetic gain was observed for leaf length, leaf width, leaf weight, fibre, oxalate and reaction to leaf blight indicating scope for improvement through selection (Priya and Celine, 2001).

2.5 PLOIDY LEVEL OF *AMARANTHUS* SPP.

All the species of *Amaranthus* are diploids except *A. dubius* which is a tetraploid. There are two chromosome groups in amaranthus, n = 16 and n = 17 (Khoshoo and Pal, 1972). The species *A. cruentus*

has n = 16 whereas *A. tricolor*, *A. spinosus*, *A. viridis* and *A. blitum* has n = 17.

Madhusoodanan and Pal (1981) studied cytology of five species of *Amaranthus* genus (Section Blitopsis) *viz.*, *A. tricolor*, *A. lividus*, *A. graecizens*, *A. viridis* and *A. albus*. They observed that all the species were diploids with x = 16 or 17, the latter being more common.

Mallika (1987) conducted cytogenetical studies in eight species of *Amaranthus* and their hybrids. The species studied were *A. tricolor*, *A. lividus*, *A. viridis*, *A. spinosus*, *A. dubius*, *A. hypochondriacus*, *A. cruentus* and *A. caudatus*. The first three belong to Blitopsis and remaining five to section Amaranthus. Meiosis in both sections were normal with regular formation of bivalents. Out of eight species, seven diploids with n = 16 or n = 17 and one species *A. dubius* was a polyploid with n = 32. *A. dubius* behaved as an allopolyploid with 32 bivalents.

While studying the chromosome number of 31 taxa belonging to 14 families of angiosperms collected from different regions of Saudi Arabia, Alturki *et al.* (2000) reported that the 2n of *A. spinosus* is 34.

Pal *et al.* (2000) reported a new basic chromosome number n = 14 for the genus *Amaranthus*, previously characterized by n = 16 or n = 17. *A. tenuifolius*, a wild delicate trailing herb, was the species whose 2n = 28.

MATERIALS AND METHODS

3. MATERIALS AND METHODS

The experiment entitled "Variability in vegetable amaranth (*Amaranthus dubius* Mart. ex Thell.) for yield, quality and resistance to leaf blight" was conducted at the Department of Olericulture, College of Agriculture, Vellayani, during the period 2000-2002. The experimental site was located at 8°5′ N latitude and 77° 1′ E longitude at an altitude of 29 m above mean sea level. Predominant soil type of the experimental site was red loam belonging to Vellayani series, texturally classified as sandy clay loam.

The experiment included 31 accessions collected from NCRPIS, Iowa State University, Ames, United States of America and one local collection of *A. dubius* (Table 1). 'Arun' a variety of *A. tricolor* was used as the susceptible check. The experiment was laid out in randomized block design with three replications. The seedlings were transplanted 25 days after sowing adopting a spacing of 30 x 20 cm. The plot size was 2 x 1.5 m. Fifty plants were maintained in each plot. The crop received timely management practices as per Package of Practices Recommendations of Kerala Agricultural University (KAU, 1996) except for the plant protection practices.

3.1 OBSERVATIONS RECORDED

Five plants were randomly selected from each plot and tagged for recording the biometrical observations. The observations were taken 30 days after transplanting and mean worked out for further analysis.

3.1.1 Growth Characters

3.1.1.1 Plant Height

The height of the plant was measured from the ground level to the top most leaf bud of all observational plants, average worked out and expressed in centimetres.

Table 1 List of *Amaranthus dubius* Mart. ex Thell. accessions used for the study

Sl. No.	Accession number	Identity number	Source country
1	AD 1	AMES 10842	Seychelles
2	AD 2	AMES 19996	Yemen
3	AD 3	AMES 15201	Nigeria
4	AD 4	AMES 2020	Puerto Rico
5	AD 5	AMES 2014	Surinam
6	AD 6	AMES 2018	Puerto Rico
7	AD 7	AMES 2068	Nepal
8	AD 8	AMES 1967	Tamil Nadu, India
9	AD 9	AMES 2009	Ghana
10	AD 10	AMES 1987	Unknown
11	AD 11	AMES 2005	Tanzania
12	AD 12	AMES 1994	Taiwan
13	AD 13	AMES 1997	Ghana
14	AD 14	AMES 5312	Jamaica
15	AD 15	AMES 5164	Puerto Rico
16	AD 16	AMES 10340	Czechoslovakia
17	AD 18	AMES 5107	Virgin Island
18	AD 19	AMES 5105	Seychelles
19	AD 20	AMES 5114	Taiwan
20	AD 21	AMES 5104	Seychelles
21	AD 22	AMES 2136	Tamil Nadu, India
22	AD 23	AMES 2098	India
23	AD 24	PI 612850	United States
24	AD 25	PI 576483	Nigeria
25	AD 26	PI 605352	Jamaica
26	AD 28	PI 536444	Maldives
27	AD 29	PI 536441	Maldives
28	AD 30	PI 536438	Maldives
29	AD 31	PI 490348	Burkina Faso
30	AD 32	PI 532151	Oman
31	AD 33	PI 482047	Zimbabwe
32	AD 34	Local	Vellayani, India

3.1.1.2 Stem Girth

The girth of the main stem at the collar region was taken using a twine. The mean girth was worked out and expressed in centimetres.

3.1.1.3 Length of Leaf Lamina

The fifth leaf from top of the selected plants was used for recording the length. The length was measured and expressed in centimetres.

3.1.1.4 Leaf Width

The width of the same leaf used for recording the length was taken at the region of maximum width and expressed in centimetres.

3.1.1.5 Petiole Length

The petiole length of the fifth leaf used for recording the length was measured and expressed in centimetres.

3.1.1.6 Number of Branches

The total number of branches of each observational plant was counted and the average worked out.

3.1.1.7 Days to 50 per cent Bolting

Days to 50 per cent bolting was recorded from the plants left unharvested.

3.1.2 Yield Characters

3.1.2.1 Leaf / Stem Ratio

Leaf / stem ratio was obtained by dividing the weight of the leaves by the weight of the stem. Leaf / stem ratio was worked out for three cuttings. First harvest was done 30 days after transplanting and the subsequent cuts at biweekly intervals.

3.1.2.2 Total Vegetable Yield

Yield per plant from the three cuttings was separately recorded and then added to get the total yield per plant and expressed in grams per plant.

3.1.3 Quality characters

3.1.3.1 Protein

The total nitrogen of the oven dried samples was estimated by the modified Microkjeldhal method (Jackson, 1967). The nitrogen values were multiplied by a factor 6.25 to obtain the protein content and expressed as percentage of dry weight of leaves (Simpson *et al.*, 1965).

3.1.3.2 Fibre

The fibre content of the leaves was estimated by acid and alkali digestion method (Sadasivam and Manickam, 1992).

Reagents : Sulphuric acid solution (0.255 ± 0.005 *N*) : 1.25 ml concentrated sulphuric acid diluted to 100 ml using distilled water.

Sodium hydroxide solution (0.313 ± 0.005 *N*) : 1.25 g sodium hydroxide in 100 ml distilled water.

Procedure : Two gram of dried plant sample was boiled with 200 ml of sulphuric acid for 30 minutes with bumping chips. Filtered through muslin cloth and washed with boiling water until washings were no longer acidic. Residue obtained was again boiled with 200 ml of sodium hydroxide solution for 30 minutes. Filtered through muslin cloth again and washed with 25 ml of boiling 1.25 per cent sulphuric acid, three 50 ml portions of water and 25 ml alcohol. The residue was transferred to ashing dish which was preweighed (W_1). Dried the residue for 2 hrs at 130 ± 2°C. Cooled the dish in a desiccator and weighed (W_2). Then it was ignited for 30 minutes at 600 ± 15°C. Cooled in a desiccator and weighed (W_3).

Percentage crude fibre in the ground sample

$$= \frac{\text{Loss in weight on ignition}}{\text{Weight of the sample}} \times 100$$

3.1.3.3 Vitamin A

Carotene content of fresh leaves at first harvest (30 DAT) was estimated according to the method proposed by Srivastava and Kumar (1998).

Reagents Acetone, anhydrous sodium sulphate, petroleum ether.

Procedure : Five gram of fresh sample was taken and crushed in 10-15 ml acetone, adding a few crystals of unhydrous sodium sulphate, with the help of pestle and mortar. The supernatant was decanted into a beaker. Repeated the process twice and transferred the combined supernatant to a separatory funnel. 10-15 ml of petroleum ether was added and mixed thoroughly. The two layers separated out on standing. The lower layer discarded and the upper layer was collected in a 100 ml volumetric flask. The volume was made upto 100 ml with petroleum ether and recorded the optical density at 452 nm using petroleum ether as blank.

$$\beta \text{ carotene } (\mu g/100 \text{ g}) = \frac{\text{Optical density} \times 13.9 \times 10^4 \times 100}{\text{Weight of sample} \times 560 \times 1000}$$

$$\text{Vitamin A (I.U.)} = \frac{\beta \text{ carotene } (\mu g/100 \text{ g})}{0.6}$$

3.1.3.4 Oxalates

Estimated by the method suggested by A.O.A.C. (1984).

Reagent : Tungsto phosphoric acid : 2.5 g sodium tungstate dissolved in mixture of 4 ml phosphoric acid and 50 ml water and diluted to 100 ml with water.

Wash liquid : 12.5 ml acetic acid diluted to 250 ml water. A pinch of calcium oxalate was added, shook and let it stand. Decanted and filtered.

Acetate buffer (pH 4.5) : 2.5 g of anhydrous calcium chloride dissolved in 50 ml acetic acid (1 : 1 diluted) and added the solution of 33 g of sodium acetate diluted to 5 ml.

Potassium permanganate : 0.01 *N*

Sulphuric acid : 2 *N*

Hydrochloric acid : 0.25 *N*

Procedure : One gram of dried powder extracted twice with 0.25 *N* hydrochloric acid in a water bath for one hour each. The centrifuge was collected in a conical flask. The extract was precipitated by adding 5 ml tungsto-phosphoric acid kept overnight and centrifuged. This was neutralized with 1 : 1 dilute ammonia solution. Then precipitated by adding 5 ml acetate buffer with calcium chloride (pH 4.5). Centrifuged and washed the precipitate twice with wash liquid (6 ml each). The precipitate was then dissolved in 10-15 ml 2 *N* sulphuric acid and transferred into a 100 ml conical flask and titrated against 0.01 *N* potassium permanganate solution at 60°C.

$$\text{Percentage oxalate} = \frac{0.063 \times V}{1g}$$

3.1.3.5 Nitrates

The nitrate content of the leaves was estimated by distillation technique (Marderosian *et al.*, 1980). One gram sample was extracted in 100 ml of distilled water for 30 minutes on a shaker. The sample was centrifuged to remove the plant material, then filtered first with Whatman No.1 paper, then by glass micro-filter paper. Five ml of the filtrate was pipetted into a 125 ml iodine flask and 0.1 g of 3, 4-dimethyl phenol added, followed by 10 ml of concentrated sulphuric acid. The flask was

glass stoppered and allowed to stand for 10 minutes. After this, 30 ml of distilled water was added (keeping the flasks cool in running tap water) and the samples were held for 30 minutes. The contents were then transferred to a flask for steam distillation and were distilled. 25 ml of distillate was collected in a volumetric flask containing 3 ml five per cent sodium hydroxide. The sample was measured spectrophotometrically at 430 nm using sodium hydroxide and water as a blank.

3.1.3.6 Organoleptic Evaluation

Organoleptic qualities and acceptability trials were done using a scoring method (Jijiamma, 1989). The major quality attributes included in the score were colour, doneness, tenderness, odour and taste (Appendix I). Each of the above mentioned quality was assessed by a five point rating scale.

The panel members were selected from a group of healthy adults in the age group of 25–45.

The leaves were washed thoroughly in water to remove the adhering dirt and cut into small pieces. 125 g of chopped leaves were boiled with 50 ml of water and 1 g of salt for ten minutes. The prepared sample was used for organoleptic quality scoring.

3.1.4 Screening for Incidence of Pests and Diseases

3.1.4.1 Reaction to Leaf Blight

3.1.4.1.1 Field Screening

The performance of the accessions were closely monitored for the incidence and intensity of leaf blight disease caused by *Rhizoctonia solani* Kühn.

3.1.4.1.2 Artificial Screening

Screening under artificial epiphytotic conditions was attempted to confirm the resistance to *R. solani* in a separate pot culture experiment.

R. solani causing leaf blight of amaranthus was isolated from naturally infected amaranthus plants collected from the Instructional Farm, College of Agriculture, Vellayani. For isolation of the pathogen, portion of the leaf showing fresh typical symptom were cut into small bits, surface sterilized with 0.1 per cent mercuric chloride and washed in three changes of sterile distilled water. They were then plated on potato dextrose agar medium (PDA) in sterile petridishes and incubated at room temperature (28 ± 1°C).

In the second day fungal growth from the infected tissue was purified by the hyphal tip method and transferred to PDA slants. The isolate was maintained on PDA slants by subculturing periodically. This pure culture of the fungus was used throughout the study.

The thirty two accessions were raised in separate pots with four replications. The variety 'Arun' belonging to *A. tricolor* was used as the susceptible check. The pathogen was inoculated thirty days after sowing. A bit of the mycelia of the pathogen was placed on the leaves and moistened cotton was put over it. The pots were covered with perforated plastic covers (Plate 1).

Scoring was done using a 0-7 scale on accessions showing the symptom (Plate 2).

0 → No incidence

1 → Upto 25 per cent leaf area infected

3 → 26-50 per cent leaf area infected

5 → 51-75 per cent leaf area infected

7 → >75 per cent leaf area infected

Percentage disease index (PDI) was calculated using the following formula :

$$PDI = \frac{\text{Sum of the score} \times 100}{\text{Number of leaves} \times \text{Highest score}}$$

Based on percentage disease severity, the accessions were grouped into five categories as suggested by Rajkumar *et al.* (1995).

0	:	Immune
1-10 %	:	Highly resistant
10.1-25 %	:	Moderately resistant
25.1-50 %	:	Moderately susceptible
>50 %	:	Highly susceptible

3.1.4.2 Reaction to White Rust

The accessions were monitored for the incidence and intensity of white rust caused by *Albugo blitii*. A scale ranging from 0-9 was followed for scoring depending upon the extent of damage to the leaves (Mayee and Datar, 1986) (Plate 2).

0	→	No symptoms on leaf
1	→	Small, raised blisters on the under surface of leaf covering 1 % or less area
3	→	Small, raised blisters covering 1-10 %
5	→	Raised blisters covering 11-25 % of leaf area
7	→	Raised shiny, white blisters covering 26-50 % of leaf area
9	→	Raised shiny blisters coalescing to form large patches covering 51 % or more of the leaf area

(A) Inoculated plants before covering

(B) Inoculated plants covered with perforated plastic covers

Plate 1. Artificial screening for leaf blight caused by *Rhizoctonia solani*

(A) Leaf blight

(B) White rust

Plate 2. Scoring for disease

3.1.4.3 Reaction to Leaf Webber

Scoring was done for leaf webbers, *Hymenia recurvalis* and *Psara basalis*, attack by using the following score chart.

0 → No incidence

1 → Mild (25 per cent)

2 → Medium (50 per cent)

3 → Severe (75 per cent)

4 → Very severe (100 per cent)

3.2 STATISTICAL ANALYSIS

The data collected were subjected to the following statistical analysis.

3.2.1 Analysis of Variance and Covariance

Analysis of variance and covariance were done according to Singh and Choudhary (1979) to test the significant difference among the accessions and to estimate variance components and other genetic parameters like correlation coefficients, heritability, genetic advance etc (Table 2).

	X	Y
Environmental variance (σ^2_e) = σ^2_{ex} = E_{xx}		$\sigma^2_{ey} = E_{yy}$
Genotypic variance (σ^2_g)= σ^2_{gx} =	$\frac{G_{xx}-E_{xx}}{r}$	$\sigma^2_{gy} = \frac{G_{yy}-E_{yy}}{r}$
Phenotypic variance (σ^2_p)= σ^2_{px}= $\sigma^2_{gx}+\sigma^2_{ex}$		$\sigma^2_{py}= \sigma^2_{gy} + \sigma^2_{ey}$

Table 2 Analysis of variance / covariance

Source	df	Observed mean square XX	Expected mean square XX	Observed mean sum of products XY	Expected mean sum of products XY	Observed mean square YY	Expected mean square YY
Block	r-1	B_{xx}		B_{xy}		B_{yy}	
Genotype	v-1	G_{xx}	$\sigma^2_{ex} + r\sigma^2_{gx}$	G_{xy}	$\sigma^2_{exy} + r\sigma^2_{gxy}$	G_{yy}	$\sigma^2_{ex} + r\sigma^2_{ge}$
Error	(v-1) (r-1)	E_{xx}	σ^2_{ex}	E_{xy}	σ^2_{exy}	E_{yy}	σ^2_{ey}
Total	(rv-1)	T_{xx}		T_{xy}		T_{yy}	

3.2.2 Coefficient of variation

Phenotypic and genotypic coefficients of variation (PCV and GCV) were estimated as :

$$GCV = \frac{\sigma_{gx}}{\bar{x}} \times 100$$

$$PCV = \frac{\sigma_{px}}{\bar{x}} \times 100$$

where σ_{gx} = genotypic standard deviation

σ_{px} = phenotypic standard deviation

$\bar{x}$ = mean of the character under study

3.2.3 Heritability (Broad sense)

$$H^2 = \frac{\sigma^2_{gx}}{\sigma^2_{px}} \times 100$$

Where H^2 is the heritability expressed in percentage (Jain, 1982).

Heritability estimates were categorized as suggested by Johnson *et al.* (1955).

0 – 30 per cent	→	Low
31 – 60 per cent	→	Moderate
>60	→	High

3.2.4 Genetic Advance as Percentage of Mean

$$GA = \frac{kH^2 \sigma_p}{\bar{x}} \times 100$$

where k is the standardised selection differential. k = 2.06 at 5 % selection intensity (Miller *et al.*, 1958).

The range of genetic advance as per cent of mean was classified according to Johnson *et al.* (1955).

0 – 10 per cent → Low

11 – 20 per cent → Moderate

>20 per cent → High

3.2.5 Correlation

Genotypic correlation coefficient $(r_{gxy}) = \frac{\sigma_{gxy}}{\sigma_{gx} \times \sigma_{gy}}$

Phenotypic correlation coefficient $(r_{pxy}) = \frac{\sigma_{pxy}}{\sigma_{px} \times \sigma_{py}}$

Environmental correlation coefficient $(r_{exy}) = \frac{\sigma_{exy}}{\sigma_{ex} \times \sigma_{ey}}$

3.2.6 Path Analysis

The path coefficient analysis was done by the method suggested by Wright (1921) using the characters which showed high correlation with yield. The simultaneous equations which give the estimates of path coefficients are as follows :

$$\begin{vmatrix} r_{1y} \\ r_{2y} \\ r_{iy} \\ r_{ky} \end{vmatrix} = \begin{vmatrix} 1 & r_{12} & r_{13} \text{-------} r_{1j} \text{-------} & r_{1k} \\ & 1 & r_{23} \text{----------} & r_{2k} \\ & & r_{ij} \text{----------} & r_{ik} \\ & & & 1 \end{vmatrix} \times \begin{vmatrix} P_1 \\ P_2 \\ P_i \\ P_k \end{vmatrix}$$

i.e., $R_y = R_x . P$ so that $P = R_x^{-1} R_y$

where, r_{ij} is the genotypic correlation between x_i and x_j ; i, j = 1,2, ...k; r_{iy} is the genotypic correlation between x_i and y and P_i is the path coefficient of x_i. The residual factor (R) which measures the contribution of other factors not defined in the casual scheme was estimated by the formula.

$$R = \sqrt{\left(1 - \sum_{i=1}^{k} P_i r_{iy}\right)}$$

Indirect effect of different characters on yield is obtained as $P_i r_{ij}$ for the i^{th} character *via* j^{th} character.

The direct and indirect effects were classified based on the scale given by Lenka and Mishra (1973).

0.00 – 0.09 → Negligible

0.10 – 0.19 → Low

0.20 – 0.29 → Moderate

0.30 – 0.99 → High

>1 → Very high

3.2.7 Selection Index

Selection index was calculated based on the method suggested by Hazel (1943).

The general form of the selection index is given below :

$I = b_1X_1 + b_2X_2 + b_3X_3 \ldots b_nX_n$

where, X_1, X_2, X_3 and X_n represent the phenotypic values of the character number 1, 2, 3 and n respectively and b_1, b_2, b_3 and b_n are the corresponding weights.

3.3 CATALOGUING OF THE GERMPLASM

3.3.1 Morphological Cataloguing

The accessions were described morphologically using descriptors developed from the standard descriptor for amaranthus by IPGRI (Appendix II).

3.3.2 Assessment of the Ploidy Level

The ploidy level of the collected accessions were ascertained by counting the chromosome number.

About 2 mm of the root tip from the germinated seeds was separated and were pretreated in a solution of two parts of colchicine and one part of hydroxy quinoline and kept at 5°C for 2-3 hours. After thorough washing, the root tips were fixed in Carnoy's solution (six parts of ethyl alcohol : one part of acetic acid : three parts of chloroform) for 24 hours. The root tips were hydrolysed in 1 *N* hydrochloric acid for 5-10 minutes. After proper washing, the root tips were placed on to a clean glass slide. A fresh drop of two percentage of acetocarmine stain was added. Then warmed the slide and placed the cover slip over the root tip and tapped with the needle to spread the tissue. After it was flattened uniformly, squashed with the tip of the right thumb giving pressure. This prepared slide was observed under 10 × 100X of the microscope. Chromosome counting was done at the metaphase stage.

RESULTS

4. RESULTS

Thirty two diverse accessions of *Amaranthus dubius* Mart. ex Thell. were evaluated in the field during 2000-2002 for biometric characters, quality characters and reaction towards biotic stresses. The data were statistically analysed for variability, heritability, correlation and path analysis. The selection indices were also worked out to locate superior genotypes. The results were presented hereunder:

4.1 MEAN PERFORMANCE OF THE ACCESSIONS

Performance of the accessions in terms of growth characters, yield characters, quality characters and reaction towards the incidence of various biotic stresses are presented in the Tables 3, 4, 5 and 6.

4.1.1 Growth Characters

Variability was observed among the accessions for the growth characters like plant height, stem girth, length of leaf lamina, leaf width, petiole length, number of branches and days to 50 per cent bolting. The plant height was maximum in AD 22 (58.20 cm) and was minimum in AD 3 (32.93 cm). The highest stem girth was also observed in AD 22 (5.91 cm). The accession AD 32 had the least stem girth (2.49 cm).

As amaranthus is a leafy vegetable, the leaf size is very important. The accession AD 21 possessed longest leaf lamina (19.68 cm) whereas AD 6 the shortest (7.73 cm). But the leaf width was maximum in AD 22 (13.02 cm) and minimum in AD 20. The petiole length was maximum in AD 7 (8.75 cm) and minimum in AD 26 (5.14 cm).

The accession AD 11 had the highest number of branches per plant (8.59) followed by AD 14 (8.43). Days to 50 per cent bolting is important as bolting stops further vegetative growth. So late bolting types are

Table 3 Mean performance of *Amaranthus dubius* accessions in terms of growth characters

Accessions	Plant height, cm	Stem girth, cm	Length of leaf lamina, cm	Leaf width, cm	Petiole length, cm	No. of branches	Days to 50 % bolting
AD 1	36.12	4.43	13.51	9.42	7.51	6.30	51.53
AD 2	38.09	4.36	9.45	9.52	8.47	6.92	58.30
AD 3	32.93	3.47	13.08	9.74	6.82	5.93	47.80
AD 4	35.73	3.68	11.60	8.11	7.07	7.94	48.07
AD 5	32.99	4.22	13.10	11.41	6.74	5.99	61.67
AD 6	36.12	3.41	7.73	6.39	5.68	6.92	49.40
AD 7	40.68	4.33	14.50	10.09	8.75	7.27	54.20
AD 8	53.39	5.28	12.50	9.59	8.50	7.70	59.30
AD 9	35.98	4.31	12.19	8.00	6.51	6.63	60.00
AD 10	39.11	4.45	11.60	9.58	7.04	6.76	65.63
AD 11	54.14	3.05	12.28	6.49	6.40	8.59	54.53
AD 12	38.22	4.45	14.11	8.07	6.15	6.10	71.13
AD 13	41.88	5.02	14.71	9.31	7.10	7.17	61.00
AD 14	51.00	4.22	12.48	7.21	6.60	8.43	50.33
AD 15	46.22	4.41	14.63	9.11	7.13	7.03	48.80
AD 16	41.57	5.29	11.50	6.40	6.50	6.63	61.60
AD 18	46.45	5.45	14.06	9.08	6.08	5.13	54.13
AD 19	41.03	5.73	15.35	8.69	6.55	4.00	52.67
AD 20	36.84	2.77	13.85	5.75	5.81	6.97	52.13
AD 21	49.08	5.27	19.68	12.47	8.23	4.24	59.00
AD 22	58.20	5.91	19.30	13.02	6.69	7.60	66.00
AD 23	55.68	5.70	14.28	9.28	5.47	6.23	73.00
AD 24	34.39	4.21	10.96	6.52	6.25	5.07	60.93
AD 25	43.57	3.27	12.39	10.17	8.08	4.83	53.67
AD 26	36.92	4.46	14.00	8.64	5.14	6.50	72.47
AD 28	57.19	5.28	14.24	7.43	6.06	5.57	61.61
AD 29	52.36	2.97	14.03	10.20	7.50	6.33	60.00
AD 30	48.77	4.61	15.06	11.07	8.06	5.80	62.13
AD 31	44.92	3.13	10.99	8.53	7.03	5.11	51.73
AD 32	37.49	2.49	16.34	10.69	5.43	4.70	64.00
AD 33	44.52	4.70	9.50	6.80	5.40	7.07	58.40
AD 34	44.67	4.04	14.18	10.17	8.07	4.64	75.13
CD (0.05)	1.989	0.358	0.168	0.246	0.115	0.602	1.253

Table 4 Mean performance of *Amaranthus dubius* accessions in terms of yield characters

Accessions	Leaf/ stem ratio (1st cutting)	Leaf/ stem ratio (2nd cutting)	Leaf/ stem ratio (3rd cutting)	Total leaf/stem ratio	Yield (1st cutting), g plant^{-1}	Yield (2nd cutting), g plant^{-1}	Yield (3rd cutting), g plant^{-1}	Total yield, g plant^{-1}	Total leaf weight, g plant^{-1}	Total stem weight, g plant^{-1}
AD 1	2.33	2.07	2.77	2.35	66.67	50.50	47.17	164.50	115.48	48.99
AD 2	1.66	1.41	1.58	1.49	160.70	105.00	86.45	352.12	213.88	143.56
AD 3	2.10	2.04	2.00	2.04	66.50	60.33	55.70	182.76	122.48	60.19
AD 4	1.04	1.07	1.81	1.18	100.00	57.77	44.00	201.00	109.31	92.55
AD 5	1.83	1.93	2.07	2.15	98.00	95.33	84.36	277.00	183.07	85.96
AD 6	1.26	2.51	2.79	1.94	80.00	64.00	48.30	192.30	127.10	65.25
AD 7	1.59	1.70	2.60	1.81	146.33	98.30	75.00	320.00	206.00	114.00
AD 8	0.84	1.09	2.16	1.08	195.00	125.76	8.80	401.00	209.16	191.84
AD 9	1.35	1.71	1.93	1.61	95.77	92.03	68.85	256.50	158.23	98.33
AD 10	1.31	1.85	2.00	1.63	67.00	56.00	42.50	165.60	102.73	62.80
AD 11	0.84	0.97	1.04	0.93	190.67	135.77	89.30	415.00	201.23	215.71
AD 12	1.27	1.39	1.70	1.41	96.66	79.33	61.70	237.00	139.01	98.71
AD 13	1.62	2.63	2.77	2.06	91.82	74.10	68.60	234.40	156.38	76.39
AD 14	0.88	0.96	2.05	1.08	171.77	100.00	80.65	352.30	183.28	169.04
AD 15	2.00	1.87	3.75	2.28	61.42	57.85	45.30	169.12	114.63	50.22
AD 16	1.03	1.56	2.68	1.57	101.70	74.89	64.24	240.80	143.90	91.52
AD 18	1.14	2.42	3.13	1.82	160.00	125.9	100.30	386.13	250.04	137.75
AD 19	1.21	1.56	2.27	1.46	108.33	55.67	43.94	211.61	123.60	84.29
AD 20	0.94	1.94	2.03	1.32	96.33	47.87	39.19	183.39	104.00	78.98
AD 21	1.08	2.40	2.86	1.78	163.00	128.00	109.00	401.33	256.86	144.42
AD 22	1.14	2.60	2.86	1.77	186.70	151.27	69.00	407.18	259.90	147.28
AD 23	1.08	2.21	3.75	1.78	190.00	144.33	111.20	445.00	285.60	159.97
AD 24	1.37	1.92	2.70	1.73	95.00	51.24	42.30	188.00	119.59	68.90
AD 25	1.17	1.85	2.84	1.57	193.33	118.08	71.00	382.00	232.54	148.40
AD 26	0.98	2.13	3.77	1.62	198.00	120.97	86.00	405.30	240.33	148.30
AD 28	1.21	1.72	2.60	1.58	124.76	88.19	61.38	274.24	167.95	106.00
AD 29	1.93	2.60	2.83	2.33	151.33	126.23	88.00	366.23	256.60	109.80
AD 30	1.34	2.66	2.55	2.22	196.75	152.80	115.00	464.80	306.28	141.71
AD 31	1.17	1.92	1.97	1.60	133.23	91.65	51.90	276.90	176.92	110.35
AD 32	1.61	2.58	2.51	2.04	73.45	50.97	41.10	165.40	111.13	54.3.00
AD 33	1.34	2.35	3.42	1.91	116.00	67.33	54.00	238.00	154.57	80.76
AD 34	1.87	3.34	3.73	2.48	80.00	41.47	34.47	155.90	110.72	45.21
CD (0.05)	0.241	0.273	0.251	0.303	9.897	7.081	7.435	18.732	14.345	14.837

Table 5 Mean performance of *Amaranthus dubius* accessions in terms of quality characters

Accessions	Protein, %	Fibre, %	Vitamin A, I.U.	Oxalate, %	Nitrate, %
AD 1	16.03	10.49	5000.65	3.01	0.25
AD 2	18.07	8.33	4331.50	1.13	0.55
AD 3	14.00	11.81	5680.25	3.85	0.85
AD 4	10.60	15.03	6376.18	2.79	0.66
AD 5	10.08	11.00	7424.39	2.30	0.89
AD 6	16.23	8.61	8244.75	0.73	0.45
AD 7	15.21	14.50	4882.78	1.65	0.95
AD 8	9.03	12.37	8915.96	0.85	0.74
AD 9	13.47	8.19	7565.25	0.87	0.75
AD 10	17.43	10.53	4807.13	1.71	0.84
AD 11	19.67	13.97	5113.48	2.82	0.81
AD 12	17.00	15.70	5310.70	0.91	0.34
AD 13	21.33	10.16	6002.05	3.30	0.76
AD 14	14.00	11.06	7504.78	1.67	0.54
AD 15	22.50	6.24	8016.77	0.88	0.97
AD 16	23.00	13.41	6812.61	3.06	0.85
AD 18	15.20	10.77	5400.52	0.96	0.64
AD 19	16.40	14.59	6627.63	3.60	0.80
AD 20	21.03	15.25	5974.75	0.95	0.54
AD 21	21.3	11.82	8231.04	2.64	0.86
AD 22	21.4	7.98	5340.29	1.54	0.67
AD 23	17.97	13.88	8346.54	0.62	0.95
AD 24	13.7	6.80	5423.66	0.81	0.82
AD 25	10.23	12.73	5043.97	2.33	0.76
AD 26	15	11.82	6908.42	1.29	0.95
AD 28	16	5.67	5329.90	0.86	0.44
AD 29	18.67	13.49	8393.60	0.76	0.96
AD 30	10	10.30	6545.14	1.04	1.09
AD 31	17.36	15.70	7763.54	0.80	0.53
AD 32	13	11.89	6245.55	2.45	0.73
AD 33	12.33	14.57	8548.66	3.19	0.47
AD 34	17.17	13.60	7438.18	0.67	0.55
CD (0.05)	1.747	2.314	8.128	0.533	0.056

Table 6 Mean performance of *Amaranthus dubius* accessions in terms of reaction towards white rust and leaf webber

Accessions	White rust (PDI)	Leaf webber (average score)
AD 1	18.06 (4.37)	1.39 (1.55)
AD 2	9.74 (3.28)	1.88 (1.69)
AD 3	12.75 (3.71)	1.00 (1.41)
AD 4	17.97 (4.35)	1.00 (1.41)
AD 5	21.84 (4.77)	1.00 (1.41)
AD 6	5.77 (2.60)	1.00 (1.41)
AD 7	8.48 (3.08)	1.8 (1.66)
AD 8	7.66 (2.94)	1.73 (1.64)
AD 9	17.67 (4.32)	1.93 (1.71)
AD 10	9.92 (3.30)	1.00 (1.41)
AD 11	24.61 (5.06)	3.00 (1.99)
AD 12	12.87 (3.72)	2.13 (1.76)
AD 13	26.53 (5.24)	1.00 (1.41)
AD 14	0.00 (1.00)	2.17 (1.77)
AD 15	7.00 (2.83)	1.00 (1.41)
AD 16	0.00 (.001)	1.00 (1.41)
AD 18	8.12 (3.02)	2.00 (1.73)
AD 19	14.47 (3.93)	1.47 (1.56)
AD 20	27.21 (5.31)	2.27 (1.80)
AD 21	22.9 (4.88)	1.73 (1.63)
AD 22	11.8 (3.58)	2.13 (1.76)
AD 23	14.89 (3.98)	1.00 (1.41)
AD 24	20.11 (4.59)	1.00 (1.41)
AD 25	21.56 (4.75)	1.20 (1.48)
AD 26	8.14 (3.02)	1.13 (1.46)
AD 28	0.00 (1.00)	1.40 (1.55)
AD 29	26.91 (5.28)	1.00 (1.41)
AD 30	23.14 (4.91)	1.00 (1.41)
AD 31	19.38 (4.51)	1.00 (1.41)
AD 32	11.55 (3.54)	1.00 (1.41)
AD 33	22.84 (4.88)	1.00 (1.41)
AD 34	29.39 (5.51)	1.00 (1.41)
CD (0.05)	1.058	0.149

Figures in parenthesis are square root transformed values

preferred. In the present study AD 34 showed late bolting (75.13 days) and AD 3 showed early bolting (47.80 days).

4.1.2 Yield Characters

Leaf / stem ratio is one of the most important yield attributing factor. The highest total leaf / stem ratio was observed in AD 34 (2.48), followed by AD 1, AD 29, AD 15 and AD 30 respectively. The lowest ratio was observed in AD 11 (0.93). However, the highest leaf / stem ratio for each cuttings were observed in AD 1, AD 34 and AD 26 respectively and the least value were observed in AD 8, AD 14 and AD 11 respectively.

The yield obtained in the three cuttings were added to obtain the total yield. The highest total yield was obtained from AD 30 (464.80 g) followed by AD 23 (445.00 g), AD 11 (415.00 g) and AD 22 (407.18 g). AD 34 (155.94g) was the lowest yielder. In the first cutting AD 26 was the highest yielder and AD 15 was the lowest yielder. But in the subsequent cuts, AD 30 and AD 34 were the highest and lowest yielders respectively. The total leaf weight was also highest in AD 30 and AD 10 had the lowest leaf weight. In the case of total stem weight, AD 11 had the highest and AD 34 had the lowest.

4.1.3 Quality Characters

The quality attributes considered in the present study were protein, fibre, vitamin A, oxalate, nitrate and organoleptic qualities.

The protein content was maximum in AD 16 (23.00 per cent) followed by AD 15 (22.50 per cent). The minimum protein content was observed in AD 8 (9.03 per cent). The highest fibre content noticed was 15.70 per cent (AD 12) and lowest was 5.67 per cent (AD 28). The vitamin A content was maximum in AD 8 (8915. 96 I.U.) and AD 33 had 8548.66 I.U. AD 2 contained the minimum, 4331.50 I.U.

The antinutrient factors oxalates and nitrates are of much concern. The least oxalate contents were noticed in AD 23 (0.62 per cent) and AD

34 (0.67 per cent). The highest values were recorded in AD 3 (3.85) and AD 19 (3.60 per cent). In the case of nitrate, the highest value was 1.09 per cent (AD 30) and the lowest value was 0.25 per cent (AD 1).

The quality attributes considered under organoleptic evaluation were colour, doneness, tenderness, odour and taste. The accessions showed significant difference for all these attributes. The accession AD 34 (22.60) was organoleptically superior than others based on the score and the lowest score was obtained for AD 28 (12.80). Organoleptic score of the 32 accessions are presented in Fig. 1.

4.1.4 Biotic stress

Leaf blight, white rust and leaf webber were the major biotic stresses observed in the amaranthus field.

In the present study, all the accessions of *A. dubius* were completely free from the natural infection by *Rhizoctonia solani* Kühn. But the disease seriously damaged the susceptible check 'Arun' (*A. tricolor*) and the PDI was 68.10 (Plate 3).

On screening under artificial epiphytotic conditions, out of the 32 accessions, 14 were totally free of any symptoms. Hence these could be designated as immune to Rhizoctonia leaf blight. Fifteen accessions had a PDI of 4.15 to 9.85 and were highly resistant. The remaining three accessions, AD 22, AD 31 and AD 33 were moderately resistant with PDI 10.48, 19.62 and 15.47 respectively. In this screening, the variety 'Arun' showed severe foliar blight with a PDI of 70.03. This variety could be designated as highly susceptible (Table 7).

The white rust infection was noticed in all the accessions except AD 14, AD 16 and AD 28. The PDI was highest in AD 34 (29.39) and was lowest in AD 6 (5.77) (Plate 4).

Leaf webber infestation was observed in all the accessions (Plate 5). Based on the percentage of number of leaves infested by the leaf webber,

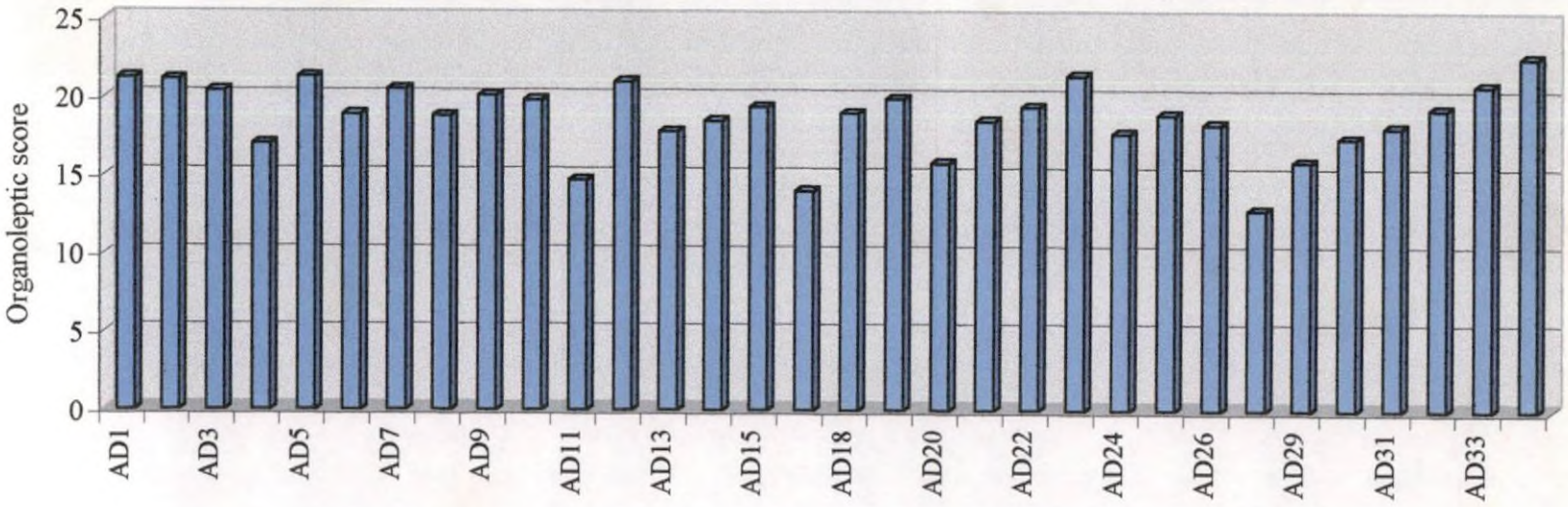


Fig. 1 Score obtained in the organoleptic evaluation of *Amaranthus dubius* accessions

Table 7 Percentage Disease Index (PDI) of *Amaranthus dubius* accessions and the susceptible check 'Arun' under artificial screening for leaf blight

Sl. No.	Accession	PDI
1	AD 1	4.74 (2.39)
2	AD 2	8.46 (3.07)
3	AD 3	9.06 (3.17)
4	AD 4	0.00 (1.00)
5	AD 5	0.00 (1.00)
6	AD 6	0.00 (1.00)
7	AD 7	0.00 (1.00)
8	AD 8	0.00 (1.00)
9	AD 9	0.00 (1.00)
10	AD 10	0.00 (1.00)
11	AD 11	5.40 (2.52)
12	AD 12	0.00 (1.00)
13	AD 13	0.00 (1.00)
14	AD 14	8.95 (3.15)
15	AD 15	4.15 (2.27)
16	AD 16	5.31 (2.51)
17	AD 18	6.21 (2.68)
18	AD 19	7.08 (2.84)
19	AD 20	8.17 (3.02)
20	AD 21	8.13 (3.02)
21	AD 22	10.48 (3.38)
22	AD 23	0.00 (1.00)
23	AD 24	4.78 (2.40)
24	AD 25	0.00 (1.00)
25	AD 26	0.00 (1.00)
26	AD 28	0.00 (1.00)
27	AD 29	6.98 (2.82)
28	AD 30	9.31 (3.21)
29	AD 31	19.62 (4.54)
30	AD 32	0.00 (1.00)
31	AD 33	15.47 (4.05)
32	AD 34	9.85 (3.29)
33	Arun	70.03 (8.42)
CD (0.05)		0.898

Figures in parenthesis are square root transformed values

(A) Symptom in Arun under field screening

(B) Symptom in AD 31 under artificial screening

Plate 3. Symptom of leaf blight caused by *Rhizoctonia solani*

(A) Lower surface

(B) Upper surface

Plate 4. Symptom of white rust caused by *Albugo blitii*

Plate 5. Symptom of leaf webber infestation

score was given. The accession AD 11 (3.00) had maximum infestation followed by AD 20 (2.27), AD 14 (2.17), AD 22 (2.13) and AD 18 (2.00). Sixteen accessions had mild infestation with their score 1.00.

4.2 GENETIC VARIABILITY, HERITABILITY AND GENETIC ADVANCE

The population mean, range, genotypic coefficients of variation (GCV) and phenotypic coefficients of variation (PCV), heritability, genetic advance and genetic gain (as percentage of mean) for the 24 characters were studied and presented in the Table 8.

4.2.1 Growth Characters

Plant height ranged from 32.93 to 58.20 cm with a mean of 43.32 cm. The character had a GCV of 17.15 and PCV of 17.38. The heritability was 97.38 per cent and the genetic gain as percentage of mean was 34.87.

Stem girth of the accessions ranged from 2.49 to 5.91 cm. The overall mean was 4.32 cm. It recorded a GCV of 20.94 and PCV of 21.54. The heritability recorded was 94.45 per cent and the genetic gain as percentage of mean was 41.92.

The mean length of leaf lamina was 13.35 cm. It recorded a range of 7.73 – 19.68 cm. This character had high heritability 99.82 per cent. The values for GCV and PCV were 18.44 and 18.46 respectively. The genetic gain as percentage of mean was 37.97.

Leaf width ranged from 5.75 to 13.02 cm and overall mean was 8.97 cm. The GCV and PCV were 19.85 and 19.92 respectively. This also possessed high heritability 99.28 per cent. The genetic gain as percentage of mean was 40.75.

The range of petiole length was 5.14 to 8.75 cm and mean was 6.84 cm. The heritability recorded was 99.49 per cent which was very high. GCV and PCV were 14.48 and 14.58. The genetic gain as percentage of mean was 29.73.

Table 8 Range, mean, PCV, GCV, heritability, genetic advance and genetic gain as percentage of mean in *Amaranthus dubius* for important characters

Characters	Range	Mean ± SE	PCV	GCV	Heritability	Genetic advance	Genetic gain (as % of mean)
Plant height, cm	32.93 – 58.20	43.32 ± 0.703	17.38	17.15	97.38	15.10	34.87
Stem girth, cm	2.49 – 5.91	4.32 ± 0.126	21.54	20.94	94.45	1.81	41.92
Length of leaf lamina, cm	7.73 – 19.68	13.35 ± 0.059	18.46	18.44	99.82	5.07	37.97
Leaf width, cm	5.75 – 13.02	8.97 ± 0.087	19.92	19.85	99.28	3.65	40.75
Petiole length, cm	5.14 – 8.75	6.84 ± 0.041	14.58	14.48	99.49	2.03	29.73
Number of branches	4.00 – 8.59	6.32 ± 0.212	19.24	18.33	90.80	2.27	35.99
Days to 50 % bolting	47.80 – 75.13	58.76 ± 0.440	12.82	12.75	98.96	15.36	26.14
Leaf/stem ratio (1st cutting)	0.84 – 2.33	1.36 ± 0.085	29.86	27.83	86.85	0.73	53.43
Leaf/stem ratio (2nd cutting)	0.96 – 3.34	1.97 ± 0.096	29.25	27.99	91.59	1.08	55.25
Leaf/stem ratio (3rd cutting)	1.04 – 3.77	2.55 ± 0.088	27.01	26.33	95.03	1.34	52.87
Total leaf/stem ratio	0.93 – 2.48	1.74 ± 0.107	24.08	21.59	80.39	0.69	39.88

Table 8 Continued

Characters	Range	Mean ± SE	PCV	GCV	Heritability	Genetic advance	Genetic gain (as % of mean)
Yield (g) (1st cutting)	61.42 – 198.00	126.77 ± 3.500	36.97	36.66	98.32	94.93	74.88
Yield (g) (2nd cutting)	41.47 – 152.80	90.29 ± 2.500	37.98	37.68	98.40	69.52	76.99
Yield (g) (3rd cutting)	34.47 – 115.00	67.59 ± 2.630	34.26	33.59	96.13	45.87	67.85
Total yield, g	155.94 – 464.80	284.91 ± 6.620	34.81	34.58	98.66	201.61	70.76
Total leaf weight, g	102.73 – 306.28	176.34 ± 5.070	34.28	33.91	97.88	121.90	69.12
Total stem weight, g	45.21 – 215.71	107.24 ± 5.240	41.64	40.77	95.86	88.20	82.25
Protein, %	9.03 – 23.00	16.09 ± 0.617	24.46	23.54	92.61	7.51	46.67
Fibre, %	5.67 – 15.70	11.63 ± 0.816	26.21	23.21	78.46	4.93	42.36
Vitamin A, I.U.	4331.50 – 8915.96	6548.46 ± 2.870	20.3959	20.3958	99.99	2751.33	42.01
Oxalate, %	0.62 – 3.85	1.75 ± 0.188	60.13	57.17	90.40	1.96	111.90
Nitrate, %	0.25 – 1.09	0.72 ± 0.019	28.58	28.17	97.18	0.41	57.22
White rust	0.00 – 29.39	15.10 ± 0.374	61.88	50.80	67.41	13.23	87.66
Leaf webber	1.00 – 3.00	1.42 ± 0.053	41.77	35.71	73.07	0.89	62.88

The mean number of branches per plant was 6.32 and the range was 4.00-8.59. The GCV was 18.33 and PCV was 19.24. The heritability was 90.80 per cent. The genetic gain as percentage of mean was 35.99.

Days to 50 per cent bolting ranged from 47.80 to 75.13 days. The general mean was 58.76. The GCV was 12.75 and PCV was 12.82. The heritability was high and was 98.96 per cent. The genetic grain as percentage of mean was 26.14.

4.2.2 Yield Characters

In the first cutting the leaf / stem ratio range and overall mean were 0.84 to 2.33 and 1.36 respectively. The GCV was 27.83 and PCV was 29.86. The heritability was 86.85 per cent. The genetic gain as percentage of mean was 53.43.

The range was 0.96 – 3.34 and mean was 1.97 in the second cutting. The GCV was 27.99 and PCV was 29.25. The heritability was 91.59 per cent. The genetic gain as percentage of mean was 55.25.

In the third cutting the range was 1.04 – 3.77 and the overall mean was 2.55. The GCV and PCV were 26.33 and 27.01. This had high heritability compared to first and second cutting and heritability was 95.03 per cent. The genetic gain as percentage of mean was 52.87.

As for as the total leaf / stem ratio, the range was 0.93 to 2.48 and the overall mean was 1.74. The GCV was 21.59 and the PCV was 24.08. The heritability was low and was 80.39 per cent. The genetic gain as percentage of mean was 39.88.

Yield in the first cutting ranged from 61.42 to 198.00 g and the general mean was 126.77 g. The GCV was 36.66 and the PCV was 36.97. The heritability percentage was 98.32. The genetic gain as percentage of mean was 74.88.

In the second cutting yield ranged from 41.47 to 152.80 g and the general mean was 90.29 g. The GCV and PCV were 37.68 and 37.98

respectively. The heritability percentage of mean was 98.40. The genetic gain as percentage of mean was 76.99.

The range was 34.47 to 115.00 g in the third cutting. The overall mean was 67.59 g. The GCV was 33.59 and PCV was 34.26. The heritability percentage was 96.13 and was less than that of second and third cutting., The genetic gain as percentage of mean was 67.85.

The total yield ranged from 155.94 to 464.80 g and the overall mean was 284.91 g. The GCV and PCV were 34.58 and 34.81 respectively. This possessed high heritability and the percentage was 98.66. The genetic gain as percentage of mean was 70.76.

The total leaf weight ranged from 102.73 to 306.28 g and the overall mean was 176.34 g. The GCV and PCV were 33.91 and 34.28 respectively. The heritability percentage was 97.88. The genetic gain as percentage of mean was 69.12.

: Total stem weight ranged from 45.21 to 215.71 g. The mean was 107.24. The GCV was 40.77 and PCV was 41.64. The heritability was 95.86 per cent. The genetic gain as percentage of mean was 82.25.

4.2.3 Quality Characters

The protein percentage ranged from 9.03 to 23.00 and the overall mean was 16.09. The GCV and PCV were 23.54 and 24.46. The heritability percentage was 92.61 and the genetic gain as percentage of mean was 46.67.

In the case of fibre, the range was 5.67 to 15. 70 per cent and the overall mean was 11.63 per cent. The GCV was 23.21 and PCV was 26.21. The heritability was low and was 78.46 per cent. The genetic gain as percentage of mean was 42.36.

The vitamin A ranged from 4331.50 to 8915.96 I.U. with a mean of 6548.46 I.U. The GCV was 20.3958 and PCV was 20.3959. The

heritability was very high 99.99 per cent. The genetic gain as percentage of mean was 42.01.

The oxalate content ranged from 0.62 to 3.85 per cent and the overall mean was 1.75. The GCV and PCV were 57.17 and 60.13. The heritability percentage was 90.40. The genetic gain as percentage of mean was 111.90.

The nitrate content ranged from 0.25 to 1.09 per cent. The overall mean was 0.72. The GCV was 28.17 and the PCV was 28.58. The heritability percentage was 97.18 per cent. The genetic gain as percentage of mean was 57.22.

4.2.4 Biotic Stress

Leaf blight was not observed in any of the *A. dubius* accessions studied. The percentage disease index of white rust ranged from 0.00 to 29.39. The overall mean was 15.10. The heritability was 67.41 per cent. The GCV and PCV were 50.80 and 61.88 respectively. The genetic gain as percentage of mean was 87.66.

Leaf webber infestation range was 1.00 – 3.00 and the mean was 1.42. The heritability percentage was 73.07. The GCV and PCV were 35.71 and 41.77 respectively. The genetic gain as percentage of mean was 62.88.

4.3 CORRELATION STUDIES

The phenotypic, genotypic and environmental correlation among 24 characters were worked out and presented in Table 9, 10 and 11.

4.3.1 Phenotypic Correlation Coefficients

Plant height had high positive correlation with total yield (0.6256). It was also highly correlated to total stem weight (0.6080), total leaf weight (0.5875) and yield at first and second cutting (0.6229 and 0.6428). Plant height had a positive correlation with other quantitative characters

1 Plant height, cm

2 Stem girth, cm

3 Length of leaf lamina, cm

4 Leaf width, cm

5 Petiole length, cm

6 Number of branches

7 Days to 50 % bolting

8 Leaf/stem ratio (1st cutting)

9 Leaf/stem ratio (2nd cutting)

10 Leaf/stem ratio (3rd cutting)

11 Total leaf/stem ratio

12 Yield (g) (1st cutting)

13 Yield (g) (2nd cutting)

14 Yield (g) (3rd cutting)

15 Total yield, g

16 Total leaf weight, g

17 Total stem weight, g

18 Protein, %

19 Fibre, %

20 Vitamin A, I.U.

21 Oxalate, %

22 Nitrate, %

23 White rust

24 Leaf webber

Table 9 Phenotypic correlation coefficients in *Amaranthus dubius* for important characters

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
1	1																							
2	0.3648	1																						
3	0.3759	0.3249	1																					
4	0.1968	0.2210	0.6608	1																				
5	0.1134	0.0463	0.1334	0.5048	1																			
6	0.1547	-0.0438	-0.286	-0.2865	-0.0253	1																		
7	0.1830	0.3097	0.2871	0.2645	-0.1559	-0.1966	1																	
8	-0.3347	-0.1839	0.0382	0.326	0.2586	-0.1986	-0.0692	1																
9	0.0348	0.0084	0.321	0.4152	-0.0561	-0.4342	0.3638	0.4122	1															
10	0.196	0.3274	0.2449	0.1962	-0.1482	-0.2741	0.3357	0.1792	0.6293	1														
11	-0.1400	-0.0146	0.2010	0.4202	0.1099	-0.3589	0.1746	0.7848	0.7826	0.5362	1													
12	0.6229	0.2362	0.2019	0.23	0.1827	0.1606	0.1773	-0.5314	-0.1361	0.0445	-0.3518	1												
13	0.6428	0.2956	0.3135	0.4015	0.1868	0.1555	0.222	-0.3663	-0.0126	0.0391	-0.161	0.9032	1											
14	0.4674	0.3213	0.2653	0.3518	0.193	0.0771	0.2074	-0.2436	-0.0115	0.0551	-0.0662	0.7686	0.8862	1										
15	0.6256	0.2915	0.2674	0.3296	0.1962	0.1467	0.2060	-0.4328	-0.0726	0.0494	-0.2364	0.9618	0.9768	0.9004	1									
16	0.5875	0.3108	0.3352	0.4599	0.2186	0.0069	0.2581	-0.2532	0.1544	0.2003	0.0117	0.883	0.958	0.9047	0.9571	1								
17	0.608	0.1995	0.1177	0.0924	0.1565	0.3132	0.0748	-0.6221	-0.3905	-0.1945	-0.5881	0.9219	0.85	0.7442	0.9008	0.7476	1							
18	0.2263	0.1461	0.2818	-0.0695	-0.0732	0.072	0.0811	0.0297	0.15	0.1328	0.0801	-0.1398	-0.0458	-0.0561	-0.0933	-0.0608	-0.1013	1						
19	-0.0552	-0.2252	-0.0189	-0.0994	0.0064	-0.0136	0.0174	-0.2109	-0.0122	-0.1559	-0.228	0.1213	-0.0154	0.001	0.0510	-0.0037	0.1313	-0.0661	1					
20	0.2275	0.0552	-0.0439	-0.0114	-0.1081	-0.0045	0.0471	-0.0996	0.1805	0.3666	0.1471	0.0658	0.100	0.142	0.1004	0.1281	0.0352	-0.0659	0.138	1				
21	-0.2499	0.029	0.0874	0.0589	-0.0023	-0.0091	-0.3134	0.1345	-0.1235	-0.1789	-0.0376	-0.2085	-0.2415	-0.1382	-0.2137	-0.2477	-0.1431	-0.0090	0.2346	-0.1808	1			
22	0.0993	0.0947	0.2914	0.3471	0.1748	-0.0603	0.1292	-0.0214	0.0825	0.1764	0.1387	0.2848	0.3732	0.4245	0.3648	0.4041	0.2040	0.0001	-0.0158	0.01653	0.0536	1		
23	-0.0863	-0.2922	0.1101	0.155	0.1582	-0.1715	0.0768	0.1807	0.3494	-0.000	0.2384	-0.0318	-0.0199	-0.0089	-0.0258	0.033	-0.1022	-0.0132	0.2602	0.0803	0.1366	0.0831	1	
24	0.2523	0.0485	0.1604	-0.1324	0.0308	0.3348	-0.11	-0.349	-0.3809	-0.4357	-0.4943	0.3509	0.3179	0.2278	0.3275	0.1791	0.5118	0.1751	0.0751	-0.2932	-0.0693	-0.2262	-0.0574	1

Table 10 Genotypic correlation coefficients in *Amaranthus dubius* for important characters

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
1	1																							
2	0.3812	1																						
3	03815	0.3358	1																					
4	0.2004	0.2249	0.664	1																				
5	0.1151	0.0471	0.1336	0.5083	1																			
6	0.1634	-0.0519	-0.301	-0.3101	-0.0261	1																		
7	0.1884	0.3175	0.2894	0.2676	-0.1585	-0.2053	1																	
8	-0.3684	-0.1946	0.0393	0.3527	0.2823	-0.2229	-0.0736	1																
9	0.0354	0.0119	0.3369	0.4349	-0.0524	-0.4829	0.3869	0.4071	1															
10	0.2023	0.3329	0.2517	0.2003	-0.1524	-0.2924	0.3457	0.2052	0.6634	1														
11	-0.1527	-0.0262	0.2251	0.4721	0.1272	-0.4292	0.186	0.8191	0.836	0.6239	1													
12	0.6367	0.2499	0.2025	0.2309	0.1846	0.1584	0.1806	-0.5727	-0.1485	0.0444	-0.3965	1												
13	0.6564	0.3063	0.3146	0.4058	0.1888	0.1536	0.227	-0.3985	-0.0172	0.0364	-0.1887	0.9093	1											
14	0.4788	0.3413	0.2697	0.3593	0.1944	0.0791	0.2069	-0.266	0.0046	0.0597	-0.0702	0.7849	0.9032	1										
15	0.6376	0.3039	0.268	0.3318	0.1971	0.1442	0.2085	-0.467	-0.076	0.0492	-0.267	0.964	0.9797	0.9099	1									
16	0.6005	0.3267	0.3378	0.467	0.2206	0.001	0.2607	-0.2914	0.1482	0.2043	-0.0177	0.888	0.9637	0.9196	0.961	1								
17	0.6256	0.2157	0.118	0.0938	0.1568	0.3284	0.0793	-0.6498	-0.395	-0.2112	-0.5936	0.9372	0.8686	0.7594	0.9145	0.7675	1							
18	0.2411	0.1635	0.2945	-0.0716	-0.0754	0.0894	0.0829	0.0255	0.174	0.1492	0.0826	-0.1357	-0.0343	-0.0476	-0.084	-0.0533	-0.0903	1						
19	-0.0621	-0.2668	-0.0203	-0.1091	-0.0029	-0.033	0.0192	-0.2568	-0.1339	-0.1697	-0.2619	0.1185	-0.0234	-0.0148	0.0429	-0.0106	0.1228	-0.0615	1					
20	0.2306	0.0566	-0.0439	-0.0115	-0.1084	-0.0046	0.0475	-0.1068	0.1884	0.376	0.1638	0.0664	0.1008	0.145	0.1011	0.1295	0.036	-0.0686	0.1557	1				
21	-0.2571	0.0292	0.0936	0.057	-0.0011	-0.0018	-0.3276	0.1534	-0.1356	-0.1971	-0.0174	-0.2262	-0.2479	-0.1474	-0.2248	-0.2598	-0.1667	-0.0194	0.2707	-0.1902	1			
22	0 1015	0.0906	0.2961	0.352	0.1788	-0.0708	0.1323	-0.019	0.0855	0.1781	0.1431	0.291	0.3808	0.4361	0.3717	0.4133	0.2149	-0.01	-0.0236	0.1676	0.0569	1		
23	-0 1069	-0.3597	0.13	0.1909	0.1952	-0.2488	0.1017	0.2422	0.4302	-0.0248	0.3235	-0.0395	-0.0177	0.0091	-0.0237	0.0509	-0.121	-0.0156	0.3978	0.0983	0.1221	0.0953	1	
24	0.3021	0.0479	0.1873	-0.1489	0.0463	0.3959	-0.1284	-0.4544	-0.5015	-0.5286	-0.6735	0.3948	0.3546	0.2711	0.3704	0.1897	0.6086	0.2248	0.0791	-0.3434	-0.0884	-0.2576	-0.077	1

Table 11 Error correlation coefficients in *Amaranthus dubius for important characters*

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
1	1																							
2	-0.02	1																						
3	-0.0371	-0.1182	1																					
4	-0.0226	0.1632	-0.0627	1																				
5	0.0066	0.0417	0.0736	-0.0563	1																			
6	0.0217	0.0607	0.0433	0.3101	-0.0236	1																		
7	-0.1189	0.1167	-0.1178	-0.0876	0.1875	-0.064	1																	
8	0.0692	-0.0885	0.1061	-0.0479	-0.1486	-0.0053	-0.026	1																
9	0.0303	-0.0391	-0.0982	0.02	-0.2942	0.0709	-0.1545	0.467	1															
10	0.0381	0.2282	-0.0179	0.0872	-0.0011	-0.0368	0.0197	-0.0901	0.1604	1														
11	-0.0678	0.0792	-0.0329	-0.0413	-0.1217	0.0583	0.1921	0.6248	0.5080	-0.0919	1													
12	-0.0064	-0.1528	0.2305	0.1645	0.0097	0.2797	-0.0635	-0.047	0.1286	0.0539	0.0134	1												
13	0.0146	0.0103	0.3244	0.0345	-0.0087	0.2703	-0.1559	0.0456	0.1012	0.1360	0.1208	0.5357	1											
14	0.1292	-0.0854	0.1346	0.0498	0.2059	0.0541	0.2825	-0.0082	-0.2773	-0.0447	-0.0517	0.2142	0.3084	1										
15	0.0369	-0.0656	0.2912	0.1205	0.1171	0.2917	0.0000	-0.0121	-0.0115	0.0679	0.0286	0.8181	0.7834	0.6251	1									
16	0.0491	-0.097	0.2121	-0.0449	0.0875	0.1356	0.1062	0.2926	0.332	0.1008	0.4261	0.6247	0.6613	0.4442	0.755	1								
17	0.1082	-0.1185	0.183	0.0529	0.2349	0.1096	-0.1183	-0.3952	-0.3455	0.1558	-0.7443	0.4562	0.2489	0.381	0.4881	0.1387	1							
18	-0.0603	-0.1068	-0.1187	-0.0338	-0.0439	-0.1213	0.0628	0.0694	-0.1292	-0.1183	0.0734	-0.2908	-0.3803	-0.209	-0.412	-0.2545	-0.2925	1						
19	-0.0122	0.0415	-0.0511	-0.0797	0.2742	0.1015	0.0096	0.0063	-0.0629	-0.0908	-0.0973	0.2863	0.0884	0.1518	0.247	0.0833	0.2624	-0.1087	1					
20	-0.0957	0.1919	0.0471	0.2148	0.046	-0.0725	-0.2703	-0.0741	0.1479	0.19	0.1244	0.0684	0.1255	-0.2363	0.0045	-0.0649	-0.0827	0.1151	0.0733	1				
21	-0.1723	0.0275	-0.1207	0.188	-0.0576	-0.0795	-0.1117	-0.0119	-0.006	0.0551	-0.1662	0.1192	-0.1975	-0.0125	-0.0361	-0.075	0.1913	0.1043	0.0457	0.0223	1			
22	0.0195	0.1993	-0.0408	0.0943	-0.0874	0.1207	-0.0314	-0.0655	0.0381	0.1388	0.1639	0.014	0.0405	0.0895	0.0451	0.0415	-0.0995	0.2112	0.0615	0.1902	0.0043	1		
23	0.0029	-0.0383	0.1426	-0.0251	-0.0402	0.1337	-0.1066	-0.0221	0.0687	0.1533	0.001	0.0054	-0.0755	-0.1447	-0.0978	-0.1014	-0.0428	-0.0054	-0.1099	-0.2019	0.2338	0.062	1	
24	-0.031	0.0717	0.0165	-0.1267	-0.2339	0.0783	-0.0147	0.0691	0.1952	0.0416	0.0955	0.2422	0.2625	0.0051	0.2167	0.2474	0.0236	-0.0695	0.063	0.1796	0.0161	-0.1052	-0.0115	1

like stem girth (0.3648), length of lamina (0.3759), leaf width (0.1968), petiole length (0.1134), number of branches (0.1547) and days to 50 per cent bolting (0.1830). Plant height was negatively correlated to total leaf / stem ratio (-0.1400).

Stem girth was positively correlated to total yield (0.2915), total stem weight (0.1995) and total leaf weight (0.3108). It was negatively correlated to total leaf / stem ratio (-0.0146) and number of branches (-0.0438).

Length of leaf lamina had positive correlation with total leaf / stem ratio (0.2010), total yield (0.2674) and total leaf weight (0.3352). Leaf width was also positively correlated with total leaf / stem ratio (0.4202), total yield (0.3296) and total leaf weight (0.4599). It is evident from the result that leaf width had high correlation to above mentioned three characters compared to length of leaf lamina. The petiole length had correlation values of 0.1099, 0.1962 and 0.2186 with total leaf / stem ratio, total yield and total leaf weight respectively.

Number of branches was positively correlated to total yield (0.1467) and total stem weight (0.3132). It was negatively correlated to total leaf / stem ratio (-0.3589) and days to 50 per cent bolting (-0.1966).

Days to 50 per cent bolting had a correlation of 0.2060 with total yield and 0.1746 with total leaf / stem ratio.

The total leaf / stem ratio and total yield were negatively correlated (-0.2364). Total stem weight and total leaf / stem ratio were also negatively correlated (-0.5881).

Protein content was negatively correlated to leaf width (-0.0695) and total yield (-0.0933). Fibre content was negatively correlated to length of leaf lamina (-0.0189) and leaf width (-0.0994) and however, it had very low positive correlation with total yield (0.0510). Vitamin A had the same correlation effect with length of leaf lamina (-0.0439), leaf width (-0.0114) and

total yield (0.1004) as in the case of fibre. Oxalate and nitrate had positive correlation with leaf length (0.0874 and 0.2914) and leaf width (0.0589 and 0.3471). Oxalate was negatively correlated to total yield (-0.2137) but nitrate had high positive correlation with total yield (0.3648). Protein was negatively correlated to fibre (-0.0661), vitamin A (-0.0659) and oxalate (-0.0090).

White rust incidence was negatively correlated to total yield (-0.0258) and protein content (-0.0132). Leaf / stem ratio (-0.4943), Vitamin A (-0.2932), oxalate (-0.0693), nitrate (-0.2262) and white rust incidence (-0.0574) were negatively correlated with leaf webber infestation.

4.3.2 Genotypic Correlation Coefficients

Plant height was highly correlated with total yield (0.6376), total leaf weight (0.6005) and total stem weight (0.6256). It was negatively correlated to total leaf / stem ratio (-0.1527). It was also positively correlated to other traits like stem girth (0.3812), leaf length (0.3815), leaf width (0.2004), number of branches (0.1634) and days to 50 per cent bolting (0.1884).

Stem girth was positively correlated to total yield (0.3039), but was negatively correlated to total leaf / stem ratio (0.0262) and number of branches (-0.0519).

Leaf length and leaf width were positively correlated to total leaf / stem ratio (0.2251 and 0.4721), total yield (0.268 and 0.3318) and total leaf weight (0.3378 and 0.4670).

Number of branches was positively correlated to total yield (0.1442) but negatively correlated to total leaf / stem ratio (-0.4292).

Days to 50 per cent bolting was positively correlated to total leaf / stem ratio (0.1860) and total yield (0.2085).

The protein content was positively correlated to leaf length (0.2945), but it was negatively correlated to leaf width (-0.0716) and total yield (-0.0840).

Fibre content was negatively correlated to leaf length (-0.0203), leaf width (-0.1091) and total leaf / stem ratio (-0.2619), but it was positively correlated to total yield (0.0429). The protein and the fibre content was negatively correlated (-0.0615).

There was also negative correlation between leaf length (-0.0439) and leaf width (-0.0115) with vitamin A content. But vitamin A was positive correlation with total leaf / stem ratio (0.1638) and total yield (0.1011).

Oxalate and nitrate content was positively correlated to leaf length (0.0936 and 0.2961) and leaf width (0.0570 and 0.3520). The oxalate content had negative correlation with total leaf / stem ratio (-0.0174) and total yield (-0.2248). In the case of nitrate there was positive correlation with total leaf / stem ratio (0.1431) and total yield (0.3717).

Oxalate content was negatively correlated to protein (-0.0194) and vitamin A (-0.1902), but has positive correlation with fibre content (0.2707).

Nitrate content was positively correlated to vitamin A (0.1676) and oxalate (0.0569), but negatively correlated to protein (-0.0100) and fibre (-0.0236). White rust had negative correlation with plant height (-0.1069), stem girth (-0.3597), number of branches (-0.2488) and total yield (-0.0237). This was positively correlated to leaf length (0.1300), leaf width (0.1909), leaf / stem ratio (0.3235), fibre content (0.3978), oxalate (0.1221) and nitrate (0.0953). The protein content and white rust incidence also had negative correlation (-0.0156).

4.3.3 Error Correlation Coefficients

These coefficients were very low. This indicated the negligible influence of environment in the expression of the characters.

Total yield showed the correlation coefficients 0.7550 and 0.4881 with total leaf weight and total stem weight respectively. There was also high correlation in yield at first cutting, second cutting and third cutting with total yield (0.8181, 0.7834 and 0.6251).

4.4 PATH COEFFICIENT ANALYSIS

The genotypic correlation among yield and its component characters were partitioned into different components to find out the direct and indirect contribution of each character on yield. Plant height, stem girth, length of leaf lamina, leaf width, number of branches, days to 50 per cent bolting and total leaf / stem ratio were the characters selected for path coefficient analysis (Table 12).

Direct effects and correlation of these yield components are presented in Fig. 2.

The plant height had genotypic correlation of 0.6376 with yield. The major portion of this was contributed by its direct effect on yield (0.5321). The indirect effect of plant height on yield, through stem girth, length of leaf lamina, leaf width, number of branches, days to 50 per cent bolting and total leaf / stem ratio were very low and were 0.0060, -0.0920, 0.1097, 0.0002, 0.0194 and 0.0623 respectively.

The direct effect of stem girth on yield was only 0.0157, but the total genotypic correlation was 0.3039. Stem girth has indirect effect on yield mainly through plant height (0.2028). The indirect effect through leaf length (-0.0810) and number of branches (-0.0001) were negative.

The total genotypic correlation of length of leaf lamina on yield was 0.2680 and its direct effect on yield was low and negative (-0.2412). The major contribution of its total correlation was through the indirect effect

Table 12 Direct and indirect effects of yield components on total yield of *Amaranthus dubius*

Characters	Plant height	Stem girth	Length of leaf lamina	Leaf width	Number of branches	Days to 50 per cent bolting	Total leaf / stem ratio	Genotypic correlation with yield
Plant height	0.5321	0.0060	-0.0920	0.1097	0.0002	0.0194	0.0623	0.6376
Stem girth	0.2028	0.0157	-0.0810	0.1231	-0.0001	0.0326	0.0107	0.3039
Length of leaf lamina	0.2030	0.0053	-0.2412	0.3635	-0.0003	0.0297	-0.0917	0.2680
Leaf width	0.1066	0.0035	-0.1602	0.5474	-0.0003	0.0275	-0.1927	0.3318
Number of branches	0.0869	-0.0008	0.0726	-0.1697	0.0011	-0.0211	0.1752	0.1442
Days to 50 per cent bolting	0.1002	0.0050	-0.0698	0.1465	-0.0002	0.1028	-0.0759	0.2085
Total leaf / stem ratio	-0.0812	-0.0004	-0.0543	0.2584	-0.0005	0.0191	-0.4082	-0.2670

Residue = 0.4084

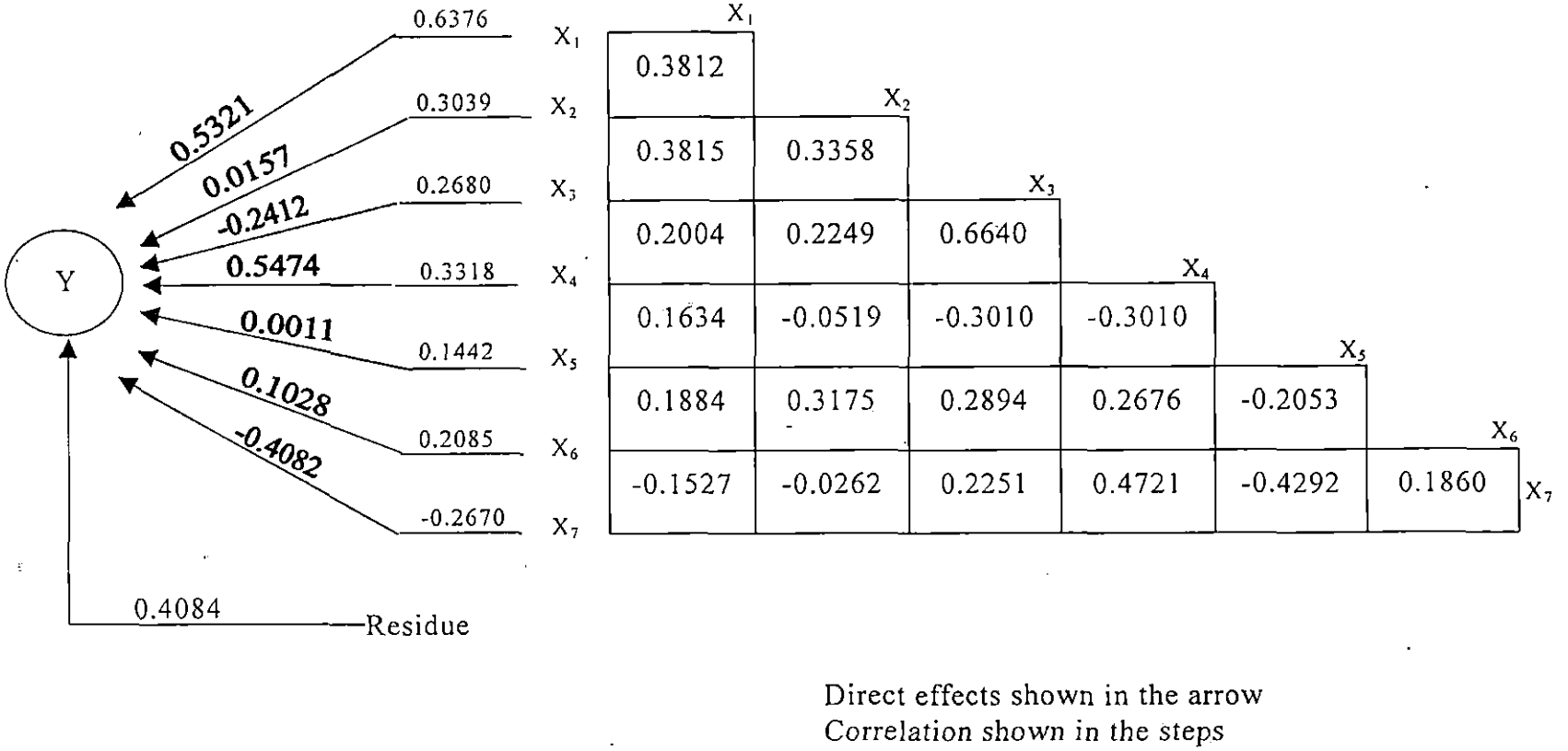


Fig. 2 Path diagram showing direct effects and correlation of yield components on total yield of *Amaranthus dubius*

of plant height (0.2030) and leaf width (0.3635). The effects through stem girth (0.0053) and days to 50 per cent bolting (0.0297) were very low. The effects of number of branches (-0.0003) and total leaf / stem ratio (-0.0917) were also very low and negative.

The genotypic correlation of leaf width on total yield was higher than that of length of lamina and was 0.3318. Its direct effect was 0.5474. Its indirect effect on yield through leaf length (-0.1602), number of branches (-0.0003) and total leaf / stem ratio (-0.1927) was negative. But the effects through plant height (0.1066), stem girth (0.0035) and days to 50 per cent bolting (0.0275) were positive.

The total genotypic correlation of number of branches on yield was low (0.1442). Its direct effect was only 0.0011. The rest of its effect on yield was contributed by the indirect effect through plant height (0.0869), stem girth (-0.0008), length of lamina (0.0726), leaf width (-0.1697), days to 50 per cent bolting (-0.0211) and total leaf / stem ratio (0.1752).

The direct effect of days to 50 per cent bolting was 0.1028 and total genotypic correlation was 0.2085. The major portion of its indirect effect was through leaf width (0.1465) followed by plant height (0.1002). The effect through stem girth was very low (0.0050). Eventhough leaf width contributed a high value, the effect through leaf length (-0.0698), total leaf / stem ratio (-0.0759) and number of branches (-0.0002) were very low and negative.

Among the selected characters, only total leaf / stem ratio had negative genotypic correlation with yield (-0.2670) and its direct effect was –0.4082. This had indirect effect of 0.2584 through leaf width on yield. But with the leaf length it had a negative effect (-0.0543).

The residue was 0.4084 indicating that the selected seven characters contributed the remaining 60 per cent.

4.5 SELECTION INDEX

Selection index was used to discriminate the varieties based on major components of yield. The characters used for constructing the index were plant height, length of leaf lamina, leaf width, total yield, total leaf / stem ratio and days to 50 per cent bolting.

The selection indices of the accessions were presented in Table 13.

The accessions AD 30 (1799.187), AD 23 (1792.349) (Plate 6), AD 22 (1698.644), AD 11 (1627.562) and AD 21 (1625.884) obtained higher values. The accessions AD 32 (894.421), AD 10 (891.1561), AD 6 (880.749), AD 20 (879.854), AD 15 (874.451), AD 3 (865.900) and AD 1 (833.034) had low values (Fig. 3).

The accession AD 30 had highest selection index value and AD 1 had lowest value.

4.6 CATALOGUING OF THE GERMPLASM

4.6.1 Morphological Cataloguing

All the 32 accessions were described morphologically using the simplified descriptor developed by IPGRI descriptor for amaranthus. The accessions were scored for 20 morphological characters on appropriate scales ranging from 0–9 (Table 14).

All the accessions studied had erect growth habit and the branches were distributed all along the stem. On grouping based on plant height, majority of the accessions came under the score 2 (30-45 cm). The others (AD 8, AD 11, AD 14, AD 15, AD 18, AD 21, AD 22, AD 23, AD 28, AD 29 and AD 30) had plant height in the range 46-60 cm.

In the case of stem pubescence, only one accession AD 28 had conspicuous stem pubescence. In 18 accessions low pubescence was noted and the remaining ones were free of the pubescence. The variation in stem pigmentation was observed among the accessions. It ranged from

Table 13 Selection index values of *Amaranthus dubius* accessions

Sl. No.	Accessions	Selection index values	Rank
1	AD 1	833.034	32
2	AD 2	1404.846	12
23	AD 3	865.900	31
4	AD 4	924.974	23
5	AD 5	1194.940	15
6	AD 6	880.749	28
7	AD 7	1319.894	13
8	AD 8	1613.475	6
9	AD 9	1121.440	17
10	AD 10	891.156	27
11	AD 11	1627.562	4
12	AD 12	1114.865	18
13	AD 13	1090.533	19
14	AD 14	1422.344	11
15	AD 15	874.451	30
16	AD 16	1089.948	20
17	AD 18	1526.279	8
18	AD 19	996.610	22
19	AD 20	879.854	29
20	AD 21	1625.884	5
21	AD 22	1698.644	3
22	AD 23	1792.349	2
23	AD 24	909.089	25
24	AD 25	1507.501	10
25	AD 26	1604.958	7
26	AD 28	1253.514	14
27	AD 29	1509.890	9
28	AD 30	1799.187	1
29	AD 31	1186.356	16
30	AD 32	894.4219	26
31	AD 33	1077.708	21
32	AD 34	916.225	24

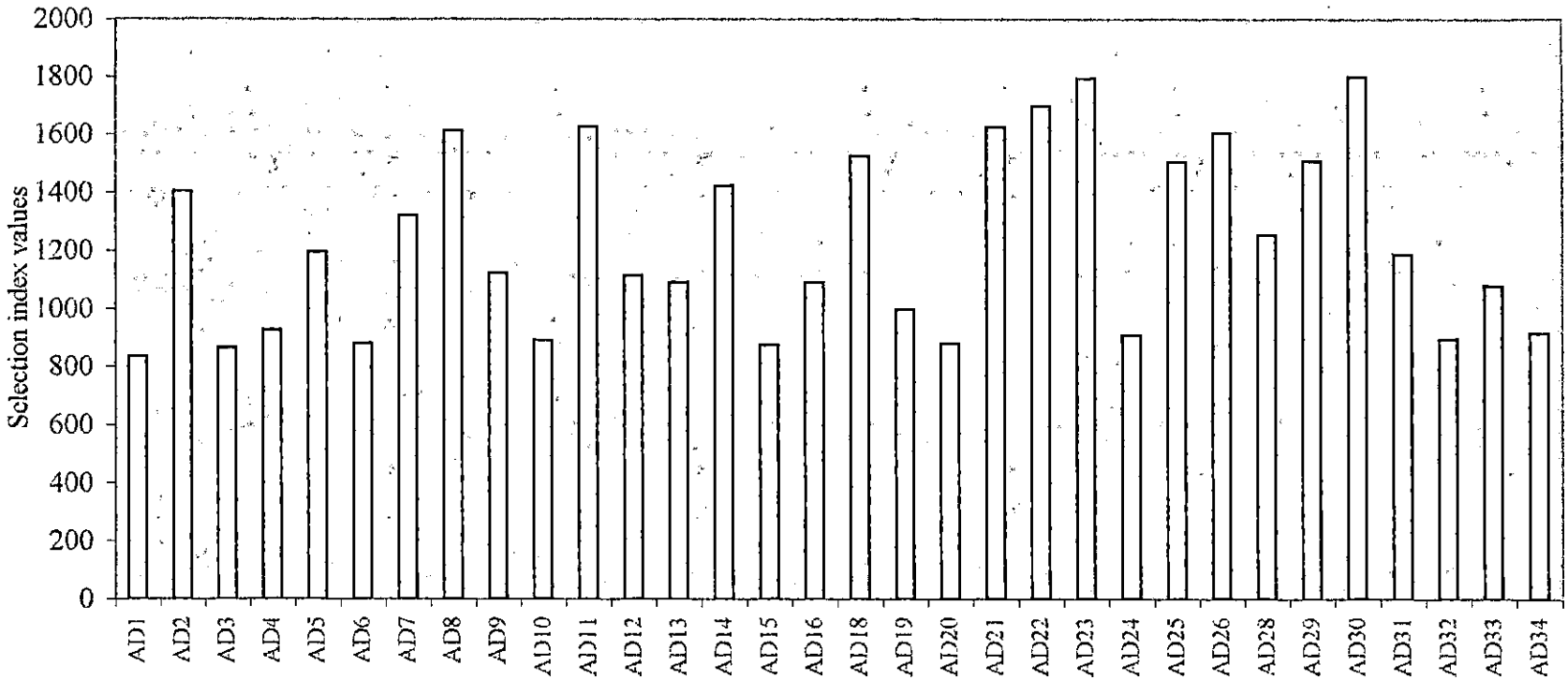


Fig. 3 Variation in selection index values of *Amaranthus dubius* accessions

Table 14 Morphological cataloguing of *Amaranthus dubius* accessions

Sl. No.	Descriptor	AD1	AD2	AD3	AD4	AD5	AD6	AD7	AD8	AD9	AD10	AD11	AD12	AD13	AD14	AD15	AD16
1	Growth habit	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
2	Plant height	2	2	2	2	2	2	2	5	2	2	5	2	2	5	5	2
3	Branching index	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4
4	Stem pubescence	3	3	3	0	3	0	3	0	0	0	0	0	0	3	3	0
5	Stem pigmentation	2	2	2	3	2	2	2	3	2	2	4	2	2	2	4	5
6	Spines in leaf axil	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
7	Leaf length	5	3	5	5	5	3	5	5	5	5	5	5	5	5	5	5
8	Leaf width	3	3	3	3	6	3	3	3	3	3	3	3	3	3	3	3
9	Leaf pubescence	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
10	Leaf pigmentation	8	8	8	8	8	9	6	8	8	8	6	9	8	9	8	8
11	Leaf shape	4	5	4	6	5	5	6	3	3	4	3	2	3	6	5	4
12	Leaf margin	3	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
13	Prominence of leaf veins	2	2	2	2	2	2	2	2	2	2	2	2	2	2	3	2
14	Petiole pigmentation	1	1	3	3	1	3	3	3	3	1	3	3	3	3	4	4
15	Terminal inflorescence shape	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	2
16	Terminal inflorescence attitude	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
17	Axillary inflorescence	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
18	Inflorescence colour	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
19	Days to 50 % bolting	2	2	2	2	3	2	2	2	2	3	2	3	3	2	2	3
20	Seed colour	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5

Table 14 Continued

Sl. No.	Descriptor	AD18	AD19	AD20	AD21	AD22	AD23	AD24	AD25	AD26	AD28	AD29	AD30	AD31	AD32	AD33	AD34
1	Growth habit	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
2	Plant height	5	2	2	5	5	5	2	2	2	5	5	5	2	2	2	2
3	Branching index	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4
4	Stem pubescence	0	0	3	3	0	3	3	3	3	5	3	0	3	3	3	3
5	Stem pigmentation	2	3	3	2	2	3	3	2	3	3	2	2	2	2	5	2
6	Spines in leaf axil	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
7	Leaf length	5	5	5	5	5	5	5	5	5	5	5	5	5	5	3	5
8	Leaf width	3	3	3	6	6	3	3	3	3	3	3	6	3	3	3	3
9	Leaf pubescence	0	0	0	0	0	0	0	0	0	3	0	0	0	0	0	0
10	Leaf pigmentation	9	6	6	9	9	9	9	9	9	6	9	9	9	8	9	9
11	Leaf shape	3	4	1	5	5	6	3	5	4	1	4	1	4	3	3	5
12	Leaf margin	1	1	1	3	3	1	1	1	1	1	3	1	1	1	1	3
13	Prominence of leaf veins	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
14	Petiole pigmentation	1	3	3	3	1	3	3	1	3	1	1	3	3	1	4	1
15	Terminal inflorescence shape	3	3	3	3	3	3	3	3	3	2	3	3	3	3	3	3
16	Terminal inflorescence attitude	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
17	Axillary inflorescence	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
18	Inflorescence colour	2	2	2	2	2	2	2	2	2	3	2	2	2	2	2	2
19	Days to 50 % bolting	2	2	2	2	3	3	3	2	3	3	2	3	2	3	2	3
20	Seed colour	5	5	5	5	5	5	5	5	5	4	5	5	5	5	5	5

pale green to deep purple (Plate 7). AD 16 and AD 33 had deep purple stem. AD 11 and AD 15 had purple stem. AD 4, AD 8, AD 19, AD 20, AD 23, AD 24, AD 26 and AD 28 had purplish green stem. Others possessed pale green stem. All the accessions were free of the spines in the leaf axil.

In the present study, the smallest leaves were observed in AD 2, AD 6 and AD 33, which had leaf length in the range 5 – 10. Others had leaf length in the range 11 and above 11. They possessed leaf width in the range 5 – 10 except AD 5, AD 21, AD 22 and AD 30 which had leaf width in the range 11 – 16.

Leaf pubescence was absent in the accessions except AD 28, which had low pubescence. In the case of leaf pigmentation, three types were noticed, i.e., green with margin and veins pigmented, normal green and dark green. AD 7, AD 11, AD 19, AD 20 and AD 28 had leaves green with margin and veins pigmented.

The variation in leaf shape was noticed (Plate 8). Lanceolate, elliptic, ovate, broad ovate, triangle ovate and rhombic ovate were the leaf shape observed in the accessions. AD 20, AD 28 and AD 30 had lanceolate leaves. AD 12 possessed elliptic leaves. AD 8, AD 9, AD 11, AD 13, AD 18, AD 24, AD 32 and AD 33 had ovate leaves. AD1, AD 3, AD 10, AD 16, AD 19, AD 26, AD 29 and AD 31 had broad ovate leaves. AD 2, AD 5, AD 6, AD 15, AD 21, AD 22, AD 25 and AD 34 had triangle ovate leaves. AD 4, AD 7, AD 14 and AD 23 had rhombic ovate leaves.

The accessions AD 1, AD 21, AD 22, AD 29 and AD 34 had undulate leaf margin. Majority had entire leaf margin. On observing the leaf veins, all the accessions except AD 15 had slightly prominent leaf veins and AD 15 had very prominent veins. The petiole colour noticed were green, purple and deep purple. The accessions AD 15, AD 16 and AD 33 possessed deep purple petiole.

(A) AD 30 (B) AD 23

Plate 6. Accessions ranked superior based on the selection index values

Plate 7. Variability in stem pigmentation

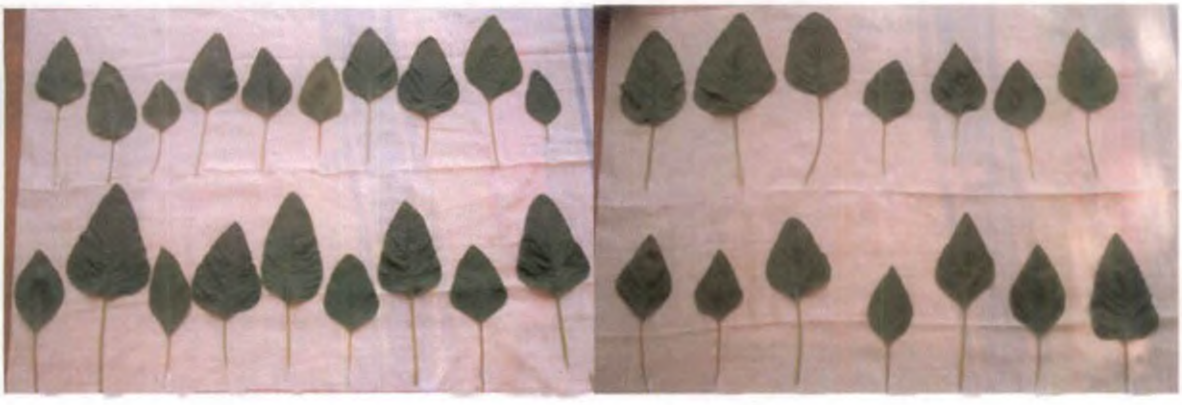


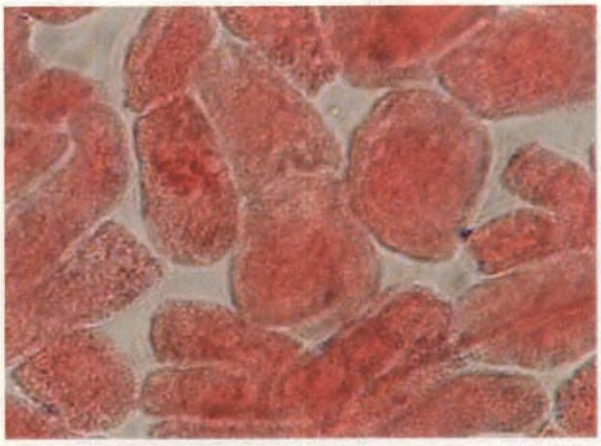
Plate 8. Variability in leaf shape and leaf size

All the accessions had large erect terminal inflorescence and axillary inflorescence were absent. In the case of terminal inflorescence shape, the accessions AD 16 and AD 28 had panicle with short branches and others had panicle with long branches. The inflorescence colour in AD 28 was pink and in all others green.

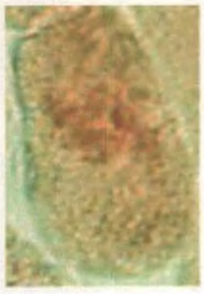
The days to 50 per cent bolting was observed in the range 46 – 60 days in about 19 accessions and in others, in the range 61 – 75 days. The two seed colours noticed were black and brown. Only in one accession AD 28, the seed colour was brown and in others it was black.

4.6.2 Assessment of the Ploidy Level

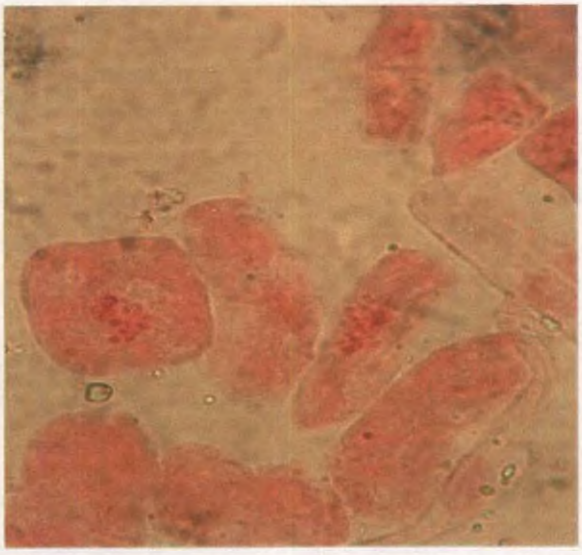
In the present study, the chromosome number of the mitotic cells of *A. dubius* accessions and *A. tricolor* variety 'Arun' were counted (Plate 9). The results revealed that *A. dubius* accessions studied were tetraploids.



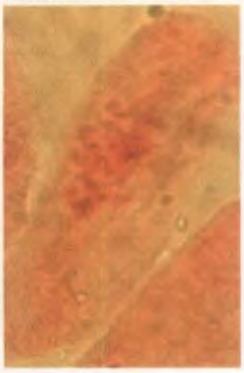
(A) Diploid cell of *Amaranthus tricolor* with 34 chromosomes (x 1000 X)



(B) Enlarged view



(C) Tetraploid cell of *Amaranthus dubius* with 64 chromosomes (x 1000 X)



(D) Enlarged view

Plate 9. Assessment of the ploidy level

DISCUSSION

5. DISCUSSION

Amaranthus is a highly nutritious tropical leafy vegetable capable of combating the problems of under nutrition and malnutrition. However, the presence of antinutrient factors like oxalates and nitrates and the widespread occurrence of leaf blight disease caused by *Rhizoctonia solani* Kühn are the two major drawbacks limiting its consumption and cultivation. Earlier reports revealed that the species *Amaranthus dubius* Mart. ex Thell. is resistant to leaf blight and low in antinutrient contents compared to the more popularly cultivated species *A. tricolor* (Priya, 1998). Hence, the present investigation was undertaken to study the extent of variability among *A. dubius* and to confirm its degree of resistance to leaf blight.

An insight into the magnitude of variability in a crop is of great importance as it provides a basis for effective selection. Of the various estimates of variability, range, mean and variation around mean are very basic ones.

Thirty two accessions of *A. dubius* from different sources were evaluated in the field and observations on biometric and quality characters and reaction to biotic stresses were recorded. These accessions were screened under artificial epiphytotic conditions for confirming resistance to *R. solani*. The chromosome number of these accessions were also counted for ascertaining the ploidy level.

The results obtained are discussed below :

5.1 MEAN PERFORMANCE OF THE ACCESSIONS

Analysis of variance showed significant difference among the accessions for all the characters studied.

The characters like yield, leaf / stem ratio, plant height, stem girth, length of leaf lamina, leaf width, petiole length, number of branches and days to 50 per cent bolting are the economically important traits in amaranthus. In the present study, the accessions AD 30 recorded highest yield per plant (464.80 g) followed by AD 23 (445.00 g) whereas lowest yield was recorded by AD 34 (155.94 g). Among the species of *Amaranthus, A. dubius* was the highest yielder as reported by Campbell and Abbott (1982) and Norman and Sichone (1993). In the present study, there was wide variation within *A. dubius* itself for yield. On comparison of yield obtained in three cuttings, the yield decreased from first cutting to third cutting which is in agreement with the findings of Allemann *et al.* (1996).

A leaf / stem ratio of 1.0 to 1.5 is optimum and is to be aimed at in selection (Mohanalekshmi *et al.*, 1998). In this study, maximum leaf / stem ratio recorded was 2.48 (AD 34) and minimum was 0.93 (AD 11). This shows the variability existing for the character within *A. dubius*. The variation in leaf / stem ratio within and between species of *Amaranthus* was reported earlier by Mohideen and Muthukrishnan (1981); Mohanalekshmi (1998) and Priya (1998). The leaf / stem ratio increased progressively with each subsequent harvests which is in line with the reports by Norman and Sichone (1993) and Shukla and Singh (2000). This can be attributed to the removal of the main stem in the first harvest leading to the development of branches for the subsequent harvests.

Bolting or premature flowering of plants before attaining enough vegetative growth is one of the major problems reducing the yield of vegetables in general and amaranthus in particular. Genetic as well as environmental stresses contribute to this condition. In the current experiment, AD 34 (75.13 days) was the late and AD 3 (47.80 days) was the earliest in bolting. For this character also variation was noticed. Variation among different species of *Amaranthus* was reported by

Devadas (1982), Priya (1998) and Hossain and Rahman (1999). So there is scope for improvement through simple selection for this character.

Important quality attributes in amaranthus are vitamin A, protein, fibre, oxalate, nitrate and organoleptic qualities. A variety with high vitamin A and protein, less fibre, oxalate and nitrate content are preferred in terms of nutrition.

Nutritive composition of amaranthus was studied by various workers and reported existence of variability (Vijayakumar and Shanmughavelu, 1985; Hossain *et al.*, 1999; Kowsalya *et al.*, 2001). Present study also reveals wide variation in nutritive value among the accessions. The maximum protein content obtained was 23.00 per cent (AD 16) minimum was 9.03 per cent (AD 8). The highest fibre content was 15.70 per cent (AD 12) and lowest was 5.67 pre cent (AD 28). The vitamin A content showed a maximum of 8915.96 I.U. (AD 8) and minimum of 4331.50 I.U. (AD 2). The nutritive value of 'Arun' (*A. tricolor*) reported by Priya (1998) was protein 17.96 per cent, fibre 7.33 per cent, vitamin A 8164.45 I.U. and oxalate 2.4 per cent. On comparing this with *A. dubius*, it is evident that *A. dubius* is nutritionally on par with the popular *A. tricolor*.

The major antinutrient factors, oxalates and nitrates are of much concern in daily use of amaranthus. In the present study, highest oxalates and nitrate contents were 3.85 per cent (AD 3) and 1.09 per cent (AD 30) respectively whereas the lowest levels were 0.62 per cent (AD 23) and 0.25 per cent (AD 1) respectively. These results reveal that certain accessions had higher oxalate contents which is contradictory to the findings of Kauffmann and Gilbert, 1981; George *et al.*, 1989; Devadas and Mallika, 1991; Thamburaj *et al.*, 1994; Priya and Celine 2001 who reported low levels of antinutrient factors in *A. dubius*. On the other hand, Marderosian *et al.* (1980) reported an oxalate content as high as five per cent in *A. dubius*. However, variability exists in oxalate and nitrate content, indicating scope for selection of genotypes with low antinutrient factors.

A high yielding variety will be accepted only when it is organoleptically superior. The results of the present study showed that the accession AD 34 had highest score (22.60) in organoleptic evaluation, which was however the lowest yielder. Therefore, AD 34 can be used in future breeding programme as a source of superior quality traits.

The major biotic stresses affecting amaranthus are leaf blight, white rust and leaf webber.

Leaf blight caused by *R. solani* is the single major disease of economic concern in amaranthus in Kerala. In the present experiment, all the accessions of *A. dubius* were free from the natural infection whereas, the susceptible check variety, 'Arun' belonging to *A. tricolor* was severely affected by leaf blight with a PDI of 68.10. This indicated that eventhough the inoculum potential of the fungus were high, the *A. dubius* accessions were resistant to this infection. This confirms the observations of Gokulapalan *et al.* (1997) and Priya (1998).

However, screening for disease resistance in artificial epiphytotic conditions under high inoculum pressure of the pathogen and favourable environmental conditions for disease development helps in identifying the genotypes with true resistance to the disease. Identification and use of resistant or tolerant genotypes is the most important aspect for developing economically viable management strategies for this disease. On artificial inoculation, only 14 accessions were found immune while others showed mild symptom development. Among the remaining ones, 15 accessions were highly resistant and three were moderately resistant. This differential reaction of the genotypes towards the leaf blight under field and artificial conditions might obviously be due to the escape in the field screening. Eventhough *R. solani* is an ubiquitous pathogen with wide host range, it failed to produce symptoms in 14 accessions of *A. dubius*.

White rust caused by *Albugo blitii* is a disease of minor importance in Kerala. The marketability of the leaves is reduced by the presence of

this rusty pustules on the under surface of leaves. According to Maiti and Mandal (2000), the white rust infected leaves had low total and reducing sugars and high phenolic compounds. In the present study, all the accessions except AD 14, AD 16 and AD 28 showed symptoms of white rust. The accession AD 34 recorded maximum disease incidence (29.39 per cent). The availability of disease free accessions provide scope for isolating lines resistant to white rust after further confirmatory tests.

Among the insect pests, leaf webbers *viz.*, *Psara basalis* and *Hymenia recurvalis* are important in amaranthus. In the present study infestation was noticed in all the accessions and about 16 accessions had only mild infestation. These accessions with less incidence should be selected for further improvement.

5.2 GENETIC VARIABILITY, HERITABILITY AND GENETIC ADVANCE

As the preliminary step in any crop improvement programme, a knowledge of the genetic variability of different characters is very essential. The variation may be due to genetic and environmental effects.

In the present study, variability was noticed for growth, yield and quality characters and response to biotic stress. The existence of high variability for yield and yield attributes in amaranthus was reported by many workers (Mohideen *et al.*, 1982; Pan *et al.* 1991; Devadas *et al.*, 1992; Varalakshmi and Reddy, 1994; Hossain and Rahman, 1999).

Coefficient of variation – phenotypic coefficient of variation (PCV) and genotypic coefficient of variation (GCV) are better indices for comparison of characters with different units of measurement, than estimates of quantitative variation like range and variation around mean.

PCV ranged from 12.82 to 61.88 and GCV ranged from 12.75 to 57.17. Among the biometric characters, stem girth, length of leaf lamina, leaf width, number of branches, leaf / stem ratio, yield, total leaf weight and total stem weight had higher PCV and GCV values.

Among the quality characters, nitrate, oxalate and fibre had higher values. Similar results were also reported by Pan *et al.* (1991), Revanappa and Madelgeri (1997) and Priya and Celine 2001). White rust also recorded high GCV and PCV values. Higher GCV and PCV for most of the characters revealed great extent of variability for these characters suggesting good scope for improvement through selection. Furthermore, the magnitude of genetic variation nearly approached the phenotypic variation, in all the characters, indicating that the selection on phenotypic basis will hold good scope on genotypic upgradation.

Heritability and genetic advance are important selection parameters. Heritability estimates along with genetic advance are more helpful in predicting the gain under selection than heritability estimates alone. However it is not necessary that a character showing high heritability will also exhibit high genetic advance (Johnson *et al.*, 1955).

High heritability along with high genetic gain as per cent of mean was observed in all the characters studied (Fig. 4).

5.3 CORRELATION STUDIES

Correlation coefficient is a statistical measure used to find out the degree and direction of relationship between two or more variables. So this helps in understanding the change caused in one character by doing selection based on another character.

In the current experiment, plant height, stem girth, length of leaf lamina, leaf width, number of branches and days to 50 per cent bolting showed positive genotypic correlation with yield. Whereas, leaf / stem ratio had negative correlation with total yield. Similar correlation was reported by Mohideen and Muthukrishnan (1979). From this it is evident that, selection based on plant height, stem girth, length of leaf lamina, leaf width, number of branches and days to 50 per cent bolting will result in

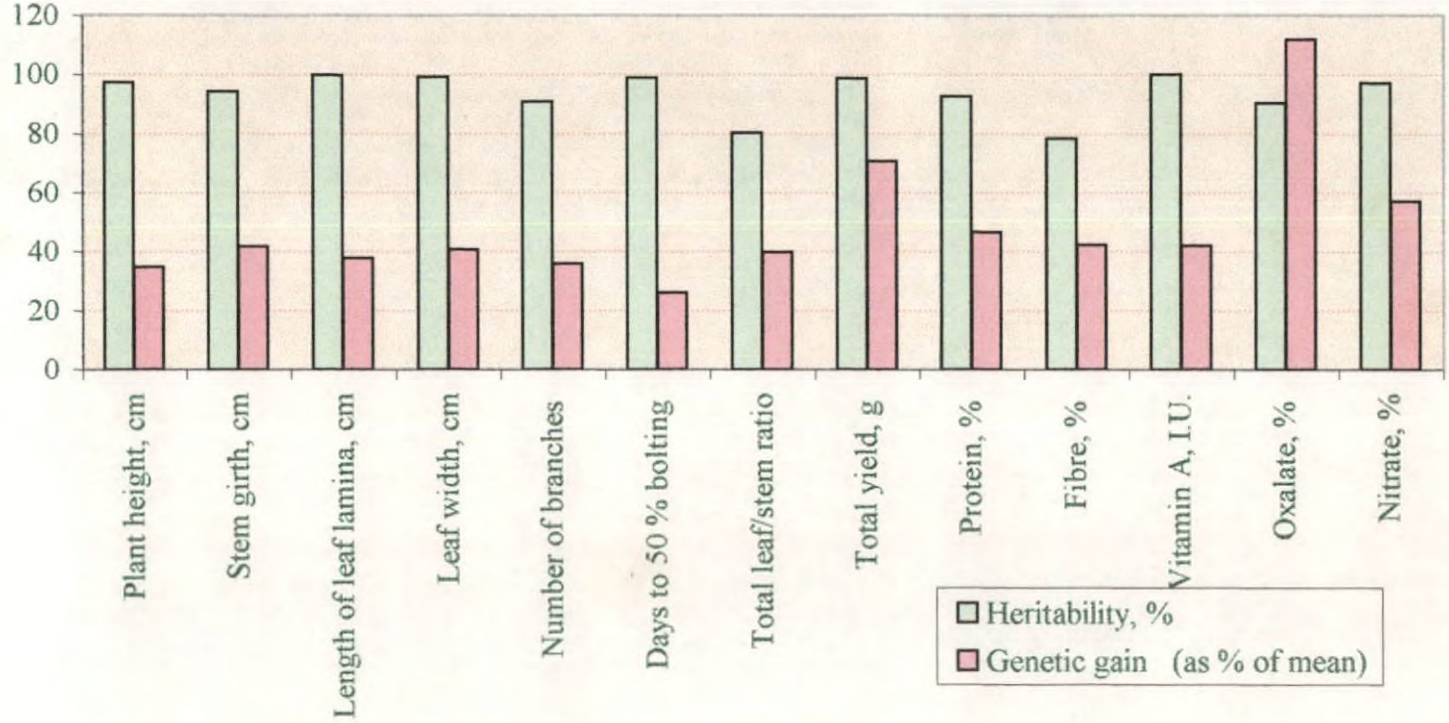


Fig. 4 Heritability and genetic gain as percentage of mean in *Amaranthus dubius* for important characters

higher yield. The characters also observed to be highly heritable with high genetic gain.

The quality characters *viz.*, fibre, vitamin A and nitrate content were positively correlated with yield. However, protein and oxalate contents were negatively correlated. Anuradha (1992) reported similar results except that, protein had high significant positive correlation with yield. Selection for higher yield leads to low oxalate but higher nitrate level. White rust and protein content had negative correlation. This also confirms that white rust infection reduces the quality of the leaves.

The phenotypic correlation includes both genetic and environmental effects. In the present study, the magnitude of genotypic correlation was higher than the corresponding phenotypic correlation indicating that environment had negligible effects on these characters.

5.4 PATH COEFFICIENT ANALYSIS

Path coefficient analysis is simply a standardised regression coefficient which splits the correlation coefficient into the measures of direct and indirect effects. It measures the direct and indirect contribution of independent variables on dependent variable. The path analysis reveals whether the association of these characters with yield is due to their direct effect or is a consequence of their indirect effects *via* other component characters.

In the present study, the characters included for path analysis were plant height, stem girth, length of leaf lamina, leaf width, number of branches, days to 50 per cent bolting and total leaf / stem ratio.

The genotypic correlation of plant height on yield was 0.6376. The major portion of this was contributed by its direct effect (0.5321 per cent). In this case too, it is evident that selection for higher plant height leads to higher yield. Its indirect effect through other selected characters were negligible.

Though the genotypic correlation of stem girth on total yield was 0.3039, its direct effect was negligible. Similarly, its indirect effect through plant height was moderate and it was the highest compared to other indirect effects. The genotypic correlation of length of leaf lamina on yield was positive and moderate, but its direct effect was negative. The indirect selection through leaf width and plant height will be effective. The direct effect of leaf width on yield was high. So direct selection through leaf width will be effective for higher yield. Eventhough the genotypic correlation of number of branches on total yield was positive, it was low. Its direct effect was negligible and indirect effect through other characters also very low. So selection based on number of branches will not be effective as in other characters.

The genotypic correlation of days to 50 per cent bolting on yield was moderate but its direct effect was low. The indirect effect through leaf width was greater than its direct effect, so indirect selection through leaf width will be more effective than its direct selection.

The total leaf / stem ratio was negatively correlated to yield and its direct effect was also negative, but its indirect effect through leaf width was moderate (0.2584) and positive.

5.5 SELECTION INDEX

The selection index refers a linear combination of characters associated with yield and is used to discriminate the varieties based on major components of yield. The characters used in the current study were plant height, length of leaf lamina, leaf width, days to 50 per cent bolting, yield and leaf / stem ratio. The accession AD 30 had highest selection index value (1799.187) and this accession also possessed highest total yield. The lowest value was obtained for AD 1 (833.034) and was a low yielder.

5.6 CATALOGUING OF THE GERMPLASM

Cataloguing of the accessions based on a standard descriptor is useful in international exchange of information about the accessions in a scientific way. This helps in locating some morphological characters linked with resistance or susceptibility, which can be utilized for indirect selection and also in understanding the characters of the accessions easily and quickly.

All the accessions studied had erect growth habit and the branches were distributed all along the stem. The accession AD 28 differed from others in having conspicuous stem pubescence, low leaf pubescence, lanceolate leaves, pink coloured panicle with short branches and brown seeds.

Earlier reports showed variation in leaf colour among *Amaranthus* spp. *i.e.*, light green to green and reddish to red (Hamid *et al.*, 1989). Only green coloured leaves were observed in the collections of the present study. There were normal green, dark green and green with margin and veins pigmented. The stem pigmentation noticed were deep purple, purple, purplish green and pale green stem and majority possessed pale green stem. Mohideen *et al.* (1983) reported brown, green, orange, yellow green, yellow with purple tint and crimson coloured stems in *Amaranthus* spp. Hamid *et al.* (1989) reported that variation in stem colour might be due to the genetic makeup. The accessions AD 7, AD 11, AD 19, AD 20 and AD 28 possessed leaves of green with margin and veins pigmented. Among these AD 19, AD 20 and AD 28 had purplish green stem.

In the genus *Amaranthus*, all the species are diploids except *A. dubius* which is a tetraploid. The somatic chromosome number 2n (= 4x) is 64 in *A. dubius* and 2n (= 2x) is 34 in *A. tricolor* (Mallika, 1987). In the present study, the chromosome counting of the collected *A. dubius* accessions in comparison to *A. tricolor* was done to ascertain the ploidy

level. The results reveal that the collected accessions are tetraploids confirming that they belong to *A. dubius*.

Yield is the character to which prime importance is given during process of selection. AD 30, AD 23 and AD 22 were ranked superior ones in decreasing order based on the selection index values.

It is evident in the present study that AD 23 can be selected as the best genotype considering its high nutritive value, resistance to leaf blight and high organoleptic score compared to AD 30 and AD 22. Therefore this line can be recommended for cultivation in leaf blight endemic areas as an ad-hoc measure. White rust free accessions AD 14, AD 16, AD 28 also deserve priority in future amaranth breeding programme. AD 23 could be crossed with these white rust resistant lines *viz.*, AD 14, AD 16 and AD 28 for evolving high yielding and multiple resistant lines of amaranth with exceptional nutritional qualities. Since AD 28 was immune to leaf blight incidence with considerable level of field resistance against white rust (Fig. 5), a cross combination of AD 23 and AD 28 can be attempted in near future for getting *A. dubius* lines with high yield, quality and multiple disease resistance.

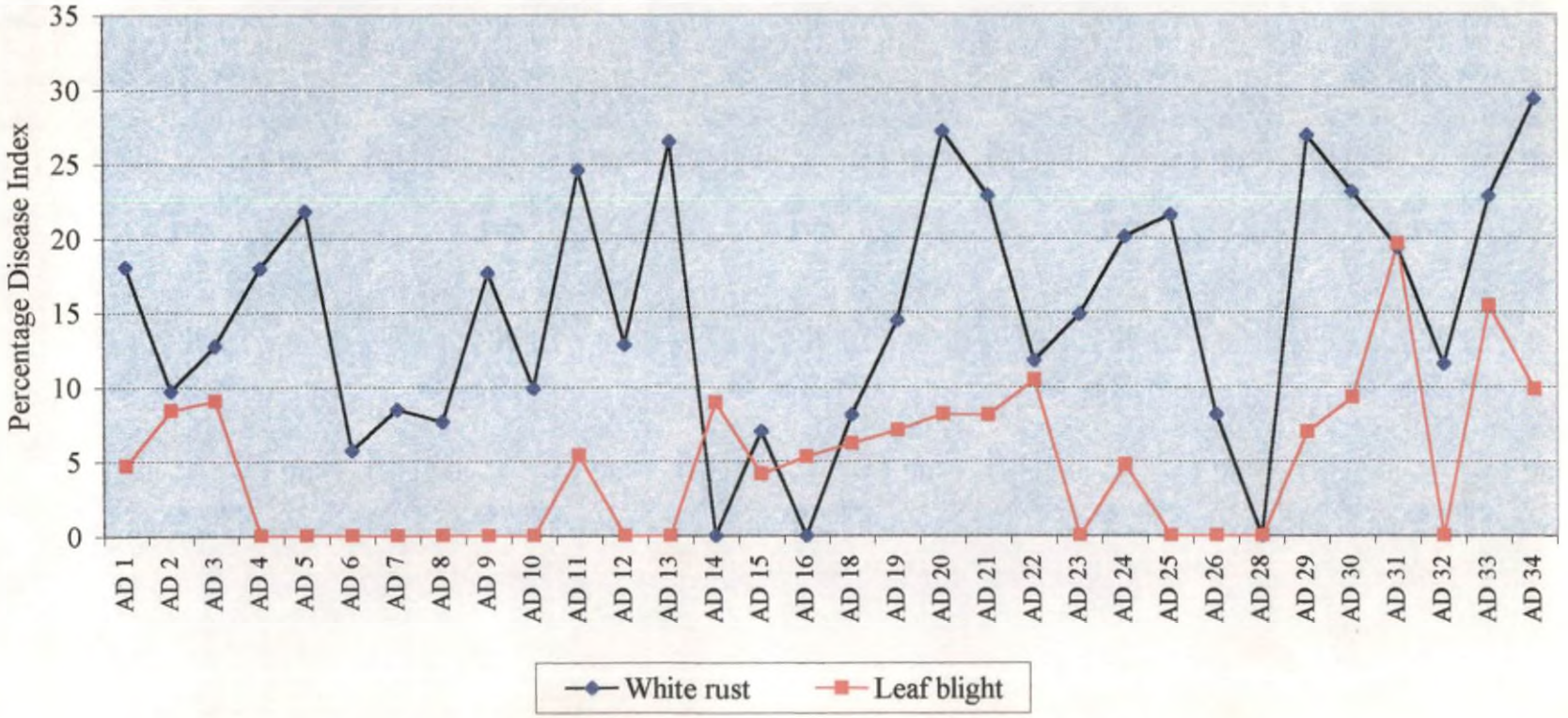


Fig. 5 Comparison of Percentage Disease Index of leaf blight (under artificial screening) and white rust (under field screening) of *Amaranthus dubius* accessions

SUMMARY

6. SUMMARY

The present study entitled "Variability in vegetable amaranth (*Amaranthus dubius* Mart. ex Thell.) for yield, quality and resistance to leaf blight" was conducted during the period 2000-2002. The objectives of this study were to assess the variability in *A. dubius* for yield, quality and reaction to biotic stress, to locate the superior genotypes and to confirm the resistance of the accessions to leaf blight caused by *Rhizoctonia solani* Kühn. The study included 32 diverse accessions of *A. dubius* and the variety 'Arun' (*A. tricolor*) was the susceptible check. The ploidy level of the collected accessions were ascertained by counting the chromosome number. The results of the study are summarised hereunder:

Analysis of variance showed significant difference between the accessions for all the characters studied. The accessions AD 30 recorded the highest yield (464.80 g) and AD 34 the lowest (155.94 g). The highest leaf / stem ratio was obtained for AD 34 (2.48) and the least value for AD 11 (0.93). The accession AD 34 was the late in bolting (75.13 days) and AD 3 was the earliest (47.80 days).

The quality characters considered were protein, fibre, vitamin A, oxalate, nitrate and organoleptic qualities. The accession AD 16 had maximum protein (23.00 per cent) whereas, AD 8 had least protein (9.03 per cent). The highest fibre content was observed in AD 12 (15.70 per cent) and lowest in AD 28 (5.67 per cent). The vitamin A was maximum in AD 8 (8915.96 I.U.) and was minimum in AD 2 (4331.50 I.U.). The accession AD 23 had lowest (0.62 per cent) and AD 3 had highest oxalate content (3.85 per cent). The nitrate level was minimum in AD 1 (0.25 per cent) and maximum in AD 30 (1.09 per cent). In the organoleptic evaluation, AD 34 had highest score value (22.60) and AD 28 had the lowest (12.80).

The important biotic stresses in amaranthus are leaf blight, white rust and leaf webber. In this experiment, all the accessions of *A. dubius* were free of the natural infection of leaf blight. But 'Arun' was seriously damaged by the disease with a PDI of 68.10. On artificial inoculation only 14 accessions were immune. Among the remaining ones, 15 accessions were highly resistant with a PDI of 4.15 to 9.85. The accessions AD 22, AD 31 and AD 33 were moderately resistant with PDI of 10.48, 19.62 and 15.47. The susceptible check 'Arun' was highly susceptible with a PDI of 70.03. The accessions AD 14, AD 16 and AD 28 were completely free from white rust infection under field conditions. Others showed disease severity in the range of 5.77 to 29.39. Mild attack of leaf webber was observed in all the accessions. The highest score was observed in AD 11 (3.00) and 16 accessions had minimum infestation with the score, 1.00.

Variability was noticed for growth characters, yield characters, quality characters and response to biotic stresses. In this study, the PCV ranged from 12.82 to 61.88 and GCV ranged from 12.75 to 57.17. Higher GCV and PCV for most of the characters revealed great extent of variability for these characters suggesting good scope for improvement through selection. High heritability along with high genetic gain as per cent of mean was observed in all the characters studied. The range of heritability was 67.41 to 99.99 per cent.

The correlation studies revealed that plant height, stem girth, length of leaf lamina, leaf width, number of branches and days to 50 per cent bolting had positive genotypic correlation with yield whereas leaf / stem ratio had negative correlation with total yield. The characters taken for path analysis were plant height, stem girth, length of leaf lamina, leaf width, number of branches, days to 50 per cent bolting and total leaf / stem ratio. Plant height and leaf width had high direct effect on yield. Days to 50 per cent bolting had low direct effect on yield. The direct effect of stem girth and number of branches were negligible. In the case of length of leaf lamina and total leaf / stem ratio the direct effect was negative.

The selection index was calculated to locate superior genotypes. The characters used for calculating the selection indices were plant height, length of leaf lamina, leaf width, days to 50 per cent bolting, yield and leaf / stem ratio. The accessions AD 30, AD 23 and AD 22 were ranked superior in decreasing order based on selection index values.

Cataloguing of the accessions was done based on morphological characters using the simplified descriptor developed from IPGRI descriptor for amaranthus. All the accessions studied had erect growth habit and the branches were distributed all along the stem. The accession AD 28 differed from others in having conspicuous stem pubescence, low leaf pubescence, lanceolate leaves, pink coloured panicle with short branches and brown seeds. The stem pigmentation noticed were deep purple, purple, purplish green and pale green. Majority had pale green stem. The leaf pigmentation types noticed were normal green, dark green and green with margin and veins pigmented. The chromosome counting was done to ascertain the ploidy level of accessions.

Among these superior accessions AD 23 is the best considering its high nutritive value, resistance to leaf blight and high organoleptic score. This can be recommended for cultivation in leaf blight endemic areas. The accessions immune to leaf blight can be used for improvement of popular high yielding cultivars by using suitable breeding programmes. The white rust free accessions AD 14, AD 16 and AD 28 could be used in breeding to incorporate white rust resistance.

The accession AD 28 was found immune to leaf blight, free from white rust infection and also with low incidence of leaf webber infestation. But it was a low yielder and with minimum organoleptic score. So the multiple pest and disease trait can be transferred to popular susceptible varieties through breeding. A cross combination of AD 23 and AD 28 will be effective for getting lines with high yield, quality and multiple disease resistance.

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*Original not seen

VARIABILITY IN VEGETABLE AMARANTH (*Amaranthus dubius* Mart. ex Thell.) FOR YIELD, QUALITY AND RESISTANCE TO LEAF BLIGHT

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Abstract of the
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8. ABSTRACT

The experiment entitled "Variability in vegetable amaranth (*Amaranthus dubius* Mart. ex Thell.) for yield, quality and resistance to leaf blight" was conducted at College of Agriculture, Vellayani during the period 2000-2002. The experiment was carried out using 32 diverse accessions of *A. dubius* and the variety 'Arun' (*A. tricolor*) as the susceptible check. The objectives were to assess the variability in *A. dubius* germplasm for yield, quality and reaction to biotic stresses, to locate superior genotypes and to confirm the resistance of the accessions to *R. solani*. The ploidy level of the accessions were ascertained by counting the chromosome number.

The accessions were grown in the field in RBD with three replications. Analysis of variance of the observations showed significant difference among the accessions for all the characters. The yield obtained in the range 155.94 (AD 34) to 464.80 g (AD 30). The leaf / stem ratio was in the range 0.93 to 2.48. AD 34 showed late bolting and AD 3 early bolting.

The range of values for the quality characters were 9.03 to 23.00 per cent for protein, 5.67 to 15.67 per cent for fibre, 4331.50 to 8915.96 I.U. for vitamin A, 0.62 to 3.85 per cent for oxalate and 0.25 to 1.09 per cent for nitrate. AD 34 was organoleptically superior compared to others.

All the accessions of *A. dubius* were free from natural leaf blight incidence. 'Arun' the susceptible check showed PDI of 68.10. To confirm the resistance, artificial inoculation of the accessions was done by raising them in pots in CRD with four replications. Fourteen were immune, 15 were highly resistant and three were moderately resistant. The check variety 'Arun' was highly susceptible. The accessions AD 14, AD 16 and AD 28 were free from white rust infection. Others showed

PDI range 5.77 to 29.39. Sixteen accessions showed minimum infestation of leaf webber with score 1.00. The highest score was 3.00 (AD 11).

Higher PCV and GCV for most of the characters revealed greater variability. The range of heritability was 67.41 to 99.99. High heritability along with high genetic gain was observed in all the characters.

Plant height, stem girth, length of leaf lamina, leaf width, number of branches and days to 50 per cent bolting had positive genotypic correlation with yield. Leaf / stem ratio was negatively correlated. Plant height and leaf width showed high direct effect on yield in path analysis. The accessions AD 30, AD 23 and AD 22 were ranked superior based on the selection index value.

The accessions were catalogued morphologically using the simplified descriptor developed from IPGRI descriptor.

AD 23 is the best compared to AD 30 considering nutritional value, resistance to leaf blight and high organoleptic score. This can be recommended for cultivation in leaf blight endemic areas. The accession AD 28 was found to be resistant to leaf blight and white rust and also with minimum infestation of leaf webber. By crossing AD 23 and AD 28 desirable traits from both can be brought into one.

APPENDICES

APPENDIX – I

Score card for the organoleptic evaluation of cooked amaranthus

Quality attributes	Subdivision of attributes	Score for each attribute	Score for sample code No. 1 2 3 4 5
Appearance – colour	Natural colour well preserved	5	
	Colour fairly preserved	4	
	Moderately preserved	3	
	Slightly discoloured	2	
	Highly discoloured	1	
Doneness	Well cooked	5	
	Fairly cooked	4	
	Just cooked	3	
	Slightly cooked	2	
	Slightly overcooked	1	
Tenderness	Very soft	5	
	Soft	4	
	Fairly soft	3	
	Fibrous	2	
	Very fibrous	1	
Odour	Very pleasant	5	
	Fairly pleasant	4	
	No odour	3	
	Fairly unpleasant	2	
	Unpleasant	1	
Taste	Very good	5	
	Good	4	
	Bland	3	
	Bad	2	
	Very bad	1	

APPENDIX-II

Descriptor for amaranthus

1. Growth habit
    1. Erect
    2. Prostrate

2. Plant height (measured in cm)
    1 < 30
    2 30-45
    5 46-60
    7 > 60

3. Branching index
    1 No branches
    2 Few branches all near the base of the stem
    3 Many branches all near the base of the stem
    4 Branches all among the stem

4. Stem pubescence
    0 None
    3 Low
    5 Conspicuous

5. Stem pigmentation
    1 Green
    2 Pale green
    3 Purplish green
    4 Pink/purple
    5 Deep purple

6. Spines in leaf axis
    0 Absent
    1 Present

7. Leaf length (measured in cm on 5^{th} leaf)
    1 <5
    3 5-10
    5 11 and above

APPENDIX-II Continued

8. Leaf width (measured in cm on 5th leaf)
   - 1 < 5
   - 3 5-10
   - 6 11-16

9. Leaf pubescence
   - 0 None
   - 3 Low
   - 5 Conspicuous

10. Leaf pigmentation
   - 1 Entire lamina purple or red
   - 2 Basal area pigmented
   - 3 Green with deep purple centre
   - 4 Two stripes (V shaped)
   - 5 One stripe (V shaped)
   - 6 Green with margin and veins pigmented
   - 7 Purplish green
   - 8 Normal green
   - 9 Dark green

11. Leaf shape
   - 1 Lanceolate
   - 2 Elliptic
   - 3 Ovate
   - 4 Broad ovate
   - 5 Triangle ovate
   - 6 Rhombic ovate
   - 7 Rhombic

12. Leaf margin
   - 1 Entire
   - 2 Crenate
   - 3 Undulate

13. Prominence of leaf veins
   - 1 Smooth
   - 2 Slightly prominent
   - 3 Very prominent

APPENDIX-II Continued

14. Petiole pigmentation
    1 Green
    2 Dark green
    3 Purple
    4 Deep purple

15. Terminal inflorescence shape
    1 Spike (dense)
    2 Panicle with short branches
    3 Panicle with long branches
    4 Club shaped at tips

16. Terminal inflorescence attitude
    1 Erect
    2 Drooping

17. Axillary inflorescence
    0 Absent
    1 Present

18. Inflorescence colour
    1 Yellow
    2 Green
    3 Pink
    4 Red

19. Days to 50 per cent bolting
    1 30-45
    2 46-60
    3 61-75

20. Seed colour
    1 Pale yellow
    2 Pink
    3 Red
    4 Brown
    5 Black