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**GENETIC STUDIES ON GROWTH AND YIELD
ATTRIBUTES IN GRAIN AMARANTH
(*Amaranthus hypochondriacus* L.)**

THESIS

BY

MADHU PATIAL

Submitted to



**CSK HIMACHAL PRADESH KRISHI VISHVAVIDYALAYA
PALAMPUR – 176 062 (H.P.) INDIA**

IN

Partial fulfilment of the requirements for the degree

OF

**MASTER OF SCIENCE IN AGRICULTURE
(PLANT BREEDING)
2004**

CHOKHIL K. KRISHI VISHVA VIDYALAYA

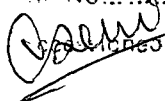
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*Tough were the days
Tougher were the nights,
I recall your precious love
and care for my smiles.
(Madhu)*

**DEDICATED TO
MY BELOVED
PARENTS, DADIJI,
SISTER AND
BROTHER**

Dr. S.R. Thakur
Sr. Plant Breeder

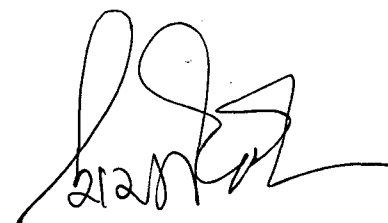
Department of Plant Breeding and
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CSK Himachal Pradesh
Krishi Vishvavidyalaya,
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CERTIFICATE I

This is to certify that the thesis entitled "**Genetic studies on growth and yield attributes in grain amaranth (*Amaranthus hypochondriacus* L.)**" submitted in partial fulfilment of the requirements for the award of the degree of **Master of Science (Agriculture)** in the subject of **Plant Breeding and Genetics** of CSK Himachal Pradesh Krishi Vishvavidyalaya, Palampur is a bonafide research work carried out by **Ms Madhu Patial (A-2002-30-21)** daughter of **Dr. K.K. Patial** under my supervision and that no part of this thesis has been submitted for any other degree or diploma.

The assistance and help received during the course of this investigation have been fully acknowledged.

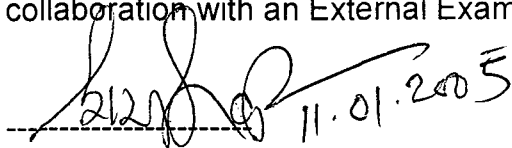
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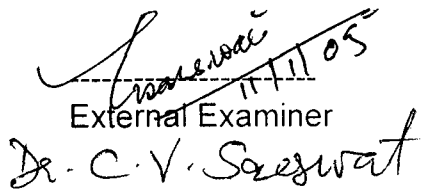
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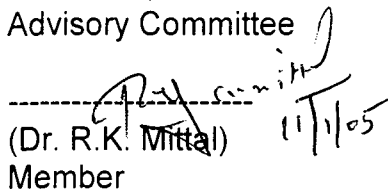
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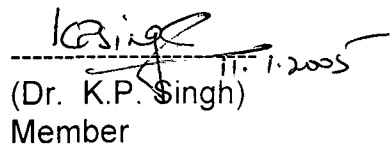
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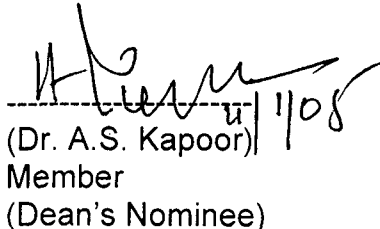

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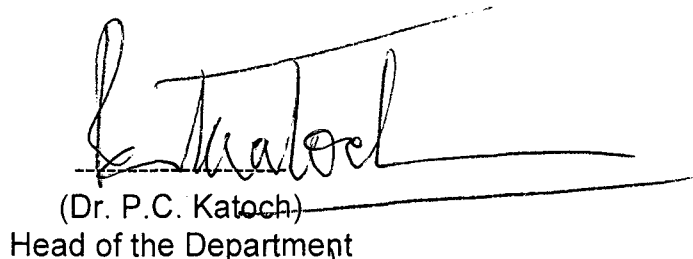
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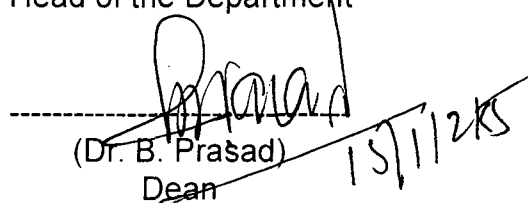

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(Dr. R.K. Mittal)
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11/1/05
(Dr. A.S. Kapoor)
Member
(Dean's Nominee)


(Dr. P.C. Katoch)
Head of the Department


15/1/2005
(Dr. B. Prasad)
Dean

Postgraduate Studies

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Twamev maata pita twamev, twamev bandhu sakha twamev;

Twamev vidya dravidum twamev, twamev sarvam mum dev devh.

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The painstaking efforts of computer centre staff for computerizing and critically editing the manuscript are sincerely acknowledged.

Needless to say, errors and omissions are mine.

Place: Palampur

Dated: 23rd December, 2004



(Madhu Patial)

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INTRODUCTION

INTRODUCTION

Grain amaranth (*Amaranthus spp.*) is a traditional crop of Himalayan region generally cultivated as mixed crop as well as sole crop as a part of subsistence agriculture in the hilly areas with comparatively lower rainfall under neglected agriculture conditions. With the advent of green revolution, the cultivation of this and many other under-utilized crops had seen a conspicuous decline. However, cultivation of amaranth has acquired increasing importance in breeders' and agronomists' mind recently and it is being considered as a potential subsidiary food crop as well as crop of future due to its excellent quality protein, tolerance to water scarcity and high photosynthetic efficiency, being a C₄ species (Teutonico and Knorr, 1985).

The decline in cultivation of this crop could also be because of the fact that the cultivators are not much aware of its complementary nutritive value and most probably the lack of efforts to promote its cultivation and the lack of suitable high yielding varieties. To reverse this declining trend of cultivation, quick varietal improvement is one of the important criteria. Though sporadic work has been done, systematic efforts have not been made for the improvement of this crop in the recent past in Himachal Pradesh.

Of the several plant breeding endeavours which have been in vogue for the improvement of crops, exploration of natural variability and use of selection *per se* or by computing a selection index is one of the most simple *ab initio* and

the modern method. This method is specifically suitable for the crops like grain amaranth, where considerable natural genetic variability is present specifically in the Himalayan region because of its geo, agro and bio-diversity.

Under the aegis of Indian Council of Agriculture Research, efforts have been intensified to prevent the declining cultivation of such crops with high nutritive value and potential to withstand adverse agro-ecological conditions thereby giving atleast some yield *vis à vis* the other cereal crops with intense agriculture requirement. Improvement of grain amaranth and some other under-utilized crops has therefore also been initiated at Department of Plant Breeding and Genetics, CSK Himachal Pradesh Krishi Vishvavidyalaya, Palampur. For the identification of high yielding genotypes at the shortest possible time, the simplest method of selecting suitable genotypes out of indigenous collections has been followed.

Since yield is a complex trait having low heritability, *per se*, selection for it is generally ambiguous and leads to unpredictable results. Indirect selection by making use of highly heritable, simple inherited traits have been advocated and used for the improvement of yield since time immemorial. Borojevic (1990) and Wallace *et al.* (1993) while reviewing the practical impact of indirect selection in yield enhancement, have concluded that indirect selection has not made much impact on practically yield improvement by following selection index or otherwise *vis a vis* in animal breeding. Borojevic (1990) has further argued that most suitable traits are needed to be found out for getting gains by indirect selection in plant species. However, Wallace *et al.* (1993) proposed that efficiency of

breeding for higher yield can be raised by applying yield system analysis. They identified the three major genetically controlled, physiological components of yield and gave a group of eight sub-component traits of yield and the group of these nine traits including yield were christened yield system traits, to be studied for making their use in indirect selection for yield. The identification of most suitable simply inherited morphological or physiological traits for indirect selection for yield is therefore sought for. Due consideration for selection of such traits for effective results have also been emphasized by Yan and Wallace (1995).

Hence, to identify most suitable traits, leading to gains in yield by indirect selection in the present study, considerations of taking observations on yield system traits, some basic yield subcomponent traits, traits associated with growth parameters and the protein content have been made. Twenty-two elite selections of grain amaranth, most of these from the endemic collections from Kinnaur and Shimla districts of Himachal Pradesh have been taken. Studies on variability, heritability and other genetic parameters, and association studies by correlations and path coefficients have been conducted. On the basis of which most suitable traits for effective selection *per se* or by making use of selection index are sought for. This piece of work has therefore been undertaken with the following objectives:

Objectives:

1. To find out nature and magnitude of variation of growth parameters, yield system, protein content and other traits.
2. To understand the association of growth parameters, yield system and other traits with yield through correlation and path coefficient.
3. To identify potential yielding genotypes.

REVIEW OF LITERATURE

REVIEW OF LITERATURE

The development of an effective plant-breeding programme is dependent upon the existence of genetic variability in a given crop species. Genetic variability, as an index of genetic architecture of a population and a pre-requisite for crop improvement programme, has been widely used in evolving high yielding varieties. The use of genetic variability for varietal improvement can be accomplished in the simplest way by selections. Selection, that is choosing plants with desirable characteristics, is the pivotal point in plant breeding. Selection at any stage, is fruitful only if the breeder is acquainted with the nature and magnitude of variability and *inter alia* association of characters with yield. Effective selection, however, depends upon the heritable part of the variations of different traits. *On a priori* biomass production in plant could be speculated due to the contribution of all the genes present in a genotype. The yield, however, is a complex trait governed by several genes, in general, with small effects and their contribution is influenced highly by environment thereby showing low heritability for this trait and therefore *per se* selection of yield, in general, is ineffective and unreliable. So, it is imperative to identify the highly heritable simple traits having high correlation with complex trait like yield. For making indirect selection for yield by selecting individual trait or group of traits, forming a selection index, hence, becomes crucial. For initiating any crop improvement programme based on selection, the perusal of literature regarding variations

present in the morphological, structural, physiological traits and traits related with growth analysis in the material under consideration alongwith their nature of associations, therefore, becomes pertinent. The available relevant literature pertaining to various aspects of the present study on grain amaranth is scanty and is briefly reviewed under the following sub heads:

2.1 Variability parameters, heritability and genetic advance.

2.2 Correlation studies.

2.3 Path analysis.

2.1 Variability parameters, heritability and genetic advance

2.1.1 Variability parameters

The simplest method of studying variability is measurement of variant values of different characters in different individuals at phenotypic level. As is well known, heritable variability is of breeders' interest. Fisher (1918) partitioned the continuous variation exhibited by a quantitative character into heritable and non-heritable components, the former being a consequence of genotype while the latter, a result of environmental factors.

Jain and Hauptil (1980) observed the range of 1000 kernel weight of amaranth from 0.6 to 1.2g. Mohideen *et al.* (1983) reported significant variability in eight genotypes of amaranth for plant height, days to flowering, and yield per plant. Plant height varied from 59.7 to 189.2 cm, days to flowering from 31 to 145 days and seed yield per plant ranged from 4.8 to 19.4g.

Joshi (1986) reported wide range of variation in amaranth for plant height, leaf length and width, inflorescence length, days to maturity, 1000 seed weight,

seed protein content and seed yield per plant. Genotypic coefficient of variation (GCV) in these traits varied from 3.1 to 24.7 per cent, highest being for leaf width (24.7%) followed by protein content (15.10 %) and yield (6.20 %). The phenotypic coefficient of variation (PCV) ranged from 9.0 to 66.8 per cent, the former being for seed yield and the latter for leaf width.

Bressani *et al.* (1987) in seven cultivars of *Amaranthus hypochondriacus* reported that days to flowering ranged from 26 to 92 days, plant height at harvest from 75 to 280 cm, days to harvest from 80 to 146 days, protein content from 13.70 to 15.60 per cent and yield from 4.94 to 14.73 kg per 36 square metre. Girenko and Chikova (1988) reported days to maturity ranging from 55 to 130 days and plant height at flowering from 30 to 250 cm. Highest seed yield was found to be 100 g per plant.

Hirano *et al.* (1990) found that Crop Growth Rate (CGR) decreased during late stage of plant growth while Leaf Area Index (LAI) increased during early stage and then decreased slowly. Net Assimilation Rate (NAR) was found to decrease as the growth progressed in amaranth.

Calderon *et al.* (1991) in a mixture of fifteen amaranthus varieties from *Amaranthus cruentus*, *Amaranthus hybridus*, *Amaranthus hypochondriacus* and two unidentified species found plant height ranged from 160 to 230 cm, protein percentage from 12.74 to 14.65 per cent and yield from 5.13 to 10.48 kg per 27 square meter.

Jha *et al.* (1992) showed variation in the growth attributes and productivity in amaranth collections. Plants of the same landrace exhibited variation in plant

height, inflorescence length and yield. Amaranth plant attained a height between 0.5 and 2.5 m and their inflorescence length was observed to be ranging between 12.0 to 41.0 cm. Maturity period of different amaranth collections varied between 120 to 150 days and the average yield ranged between 380 to 1480kg per ha.

Geetha *et al.* (1994) found weight of 1000 kernel of amaranth grains to range from 0.60 to 1.0g in eleven varieties and the range of protein content was 15.20 to 19.60 per cent. Bansal *et al.* (1995) in a varietal trial consisting of five entries of amaranth, reported plant height to be ranging from 72.3 to 193.3 cm, leaf area index of 3.10 to 3.59, days to flowering from 44.5 to 91.8 days, days to maturity from 86.5 to 117.8 days, spike length from 39.4 to 51.5 cm and seed yield per plant from 10.09 to 13.19g.

According to Joshi and Rana (1995 b), plant height in grain amaranth ranged from 212.17 to 250.72 cm, inflorescence length from 60.50 to 97.63 cm, days to maturity from 134.83 to 140.44 days, protein content from 13.70 to 16.25 per cent and grain yield per plant from 33.50 to 55.16 g.

Lohithaswa *et al.* (1996) found considerable amount of phenotypic and genotypic variability for grain yield, stem girth and plant height of amaranth. However, Ghosh *et al.* (1999) reported very high genotypic and phenotypic coefficient of variation for main panicle length and plant height.

Johnson and Henderson (2002) observed significant differences among cultivars of amaranth for plant height and harvest index. Shukla and Singh (2002) reported days to flowering ranging from 44.33 to 75.33 days, days to

maturity from 123.5 to 160.6 days, plant height from 31.67 to 125.33 cm, inflorescence length from 10.0 to 39.0 cm and grain yield per plant from 6.17 to 27.73 g.

Sarma *et al.* (2003) found range of variation in amaranth for plant height from 147 to 210 cm, inflorescence length from 375 to 894 mm, 1000 seed weight from 580 to 924 mg and yield per plant from 15 to 42 g.

2.1.2 Heritability and genetic advance

Heritability is the portion of genotypic variation which is transmitted from generation to generation. Lush (1940) classified heritability into broad sense and narrow sense. Heritability in broad sense is the portion of genetic variance to the total variance and therefore, gives the broad perspective, whereas the narrow sense heritability is the portion of additive genetic variance to the total variance and gives precise estimate of genetic variability. The knowledge of heritability for different traits is therefore essential for crop improvement.

Expected genetic gain gives a measure of effectiveness of selection. Burton and Devane (1953) suggested that a combination of genetic coefficient of variation and heritability estimates give a reliable indication of amount of improvement to be expected from selection and further remarked that expected genetic advance under particular system supplies a practical information that is needed by the breeder for varietal improvement. Panse (1957) advocated that the magnitude of heritable variability and its genetic component is the most important aspect of the genetic constitution of the breeding material which has a close bearing on its response to selection.

Heritability itself does not provide any indication for genetic improvement in any character. An estimate of genetic advance which depends upon selection differential and heritability helps in predicting the possible improvement when selection is made in the desired direction.

Joshi (1986) showed that heritability estimates and expected genetic advance were higher for 1000 seed weight, inflorescence length and plant height, followed by seed yield and percentage of protein in grain amaranth. Joshi and Rana (1995a) found high heritability and genetic advance for inflorescence length and grain yield in amaranth.

Lohithaswa *et al.* (1996) reported high heritability coupled with moderate genetic advance for plant height and days to 50 per cent flowering indicating that additive gene effects were operative for these characters and selection pressure could be applied on them for yield improvement. Moderate heritability with moderate genetic advance was observed for stem girth at collar region indicating the importance of both additive and non-additive gene action for the character.

Ghosh *et al.* (1999) revealed high heritability together with high to moderate genetic advance for main panicle length, plant height and seed yield of amaranth.

Heritability estimates (broad sense) were found to be high for days to maturity (97.90 %) and days to 50 % flowering (95.50 %) which was reported by Sarma *et al.* (2003) and the genetic advance was high for plant height (23.16 %).

2.2 Correlation Studies

Yield being polygenic, shows low heritability due to which selection in general remains ineffective. For selection to be effective, the concept of correlation of yield with other simply inheritable traits with high heritability is explored.

Correlation coefficient is a measure of the degree of association between the two traits worked out at the same time. The basic idea of correlation was put forth by Galton (1889) and was elaborated by Fisher (1918) and Wright (1921). Engledow and Wadham (1923) advocated studies of the physiological basis of yield, and correlations between physiological components and yield.

Gregory (1926) and Watson (1952) in separate studies emphasized the importance of leaf area in build-up of dry matter of crop plants. They observed that increase in yield was mainly dependent on the improved conditions of leaf production. Positive relationship between production of dry matter and leaf area development had been reported till the latter reached maximum, following which a reduction in dry matter production was observed when leaf area further increased (Kasanga and Monsi, 1954 and Donald, 1961). Johnson *et al.* (1955) stated that estimates of genotypic and phenotypic correlations among characters are useful in planning and evaluation of breeding programmes.

Bressani *et al.* (1987) revealed a positive relationship between plant height at harvest and grain yield, seed weight was not correlated with yield and protein content was negatively correlated with yield. Imeri *et al.* (1987) reported positive correlation between yield and protein content of amaranth.

Ayiecho and Jain (1990) on the basis of simple correlations reported the importance of plant height, seed weight, harvest index and days to flowering for seed yield improvement in amaranth. Agong and Ayiecho (1992) in grain amaranth found that head length showed positive correlation with seed yield per plant and plant height. They also reported that days to flowering and maturity were positively correlated with each other and with seed yield per plant.

Joshi and Rana (1995a) observed that grain yield showed significant positive correlation with plant height, leaf length and breadth and inflorescence length in amaranth. Ghosh *et al.* (1999) showed plant height of amaranth to be significantly correlated with days to flowering and main panicle length.

Sarma *et al.* (2003) revealed significant positive correlation of seed yield with inflorescence length, plant height and maturity. Days to maturity and inflorescence length alone contributed 72.6 per cent towards grain yield.

A correlation analysis of yield and yield components viz., number of days to flowering, number of days to maturity, plant height, inflorescence length and leaf size was conducted using sixty-six amaranthus genotypes by Shukla and Singh (2003). They found that genotypic correlation was higher than the corresponding phenotypic correlation. At the phenotypic level, significant and positive association was observed between grain yield per plant and plant height. Number of days to flowering and number of days to maturity were negatively correlated.

2.3 Path Analysis

Path coefficient proposed by Wright (1921, 1923, 1934 and 1960) and also discussed by Niles (1922), Turkey (1954), Li (1956), Kempthorne (1957) and Turner and Stewans (1959) is a standardized partial regression coefficient. It permits the partitioning of the correlation coefficient into direct and indirect effects.

Joshi and Rana (1995a) observed that plant height and 1000 grain weight have direct effect on grain yield and reported that inflorescence length was the most potential trait for genetic improvement.

Shukla and Singh (2003) reported the positive and indirect association of plant height with grain yield *via* days to flowering and inflorescence length.

MATERIALS AND METHODS

MATERIALS AND METHODS

The experiments were executed in the farm of the Department of Plant Breeding and Genetics, CSK Himachal Pradesh Krishi Vishvavidyalaya, Palampur during *kharif* 2002 and 2003. The farm is situated at an elevation of about 1300 m.a.m.s.l with 36°6'N latitude and 76°3'E longitude, which represents the mid-hill zone of Himachal Pradesh.

3.1 Experimental Material

Twenty-two grain amaranth genotypes *viz*, Annapurna, IC35407, JRS502, JRS503, JRS504, JRS505, JRS506, JRS507, JRS508, PRA9101, Sangla A1, Sangla A2, Sangla A3, Sangla A4, Sangla A5, Sangla A6, Sangla A7, Sangla A8, Sangla A9, Sangla A10, Sangla A11 and Shimla A1 were used as the experimental material. The exact locations of twelve genotypes which are the selections from collection of germplasm from various parts of Kinnaur and Shimla district are given in table 1. Other lines have been got from National Bureau of Plant Genetic Resources, New Delhi.

Table 1. List of a few grain amaranthus genotypes and their location of collection

Genotypes	Location of Collection	District Name
Sangla A1	Katgaon	Kinnaur
Sangla A2	Dang-Dang See	Kinnaur
Sangla A3	Kuppa	Kinnaur
Sangla A4	Jeori	Shimla
Sangla A5	Badhal	Shimla
Sangla A6	Powari	Kinnaur
Sangla A7	Telungy	Kinnaur
Sangla A8	Kafnu	Kinnaur
Sangla A9	Bara Gambha	Kinnaur
Sangla A10	---	Kinnaur
Sangla A11	Spillo	Kinnaur
Shimla A1	---	Shimla

3.2 Field Experimentation

The twenty-two genotypes of grain amaranth (*Amaranthus hypochondriacus* L.) were raised in a Randomized Complete Block Design with three replications during *kharif* 2002 and 2003. The plot size was kept as 1.5m x 3.15m. Each entry was raised in three rows and the rows were 50 cm apart and plant to plant distance was 15 cm, which was maintained by thinning. The plant population of 20 ± 1 plants per row was maintained. All the recommended package of practices was followed for raising a good crop.

3.3 Experimental Procedure for Recording of Observations

Data were recorded on several traits grouped into – traits associated with growth analysis, yield system traits as described by Wallace *et al.* (1993) as well as a few other traits.

3.3.1 Data recording for growth analysis

3.3.1.1 Growth Stages: During 2002 and 2003, the data for growth parameter analysis was recorded at an interval of twelve days, these intervals have been treated as individual growth stage. During *kharif* 2002, data recording was started from seventy-third day after sowing, covering three stages till harvesting and during 2003 it began on thirty-fifth day after sowing, covering six stages till harvesting. The different stages taken during 2003 were 35-47 days = GS₁, 48-60 days = GS₂, 61-73 days = GS₃, 74-86 days = GS₄, 87-99 days = GS₅ and 100- days to harvesting = GS₆. During 2002, observations on growth parameters

were recorded in the stages designated from 73-85 days=GS₄, 86-98 days=GS₅ and 99 – days to harvesting = GS₆.

3.3.1.2 Leaf Area: During *kharif* 2002 and 2003, three plants of each genotype in each replication were randomly selected and were cut very close to the ground. All the leaves were separated from the stem and grouping of leaves into different categories based on size (ranging from small to large) was done. The area of three randomly selected leaves from each group was measured with the help of Leaf Area Meter (ΔT Area Meter MK2; Hitachi). Based on this, the area of one leaf was computed which was then multiplied by total number of leaves in each group. The area of different groups was added and total leaf area per plant in decimeter square was calculated.

3.3.1.3 Dry Matter Accumulation: All the leaves of each genotype in each replication (whose leaf area was calculated earlier) were collected in a tassel bag and twigs, stems and inflorescence of the same plant were put in other tassel bag. These were dried in an oven at about 80°C till a constant weight was achieved. The sum total weight of leaves, twigs, stems and inflorescence was taken as the measure of total dry matter accumulation at each stage.

3.3.1.4 Growth Parameters: Eleven growth parameters *viz.*, Absolute Growth Rate (AGR), Relative Growth Rate (RGR), Net Assimilation Rate (NAR), Leaf Area Ratio (LAR), Relative Leaf Growth Rate (RLGR), Specific Leaf Area (SLA), Specific Leaf Weight (SLW), Leaf Weight Ratio (LWR), Crop Growth Rate (CGR), Leaf Area Index (LAI) and Leaf Area Duration (LAD) were calculated during *kharif* 2002 and 2003. These growth parameters were calculated on the

basis of the average of the data recorded at three stages (73 days - harvesting) during 2002 and six stages (35 days - harvesting) during 2003. The total period for which data for growth parameters was recorded i.e. from 35 days of growth to harvesting have been arbitrarily divided into four different stages i.e. initial active vegetative stage (S_1), initial active vegetative stage to pre flowering stage (S_2), initial post flowering stage (S_3) and initial post flowering to grain filling period (S_4). This has been done to understand the importance of some specific growth periods where the calculation of growth parameters will be of utmost importance than their calculation based on average of several stages.

3.3.1.5 Data recording of yield system and other traits: Data was recorded on nine yield system traits (Wallace *et al.*, 1993) viz., days to flowering, days to maturity, days to seed fill, aerial biomass per plant at harvest maturity, seed yield per plant at harvest maturity, yield per day to maturity, yield per day to seed fill, biomass per day to plant growth and harvest index. Other traits recorded on different grain amaranth genotypes were panicle length, plant height, panicle girth, stem girth, 10ml seed weight, leaf area and protein content. Though leaf area was recorded at several growth stages, however, leaf area at maximum leaf weight stage i.e. GS_5 (87-99 days) has only been taken for calculating its correlation with yield system and other traits during both the years.

Data on different traits was recorded on five randomly selected competitive plants in each replication for each grain amaranth genotype, except on days to flowering, days to maturity and days to seed fill where it was recorded

on plot basis and 10 ml seed weight (g) and protein content (%), based on composite mixture of seeds for each entry in each replication.

The methodologies used for data recording of different plant traits have been described in the individual head here under.

1. **Days to flowering:** Number of days from sowing to when approximately 50 per cent plants beared flowers was recorded.
2. **Days to maturity:** The number of days from sowing till about 75 per cent plants showed maturity was recorded.
3. **Days to seed fill:** Difference between days to maturity and days to flowering was taken as days to seed fill.
4. **Aerial biomass/plant at harvest maturity (g):** Total weight (g) of aerial biomass of each plant was taken.
5. **Seed yield/plant at harvest maturity (g):** Seed weight (g) produced at harvest maturity was recorded.
6. **Yield/day to maturity (g/day):** It was calculated as

$$\frac{\text{Seed yield/plant (g)}}{\text{Number of days to maturity}}$$
7. **Yield/day to seed fill (g/day):** It was calculated as

$$\frac{\text{Seed yield/plant(g)}}{\text{Days to seed fill}}$$
8. **Biomass/day to plant growth (g/day):** It was calculated as

$$\frac{\text{Aerial biomass/plant (g)}}{\text{Days to maturity}}$$

9. **Harvest index (%)**: Harvest index was calculated as

$$\frac{\text{Seed yield/plant (g)}}{\text{Aerial biomass/plant (g)}} \times 100$$
10. **Plant height (cm)**: Height of each grain amaranth genotype was measured from ground level to the tip of panicle at maturity.
11. **Panicle length (cm)**: Length of main panicle was recorded at the time of maturity.
12. **Panicle girth (cm)**: Girth of main panicle was measured at the time of maturity.
13. **Stem girth (cm)**: The stem girth of each selected plant was measured from the middle of plant.
14. **10 ml seed weight (g)**: 10 ml seeds were weighted out to work out 10 ml seed weight of each genotype.
15. **Leaf area (dm²)**: Methodology has already been described under heading 3.3.1.2.
16. **Estimation of protein content (%)**: A composite seed sample from the bulk produce of each replication was analysed for the estimation of nitrogen content. The grains were ground to fine powder. Total nitrogen was estimated by the standard micro Kjeldahl's method (Jackson, 1967). The protein percentage was calculated as follows:

$$\% \text{ Protein} = \% \text{N} \times 6.25$$

3.4 Formulae for the Calculation of Growth Parameters

Various growth parameters were worked out from the data obtained on leaf area and dry weight of different plant parts (i.e. stems, twigs, leaves and panicle). The formulae used in the present studies are described below.

1. **Absolute growth rate (AGR):** The AGR exhibits the dry matter accumulation per unit of time and was calculated by formula suggested by Radford (1967) and expressed in g/day.

$$\text{AGR} = \frac{W_2 - W_1}{T_2 - T_1}$$

2. **Crop growth rate (CGR):** It is the rate of dry matter production per unit of time per unit of ground area (Watson, 1952) and expressed as g/dm²/day.

$$\text{CGR} = \frac{W_2 - W_1}{T_2 - T_1} \times \frac{1}{A}$$

3. **Relative growth rate (RGR):** It indicates the rate of increase in dry weight per unit of dry weight already present and calculated as given by Blackman (1919) and expressed in g/g/day.

$$\text{RGR} = \frac{\text{Log}_e W_2 - \text{Log}_e W_1}{T_2 - T_1}$$

4. **Net assimilation rate (NAR):** It is the rate of increase of dry weight per unit of leaf area per unit time (Radford, 1967) and expressed as g/dm²/day.

$$\text{NAR} = \frac{(W_2 - W_1)}{(T_2 - T_1)} \times \frac{(\text{Log}_e L_2 - \text{Log}_e L_1)}{(L_2 - L_1)}$$

5. **Leaf area ratio (LAR):** LAR is the ratio of the assimilatory material (leaf area) per unit of plant material present (Radford, 1967) and calculated as

$$\text{LAR} = \frac{(L_2 - L_1)}{(W_2 - W_1)} \times \frac{(\text{Log}_e W_2 - \text{Log}_e W_1)}{(\text{Log}_e L_2 - \text{Log}_e L_1)}$$

6. **Relative leaf growth rate (RLGR):** It is the increase in the rate of leaf area per unit of leaf area present per unit of time (Watson, 1952) and expressed as $\text{dm}^2/\text{dm}^2/\text{day}$.

$$\text{RLGR} = \frac{(\text{Log}_e L_2 - \text{Log}_e L_1)}{T_2 - T_1}$$

7. **Leaf area index (LAI):** Leaf area index is defined as the ratio of leaf area per unit area of land and calculated as given by Watson (1952).

$$\text{LAI} = \frac{\text{Leaf area (dm}^2/\text{plant)}}{\text{Land area (dm}^2/\text{plant)}}$$

8. **Leaf area duration (LAD):** LAD is defined as a measure of the ability of plant in duration to produce and maintain leaf area on unit area of land throughout its life and hence its whole opportunity for assimilation (Welbank *et al.*, 1966) and expressed in days.

$$\text{LAD} = \frac{\text{LAI}_1 + \text{LAI}_2}{2} \times (T_2 - T_1)$$

9. **Specific leaf weight (SLW):** It indicates the thickness of leaf and was calculated by the method given below and expressed in g/dm^2 .

$$\text{SLW} = \frac{\text{Leaf dry weight (g)}}{\text{Leaf area (dm}^2\text{)}}$$

10. **Specific leaf area (SLA):** It is the increase in per unit of leaf area to increase in per unit of leaf weight and was calculated by the following relationship and expressed in dm^2/g .

$$\text{SLA} = \frac{(L_2 - L_1)}{(\text{Log}_e L_2 - \text{Log}_e L_1)} \times \frac{(\text{Log}_e \text{LW}_2 - \text{Log}_e \text{LW}_1)}{(\text{LW}_2 - \text{LW}_1)}$$

11. **Leaf weight ratio (LWR):** LWR is the ratio of leaf weight to total dry weight of plant and was worked out by the formula.

$$\text{LWR} = \frac{(\text{LW}_2 - \text{LW}_1)}{(\text{Log}_e \text{LW}_2 - \text{Log}_e \text{LW}_1)} \times \frac{(\text{Log}_e W_2 - \text{Log}_e W_1)}{(W_2 - W_1)}$$

where,

W_1 and W_2	=	Total dry weight of plant at stage I & II (grams)
L_1 and L_2	=	Total leaf area at stage I & II (dm^2)
LW_1 and LW_2	=	Total leaf weight at stage I and II (gram)
$T_2 - T_1$	=	Time interval between stage II and I (days)
A	=	Land area covered by plant (dm^2)

3.5 Analysis of Variance

To test the significance of differences among different genotypes/breeding material used in the study, the data on mean values for yield, its components and grain quality traits was analysed as per the standard procedures, for a Randomized Complete Block Design (Panse and Sukhatme, 1984). Analysis of variance for each trait was based on the following linear model as given by Fisher (1954) and also referred by Panse and Sukhatme (1984).

$$P_{ij} = \mu + g_i + b_j + e_{ij}$$

where,

- P_{ij} = phenotypic effect of the i th genotypes in the j th replication,
- μ = general population mean,
- g_i = effect of i th genotype,
- b_j = effect of j th replication, and
- e_{ij} = random error associated with i th genotype in j th replication.

The total variance based on this model was partitioned into different components as under.

Source	df	Ms	Expected Ms	F cal
Replication	(r - 1)	Mr	$\sigma^2_e + g\sigma^2_r$	Mr/Me
Genotypes	(g - 1)	Mg	$\sigma^2_e + r\sigma^2_g$	Mg/Me
Error	(g - 1) (r - 1)	Me	σ^2_e	

where,

- r = number of replications, and
- g = number of genotypes
- Genotypic variance (σ^2_g) = $(Mg - Me)/r$
- Phenotypic variance (σ^2_p) = $\sigma^2_g + \sigma^2_e$
- Error Variance (σ^2_e) = Me

The standard error of mean [SE(m)], stand error of difference [SE (d)] and critical difference [CD] for comparing the means of any two genotypes were calculated as below:

$SE (m) = \pm (Me/r)^{1/2}$
 $SE (d) = \pm (2Me/r)^{1/2}$
 $CD = SE(d) \times t (5\%) \text{ value at error degree of freedom.}$

3.6 Estimation of Components of Variability and Genetic Parameters

The phenotypic and genotypic coefficients of variation, heritability in broad sense and expected genetic advance were calculated as suggested by Burton and Devane (1953) and Johnson *et al.* (1955).

i Phenotypic coefficient of variation (PCV%) = $(\sigma_p / \bar{x}) \times 100$

ii Genotypic coefficient of variation (GCV %) = $(\sigma_g / \bar{x}) \times 100$

where,

σ_p = phenotypic standard deviation,

σ_g = genotypic standard deviation, and

$\bar{x}$ = grand mean

iii Heritability in broad sense was calculated as suggested by Allard (1960)

$$\text{Heritability } [h^2_{bs} \text{ \%}] = \frac{\sigma^2_g}{\sigma^2_g + \sigma^2_e} \times 100$$

iv Genetic advance was calculated as suggested by Lush (1940) and further used by Burton and Devane (1953) and Johnson *et al.* (1955).

Genetic advance (GA) = $K \times \sigma_p \times h^2_{bs}$

Expected genetic advance of mean (%) = $(GA / \bar{x}) \times 100$

where,

K = selection differential at 5% selection index i.e. 2.06,

σ_p = phenotypic standard deviation.

For categorizing the magnitude of different parameters, the following limits were used:

PCV and GCV: >20% - high; 10-20% - moderate; <10% - low

Heritability : >60% - high; 30-60% - medium; <30%-low

Genetic advance: >30% - high; 20 – 30% - medium; <20% - low

3.7 Correlation coefficients

For computing the phenotypic and genotypic coefficient of correlation, analysis of covariance was performed in all possible paired combinations of various traits studied. The analysis of covariance table was set up as follows:

Analysis of Co-variance			
Source	df	Mean sum of products	Expected mean sum of products
Replication	(r - 1)	Mr_{xy}	$\sigma^2 e_{xy} + g\sigma r_{xy}$
Genotypes	(g - 1)	Mg_{xy}	$\sigma^2 e_{xy} + r\sigma g_{xy}$
Error	(g - 1) (r - 1)	Me_{xy}	σe_{xy}

where,

r = number of replications, and

g = number of genotypes.

Genotypic covariance (σg_{xy}) = $(Mg_{xy} - Me_{xy})/r$

Phenotypic covariance (σp_{xy}) = $\sigma g_{xy} + \sigma e_{xy}$

Environmental covariance (σe_{xy}) = Me_{xy}

The genotypic and phenotypic coefficient of correlations were computed as per Al Jibouri *et al.* (1958).

i Phenotypic coefficient of correlation

$$rp_{xy} = \sigma p_{xy} / (\sigma^2 p_x \times \sigma^2 p_y)^{1/2}$$

where,

σp_{xy} = phenotypic covariance between two characters x and y,

$\sigma^2 p_x$ = phenotypic variance of character x, and

$\sigma^2 p_y$ = phenotypic variance of character y.

ii Genotypic coefficient of correlation

$$rg_{xy} = \sigma g_{xy} / (\sigma^2 g_x \times \sigma^2 g_y)^{1/2}$$

where,

σg_{xy} = genotypic covariance between two characters x and y,

$\sigma^2 g_x$ = genotypic variance of character x, and

$\sigma^2 g_y$ = genotypic variance of character y.

The significance of phenotypic coefficient was tested against table value of 'r' at n-2 and (r-1) (n-1)-1 degrees of freedom as given by Fisher and Yates (1963).

3.8 Path Coefficient Analysis

Path coefficient is a standardized partial regression coefficient. It permits the partitioning of the correlation into direct and indirect effects. Path coefficient analysis of various growth parameters, yield system and other traits including protein content with seed yield was worked out, following Dewey and Lu (1959) as under.

$$P_{y1} + P_{y2} \cdot r_{12} + P_{y3} \cdot r_{13} + \dots + P_{yn} \cdot r_{1n} = r_{y1}$$

$$P_{y1} \cdot r_{12} + P_{y2} + P_{y3} \cdot r_{23} + \dots + P_{yn} \cdot r_{2n} = r_{y2}$$

$$\dots$$

$$\dots$$

$$\dots$$

$$P_{y1} \cdot r_{n1} + P_{y2} \cdot r_{n2} + P_{y3} \cdot r_{n3} + \dots + P_{ny} = r_{ny}$$

where,

$P_{y1}, P_{y2}, P_{y3}, \dots, P_{yn}$ are the direct path effects of 1,2,3, ..., n variables on the dependent variable 'y'.

$r_{12}, r_{13}, \dots, r_{(n-1)n}$ are the possible coefficients of correlation between various independent variables.

$r_{y1}, r_{y2}, \dots, r_{yn}$ are the coefficient of correlation of independent variables with dependent variable y.

The residual factor (i.e. the variation in yield unaccounted for those associations) was calculated from the following formula.

$$\text{Residual factor (x)} = 1 - R^2$$

$$R^2 = P_{y1} r_{y1} + P_{y2} r_{y2} + \dots + P_{yn} r_{yn}$$

where,

R^2 is the squared multiple correlation coefficient and is the amount of variation in yield that can be accounted for by the yield component character.

RESULTS

RESULTS

The results obtained on various aspects of the investigation carried out during *kharif*, 2002 and *kharif*, 2003 in grain amaranth are presented below

4.1 Studies on Genetic Variability

4.1.1 Analysis of Variance

Growth parameters were estimated and data were analysed at three specific stages *viz.*, GS₄, GS₅ and GS₆ during 2002 and six specific stages *viz.*, GS₁, GS₂, GS₃, GS₄, GS₅ and GS₆ during 2003. However the growth parameters based on the average of three stages during 2002 and of six stages during 2003 have been taken as a base data for all general descriptions, and, some values of significance at some specific individual stages have also been referred wherever felt necessary.

The analysis of variance for eleven growth parameters (Absolute Growth Rate, AGR; Crop Growth Rate, CGR; Relative Growth Rate, RGR; Net Assimilation Rate, NAR; Leaf Area Ratio, LAR; Relative Leaf Growth Rate, RLGR; Specific Leaf Area, SLA; Specific Leaf Weight, SLW; Leaf Weight Ratio, LWR; Leaf Area Index, LAI; and Leaf Area Duration, LAD) estimated on the basis of mean of all the stages is presented in table 1. Analysis of variance showed that the difference due to genotypes for all growth parameters were significant at all growth parameters during both the years.

Table 1: Analysis of variance for different growth parameters in grain amaranth during 2002 and 2003 based on means of different stages

Growth parameters	Source	df	2002	2003
Absolute growth rate AGR(g/day)	Replications	2	0.27×10^{-2}	0.39×10^{-3}
	Genotypes	21	0.13*	$0.44 \times 10^{-1*}$
	Error	42	0.24×10^{-2}	0.17×10^{-3}
Crop growth rate CGR(g/dm²/day)	Replications	2	0.94×10^{-2}	0.29×10^{-4}
	Genotypes	21	$0.21 \times 10^{-2*}$	$0.83 \times 10^{-3*}$
	Error	42	0.11×10^{-3}	0.82×10^{-5}
Relative growth rate RGR(g/g/day)	Replications	2	0.20×10^{-5}	0.65×10^{-4}
	Genotypes	21	$0.77 \times 10^{-4*}$	$0.49 \times 10^{-4*}$
	Error	42	0.99×10^{-6}	0.80×10^{-5}
Net assimilation rate NAR (g/dm²/day)	Replications	2	0.45×10^{-4}	0.45×10^{-5}
	Genotypes	21	$0.12 \times 10^{-3*}$	$0.36 \times 10^{-4*}$
	Error	42	0.41×10^{-5}	0.30×10^{-5}
Leaf area ratio LAR	Replications	2	0.12×10^{-1}	0.25×10^{-2}
	Genotypes	21	$0.77 \times 10^{-1*}$	$0.62 \times 10^{-1*}$
	Error	42	0.12×10^{-2}	0.30×10^{-3}
Relative leaf growth rate RLGR (dm²/dm²/day)	Replications	2	0.63×10^{-3}	0.93×10^{-9}
	Genotypes	21	$0.52 \times 10^{-4*}$	$0.17 \times 10^{-4*}$
	Error	42	0.48×10^{-5}	0.32×10^{-5}
Specific leaf area SLA (dm²/g)	Replications	2	0.68×10^{-1}	0.13×10^{-2}
	Genotypes	21	0.18*	0.11*
	Error	42	0.18×10^{-2}	0.48×10^{-3}
Specific leaf weight SLW (g/dm²)	Replications	2	0.87×10^{-1}	0.17×10^{-2}
	Genotypes	21	$0.39 \times 10^{-1*}$	$0.22 \times 10^{-1*}$
	Error	42	0.23×10^{-2}	0.33×10^{-3}
Leaf weight ratio LWR	Replications	2	0.14×10^{-2}	0.40×10^{-2}
	Genotypes	21	$0.29 \times 10^{-1*}$	$0.50 \times 10^{-1*}$
	Error	42	0.91×10^{-4}	0.11×10^{-3}
Leaf area index LAI	Replications	2	1.20	0.65×10^{-1}
	Genotypes	21	3.82*	1.61*
	Error	42	0.25×10^{-1}	0.63×10^{-2}
Leaf area duration LAD (day)	Replications	2	142.27	8.90
	Genotypes	21	547.57*	251.35*
	Error	42	3.60	0.92

Significant at 5% level

The stage-wise analysis of variance for the three stages i.e. GS₄, GS₅ and GS₆ during 2002 (Table 2) and for six stages i.e. GS₁ to GS₆ during 2003 (Table3) revealed that mean squares due to genotypes for all the growth parameters were significant at all the stages studied during both the years.

Analysis of variance for the growth parameters studied at S₁ (active vegetative stage), S₂ (average of duration from active vegetative upto preflowering stage) given in table 4 and S₃ (initial post flowering stage, Table 5) and also S₄ stage (average of duration from initial post flowering to harvesting stage, Table 6) showed significant difference among the genotypes, during 2003. During 2002 where only S₃ and S₄ stages were taken also showed significant differences for all the growth parameters (Table 5 and 6).

Analysis of variance for all nine yield system traits viz., days to flowering, days to maturity, days to seed fill, aerial biomass per plant at harvest maturity, seed yield per plant at harvest maturity, yield per day to maturity, yield per day to seed fill, biomass per day to plant growth and harvest index; and seven other traits (stem girth, plant height, panicle length, panicle girth, 10 ml seed weight, protein content and leaf area) exhibited high significant differences among the genotypes for both the years (Table 7).

4.1.2 Mean performance and components of variability of different traits

The values of general mean, phenotypic coefficient of variation (PCV%), genotypic coefficient of variation (GCV%), heritability (%) in broad sense and

genetic advance (%) have been presented in table 8. Genotype-wise mean values for all traits studies during 2002 and 2003 have been given in table 9 and 10, respectively. The mean of growth parameters obtained at different stages of growth during 2002 and 2003 has been tabulated in table 11. The accounts of genetic parameters at stages S_2 (active vegetative growth period) and S_4 (grain filling period) which have been found to be important for growth parameter estimation have also been made and mean, PCV, GCV, heritability and genetic advance values calculated have been shown in table 12.

4.1.2.1 Absolute growth rate (AGR, g/day): The general means obtained were 0.77 and 0.59 having range between 0.45 to 1.26 and 0.44 to 0.91 during 2002 and 2003, respectively. At GS_6 (100-days to harvesting) highest mean performances of 0.84 during 2002 and 0.81 during 2003 were recorded. PCV and GCV were 27.65, 26.91 and 20.38, 20.27 per cent during the two years, respectively. Heritabilities estimated were 94.80 and 98.90 per cent with genetic advances 54.54 and 42.37 per cent, respectively. Among genotypes highest AGR value was recorded in JRS504 (1.26) during 2002 and Annapurna (0.91) during 2003 based on averages of all the stages. General mean at S_2 was 0.43 and PCV and GCV were 44.21 per cent and 43.52 per cent, respectively. High heritability (96.90%) and high genetic advance (88.37%) was observed at this stage during 2003. At S_4 mean was 0.77 during 2002 and 0.76 during 2003. PCV, GCV, heritabilities and genetic advances were 27.68, 26.94, 94.80 and 54.55 and 28.10, 27.71, 97.20 and 56.58 per cent during the years 2002 and 2003, respectively.

Table 2: Analysis of variance of different growth parameters at different stages in grain amaranth during 2002

Growth parameters	Source	df	GS ₄	GS ₅	GS ₆
			73-85 days	86-98 days	99-days to harvesting
AGR (g/day)	Replications	2	0.18	0.17	0.18x10 ⁻¹
	Genotypes	21	0.33*	0.12*	1.06*
	Error	42	0.32x10 ⁻¹	0.23x10 ⁻¹	0.70x10 ⁻²
CGR (g/dm ² /day)	Replications	2	0.33x10 ⁻²	0.31x10 ⁻²	0.33x10 ⁻³
	Genotypes	21	0.60x10 ^{-2*}	0.22x10 ^{-2*}	0.19x10 ^{-1*}
	Error	42	0.57x10 ⁻³	0.41x10 ⁻³	0.12x10 ⁻³
RGR (g/g/day)	Replications	2	0.32x10 ⁻⁴	0.64x10 ⁻⁴	0.61x10 ⁻⁵
	Genotypes	21	0.21x10 ^{-3*}	0.71x10 ^{-4*}	0.25x10 ^{-3*}
	Error	42	0.12x10 ⁻⁴	0.86x10 ⁻⁵	0.11x10 ⁻⁵
NAR (g/dm ² /day)	Replications	2	0.24x10 ⁻⁴	0.22x10 ⁻³	-
	Genotypes	21	0.30x10 ^{-3*}	0.17x10 ^{-3*}	-
	Error	42	0.21x10 ⁻⁴	0.17x10 ⁻⁴	-
LAR	Replications	2	0.44x10 ⁻¹	0.17x10 ⁻²	-
	Genotypes	21	0.96x10 ^{-1*}	0.61x10 ^{-1*}	-
	Error	42	0.18x10 ⁻²	0.94x10 ⁻³	-
RLGR (dm ² /dm ² /day)	Replications	2	0.22x10 ⁻²	0.18x10 ⁻⁴	-
	Genotypes	21	0.14x10 ^{-3*}	0.97x10 ^{-4*}	-
	Error	42	0.47x10 ⁻⁵	0.13x10 ⁻⁴	-
SLA (dm ² /g)	Replications	2	0.16	0.18x10 ⁻¹	-
	Genotypes	21	0.19*	0.17*	-
	Error	42	0.18x10 ⁻²	0.23x10 ⁻²	-
SLW (g/dm ²)	Replications	2	0.51	0.11x10 ⁻¹	0.10x10 ⁻¹
	Genotypes	21	0.57x10 ^{-1*}	0.35x10 ^{-1*}	0.44x10 ^{-1*}
	Error	42	0.58x10 ⁻²	0.14x10 ⁻²	0.22x10 ⁻²
LWR	Replications	2	0.44x10 ⁻²	0.16x10 ⁻²	0.15x10 ⁻³
	Genotypes	21	0.67x10 ^{-1*}	0.29x10 ^{-1*}	1.00x10 ^{-2*}
	Error	42	0.41x10 ⁻³	0.84x10 ⁻⁴	0.38x10 ⁻⁴
LAI	Replications	2	5.39	0.60	0.28
	Genotypes	21	4.23*	3.81*	3.79*
	Error	42	0.20x10 ⁻¹	0.28x10 ⁻¹	0.53x10 ⁻¹
LAD (day)	Replications	2	299.60	61.56	-
	Genotypes	21	567.29*	536.77*	-
	Error	42	3.32	4.53	-

* Significant at 5% level

Table 3: Analysis of variance for different growth parameters at different stages in grain amaranth during 2003

Growth parameters	Source	df	GS ₁	GS ₂	GS ₃	GS ₄	GS ₅	GS ₆
			35-47 days	48-60 days	61-73 days	74-86 days	87-99 days	100-days to harvesting
AGR(g/day)	Replications	2	0.10x10 ⁻¹	0.14x10 ⁻¹	0.45x10 ⁻¹	0.75x10 ⁻¹	0.18x10 ⁻¹	0.13x10 ⁻¹
	Genotypes	21	0.16*	0.42*	0.61*	0.37*	0.16*	1.01*
	Error	42	0.86x10 ⁻³	0.89x10 ⁻³	0.10x10 ⁻¹	0.99x10 ⁻²	0.13x10 ⁻³	0.52x10 ⁻²
CGR(g/dm ² /day)	Replications	2	0.18x10 ⁻³	0.24x10 ⁻³	0.81x10 ⁻³	0.13x10 ⁻²	0.32x10 ⁻³	0.24x10 ⁻³
	Genotypes	21	0.29x10 ^{-2*}	0.74x10 ^{-2*}	0.11x10 ^{-1*}	0.66x10 ^{-2*}	0.28x10 ^{-2*}	0.18x10 ^{-1*}
	Error	42	0.15x10 ⁻⁴	0.16x10 ⁻⁴	0.18x10 ⁻³	0.18x10 ⁻³	0.24x10 ⁻⁵	0.93x10 ⁻⁴
RGR(g/g/day)	Replications	2	0.19x10 ⁻⁴	0.11x10 ⁻⁴	0.47x10 ⁻⁴	0.18x10 ⁻⁴	0.17x10 ⁻⁴	0.38x10 ⁻⁵
	Genotypes	21	0.18x10 ^{-3*}	0.36x10 ^{-3*}	0.43x10 ^{-3*}	0.19x10 ^{-3*}	0.11x10 ^{-3*}	0.25x10 ^{-3*}
	Error	42	0.15x10 ⁻⁵	0.16x10 ⁻⁵	0.33x10 ⁻⁵	0.33x10 ⁻⁵	0.15x10 ⁻⁶	0.82x10 ⁻⁶
NAR(g/dm ² /day)	Replications	2	0.29x10 ⁻⁴	0.18x10 ⁻⁴	0.83x10 ⁻⁴	0.51x10 ⁻⁴	0.39x10 ⁻⁴	-
	Genotypes	21	0.48x10 ^{-3*}	0.78x10 ^{-3*}	0.69x10 ^{-3*}	0.30x10 ^{-3*}	0.21x10 ^{-3*}	-
	Error	42	0.22x10 ⁻⁵	0.20x10 ⁻⁵	0.12x10 ⁻⁴	0.10x10 ⁻⁴	0.11x10 ⁻⁵	-
LAR	Replications	2	0.11x10 ⁻¹	0.40x10 ⁻²	0.94x10 ⁻³	0.16x10 ⁻²	0.59x10 ⁻⁴	-
	Genotypes	21	0.62x10 ^{-1*}	0.95x10 ^{-1*}	0.90x10 ^{-1*}	0.99x10 ^{-1*}	0.62x10 ^{-1*}	-
	Error	42	0.71x10 ⁻³	0.66x10 ⁻³	0.51x10 ⁻³	0.36x10 ⁻³	0.36x10 ⁻³	-
RLGR(dm ² /dm ² /day)	Replications	2	0.17x10 ⁻⁴	0.17x10 ⁻⁴	0.25x10 ⁻⁵	0.26x10 ⁻⁴	0.80x10 ⁻⁴	-
	Genotypes	21	0.56x10 ^{-3*}	0.39x10 ^{-3*}	0.27x10 ^{-3*}	0.12x10 ^{-3*}	0.10x10 ^{-3*}	-
	Error	42	0.50x10 ⁻⁴	0.35x10 ⁻⁵	0.73x10 ⁻⁶	0.82x10 ⁻⁶	0.14x10 ⁻⁴	-

Contd....

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Growth parameters	Source	df	GS ₁	GS ₂	GS ₃	GS ₄	GS ₅	GS ₆
			35-47 days	48-60 days	61-73 days	74-86 days	87-99 days	100-days to harvesting
SLA(g/dm ²)	Replications	2	0.39x10 ⁻³	0.20x10 ⁻²	0.96x10 ⁻²	0.51x10 ⁻³	0.29x10 ⁻²	-
	Genotypes	21	0.41x10 ^{-1*}	0.13*	0.19*	0.17*	0.17*	-
	Error	42	0.18x10 ⁻²	0.81x10 ⁻³	0.41x10 ⁻³	0.26x10 ⁻³	0.90x10 ⁻³	-
LWR	Replications	2	0.77x10 ⁻²	0.94x10 ⁻²	0.78x10 ⁻²	0.25x10 ⁻²	0.99x10 ⁻³	0.41x10 ⁻³
	Genotypes	21	0.65x10 ^{-1*}	0.10*	0.97x10 ^{-1*}	0.72x10 ^{-1*}	0.31x10 ^{-1*}	0.97x10 ^{-2*}
	Error	42	0.30x10 ⁻³	0.25x10 ⁻³	0.25x10 ⁻³	0.11x10 ⁻³	0.43x10 ⁻⁴	0.29x10 ⁻⁴
LAI	Replications	2	0.56x10 ⁻²	0.14x10 ⁻¹	0.99x10 ⁻¹	0.13	0.27x10 ⁻¹	0.35
	Genotypes	21	0.26*	0.64*	2.15*	4.01*	3.51*	3.64*
	Error	42	0.25x10 ⁻¹	0.11x10 ⁻¹	0.78x10 ⁻²	0.86x10 ⁻²	0.91x10 ⁻²	0.39x10 ⁻¹
LAD(day)	Replications	2	0.75	6.68	16.73	9.91	19.06	-
	Genotypes	21	42.77*	157.20*	413.92*	529.29*	503.72*	-
	Error	42	1.35	1.26	1.06	1.01	2.14	-
SLW(g/dm ²)	Replications	2	0.19x10 ⁻²	0.79x10 ⁻³	0.96x10 ⁻²	0.44x10 ⁻²	0.34x10 ⁻²	0.11x10 ⁻¹
	Genotypes	21	0.11x10 ^{-1*}	0.54x10 ^{-1*}	0.75x10 ^{-1*}	0.39x10 ^{-1*}	0.35x10 ^{-1*}	0.43x10 ^{-1*}
	Error	42	0.20x10 ⁻²	0.12x10 ⁻²	0.50x10 ⁻³	0.20x10 ⁻³	0.22x10 ⁻³	0.19x10 ⁻²

* Significant at 5% level.

Table 4: Analysis of variance of growth parameters at S₁ (active vegetative stage) and S₂ (average of duration from active vegetative upto preflowering stage) in grain amaranth during 2003

Growth parameters	Sources	df	S ₁	S ₂
CGR (g/dm ² /day)	Replications	2	0.22x10 ⁻³	0.38x10 ⁻⁴
	Genotypes	21	0.30x10 ^{-2*}	0.19x10 ^{-2*}
	Error	42	0.23x10 ⁻⁴	0.16x10 ⁻⁴
RGR (g/g/day)	Replications	2	0.20x10 ⁻⁴	0.71x10 ⁻⁵
	Genotypes	21	0.18x10 ^{-3*}	0.46x10 ^{-4*}
	Error	42	0.18x10 ⁻⁵	0.41x10 ⁻⁶
NAR (g/dm ² /day)	Replications	2	0.31x10 ⁻⁴	0.99x10 ⁻⁵
	Genotypes	21	0.48x10 ^{-3*}	0.12x10 ^{-3*}
	Error	42	0.23x10 ⁻⁵	0.15x10 ⁻⁵
LAR	Replications	2	0.99x10 ⁻²	0.45x10 ⁻²
	Genotypes	21	0.61x10 ^{-1*}	0.69x10 ^{-1*}
	Error	42	0.73x10 ⁻³	0.39x10 ⁻³
RLGR (dm ² /dm ² /day)	Replications	2	0.15x10 ⁻⁴	0.47x10 ⁻⁵
	Genotypes	21	0.55x10 ^{-3*}	0.79x10 ^{-4*}
	Error	42	0.50x10 ⁻⁴	0.48x10 ⁻⁵
LAI	Replications	2	0.56x10 ⁻²	0.22x10 ⁻¹
	Genotypes	21	0.26*	0.61*
	Error	42	0.25x10 ⁻¹	0.69x10 ⁻²
LAD (day)	Replications	2	0.74	6.22
	Genotypes	21	42.77*	151.38*
	Error	42	1.35	0.92
AGR (g/day)	Replications	2	0.11x10 ⁻¹	0.39x10 ⁻²
	Genotypes	21	0.16*	0.11*
	Error	42	0.82x10 ⁻³	0.11x10 ⁻²
SLA (dm ² /g)	Replications	2	0.38x10 ⁻³	0.18x10 ⁻²
	Genotypes	21	0.41x10 ^{-1*}	0.97x10 ^{-1*}
	Error	42	0.18x10 ⁻²	0.73x10 ⁻³
LWR	Replications	2	0.75x10 ⁻²	0.71x10 ⁻²
	Genotypes	21	0.65x10 ^{-1*}	0.81x10 ^{-1*}
	Error	42	0.31x10 ⁻³	0.18x10 ⁻³
SLW (g/dm ²)	Replications	2	0.21x10 ⁻²	0.13x10 ⁻²
	Genotypes	21	0.11x10 ^{-1*}	0.30x10 ^{-1*}
	Error	42	0.19x10 ⁻²	0.55x10 ⁻³

* Significant at 5% level

Table 5: Analysis of variance of growth parameters at S₃ (initial post flowering stage) in grain amaranth during 2002 and 2003

Growth parameters	Sources	df	2002	2003
CGR (g/dm ² /day)	Replications	2	0.25x10 ⁻²	0.15x10 ⁻²
	Genotypes	21	0.60x10 ⁻² *	0.67x10 ⁻² *
	Error	42	0.59x10 ⁻³	0.20x10 ⁻³
RGR (g/g/day)	Replications	2	0.29x10 ⁻⁴	0.19x10 ⁻⁴
	Genotypes	21	0.25x10 ⁻³ *	0.19x10 ⁻³ *
	Error	42	0.29x10 ⁻⁴	0.34x10 ⁻⁵
NAR (g/dm ² /day)	Replications	2	0.24x10 ⁻⁴	0.51x10 ⁻⁴
	Genotypes	21	0.30x10 ⁻³ *	0.30x10 ⁻³ *
	Error	42	0.21x10 ⁻⁴	0.10x10 ⁻⁴
LAR	Replications	2	0.43x10 ⁻¹	0.16x10 ⁻²
	Genotypes	21	0.97x10 ⁻¹ *	0.99x10 ⁻¹ *
	Error	42	0.18x10 ⁻²	0.35x10 ⁻³
RLGR (dm ² /dm ² /day)	Replications	2	0.21x10 ⁻²	0.25x10 ⁻⁴
	Genotypes	21	0.14x10 ⁻³ *	0.12x10 ⁻³ *
	Error	42	0.11x10 ⁻⁴	0.91x10 ⁻⁶
LAI	Replications	2	5.40	0.14
	Genotypes	21	4.23*	4.01*
	Error	42	0.20x10 ⁻¹	0.86x10 ⁻²
LAD (day)	Replications	2	299.62	9.91
	Genotypes	21	567.35*	529.27*
	Error	42	3.32	1.02
AGR (g/day)	Replications	2	0.18	0.75x10 ⁻¹
	Genotypes	21	0.34*	0.37*
	Error	42	0.32x10 ⁻¹	0.99x10 ⁻²
SLA (dm ² /g)	Replications	2	0.17	0.70x10 ⁻³
	Genotypes	21	0.19*	0.17*
	Error	42	0.18x10 ⁻²	0.26x10 ⁻³
LWR	Replications	2	0.42x10 ⁻²	0.21x10 ⁻²
	Genotypes	21	0.67x10 ⁻¹ *	0.72x10 ⁻¹ *
	Error	42	0.40x10 ⁻³	0.11x10 ⁻³
SLW (g/dm ²)	Replications	2	0.52	0.42x10 ⁻²
	Genotypes	21	0.58x10 ⁻¹ *	0.39x10 ⁻¹ *
	Error	42	0.57x10 ⁻²	0.21x10 ⁻³

* Significant at 5% level.

Table 6: Analysis of variance of growth parameters at S₄ (average of duration from initial post flowering to harvesting) stage in grain amaranth during 2002 and 2003

Growth parameters	Sources	df	2002	df	2003
CGR(g/dm²/day)	Replications	2	0.98x10 ⁻²	2	0.22x10 ⁻³
	Genotypes	21	0.21x10 ^{-2*}	21	0.23x10 ^{-2*}
	Error	42	0.13x10 ⁻³	42	0.32x10 ⁻⁴
RGR(g/g/day)	Replications	2	0.15x10 ⁻⁵	2	0.26x10 ⁻⁵
	Genotypes	21	0.13x10 ^{-3*}	21	0.77x10 ^{-4*}
	Error	42	0.15x10 ⁻⁵	42	0.50x10 ⁻⁶
NAR(g/dm²/day)	Replications	2	0.38x10 ⁻⁴	2	0.36x10 ⁻⁵
	Genotypes	21	0.17x10 ^{-3*}	21	0.12x10 ^{-3*}
	Error	42	0.77x10 ⁻⁵	42	0.30x10 ⁻⁵
LAR	Replications	2	0.12x10 ⁻¹	2	0.72x10 ⁻³
	Genotypes	21	0.76x10 ^{-1*}	21	0.78x10 ^{-1*}
	Error	42	0.12x10 ⁻²	42	0.31x10 ⁻³
RLGR(dm²/dm²/day)	Replications	2	0.77x10 ⁻³	2	0.66x10 ⁻⁵
	Genotypes	21	0.81x10 ^{-4*}	21	0.47x10 ^{-4*}
	Error	42	0.47x10 ⁻⁵	42	0.37x10 ⁻⁵
LAI	Replications	2	1.21	2	0.13
	Genotypes	21	3.82*	21	3.50*
	Error	42	0.25x10 ⁻¹	42	0.97x10 ⁻²
LAD(day)	Replications	2	142.27	2	13.86
	Genotypes	21	547.61*	21	512.21*
	Error	42	3.60	42	1.23
AGR(g/day)	Replications	2	0.30x10 ⁻²	2	0.71x10 ⁻²
	Genotypes	21	0.13*	21	0.13*
	Error	42	0.24x10 ⁻²	42	0.13x10 ⁻²
SLA(dm²/g)	Replications	2	0.66x10 ⁻¹	2	0.13x10 ⁻²
	Genotypes	21	0.18*	21	0.17*
	Error	42	0.19x10 ⁻²	42	0.40x10 ⁻³
LWR	Replications	2	0.14x10 ⁻²	2	0.10x10 ⁻²
	Genotypes	21	0.29x10 ^{-1*}	21	0.31x10 ^{-1*}
	Error	42	0.10x10 ⁻³	42	0.61x10 ⁻⁴
SLW(g/dm²)	Replications	2	0.88x10 ⁻¹	2	0.19x10 ⁻²
	Genotypes	21	0.39x10 ^{-1*}	21	0.31x10 ^{-1*}
	Error	42	0.23x10 ⁻²	42	0.36x10 ⁻³

* Significant at 5% level

Table 7: Analysis of variance for yield system and other traits in grain amaranth during 2002 and 2003

Mean Squares									
Traits		2002				2003			
		Source	Replications	Genotypes	Error	Replications	Genotypes	Error	
	df	2	21	42	2	21	42	2	42
Days to flowering		7.11	30.66*	2.99	2.02	55.78*	1.51		
Days of maturity		1.75	49.10*	3.27	0.81	62.02*	2.15		
Days to seed fill (g)		2.11	20.06*	6.42	1.68	61.49*	3.51		
Aerial biomass/plant(g)		0.80	59.02*	0.98	1.69	57.36*	1.15		
Yield/day to maturity(g)		0.92x10 ⁻⁴	0.67x10 ⁻³ *	0.21x10 ⁻⁴	0.65x10 ⁻⁴	0.51x10 ⁻³ *	0.29x10 ⁻⁴		
Yield/day to seed fill (g)		0.74x10 ⁻⁴	0.34x10 ⁻² *	0.11x10 ⁻³	0.87x10 ⁻⁴	0.32x10 ⁻² *	0.10x10 ⁻³		
Biomass/day to plant growth (g)		0.32x10 ⁻⁴	0.18x10 ⁻² *	0.10x10 ⁻³	0.10x10 ⁻³	0.16x10 ⁻² *	0.67x10 ⁻⁴		
Harvest index (%)		2.48	14.66*	0.50	2.38	12.02*	0.41		
Stem girth (cm)		0.50x10 ⁻¹	0.67*	0.20	0.50x10 ⁻¹	0.63*	0.20		
Plant height (cm)		204.00	610.08*	158.40	98.50	648.33*	164.62		
Panicle length (cm)		0.31	20.75*	0.46	0.14	15.95*	3.52		
Panicle girth (cm)		0.45	22.30*	0.19	0.45	24.20*	0.19		
10 ml seed weight (g)		0.42x10 ⁻²	0.43*	0.40x10 ⁻¹	0.46x10 ⁻²	0.49*	0.40x10 ⁻¹		
Protein content (%)		0.11x10 ⁻¹	1.65*	0.41	0.11x10 ⁻¹	1.60*	0.41		
Leaf area (dm ²)		0.72	23.76*	5.64	0.69	24.15*	5.64		
Seed yield/plant (g)		0.72	12.61*	0.16	0.76	12.43*	0.16		

* Significant at 5% level

Table 8: General mean, coefficients of variation (PCV, GCV), heritability and genetic advance values for different characters in grain amaranth during 2002 and 2003

Traits	General Mean		Range		PCV		GCV		Heritability (%)		Genetic advance (%)	
	2002	2003	2002	2003	2002	2003	2002	2003	2002	2003	2002	2003
AGR (g/day)	0.77	0.59	0.45-1.26	0.44-0.91	27.65	20.38	26.91	20.27	94.80	98.90	54.54	42.37
CGR (g/dm ² /day)	0.09	0.08	0.05-0.16	0.06-0.12	30.11	21.08	27.87	20.77	85.70	97.10	55.55	37.50
RGR (g/g/day)	0.02	0.01	0.01-0.03	0.01-0.02	32.86	34.56	32.24	27.46	96.30	63.10	52.62	97.67
NAR (g/dm ² /day)	0.02	0.02	0.01-0.04	0.01-0.03	27.86	18.24	26.46	16.19	90.20	78.80	52.00	50.00
LAR	0.72	0.77	0.49-1.04	0.53-0.97	22.73	18.79	22.20	18.65	95.40	98.60	44.44	37.66
SLA (dm ² /g)	1.18	1.16	1.02-2.22	1.01-1.97	20.79	16.46	20.47	16.35	96.90	98.70	41.52	33.62
SLW (g/dm ²)	0.88	0.88	0.45-1.01	0.55-0.98	13.56	9.95	12.41	9.74	83.30	95.70	23.86	19.32
LWR	0.54	0.63	0.38-0.72	0.42-0.84	18.26	20.59	18.18	20.53	99.10	99.40	37.03	41.27
RLGR (dm ² /dm ² /day)	0.01	0.01	0.00-0.01	0.01-0.02	79.79	26.58	69.84	20.39	76.60	58.90	99.45	99.34
LAI	4.32	3.61	3.20-9.01	2.88-6.33	26.32	20.36	26.06	20.25	98.00	98.80	53.01	41.55
LAD (day)	53.06	43.96	39.43-108.93	35.47-81.75	25.63	20.90	25.38	20.78	98.10	98.90	51.77	42.58
Days to flowering	74.03	77.26	69.00-79.33	69.00-82.67	4.72	5.73	4.10	5.51	75.50	92.30	7.34	10.90
Days to maturity	135.86	137.85	129.00-143.33	129.33-145.33	3.17	3.41	2.88	3.24	82.40	90.30	5.38	6.34
Days to seed fill	61.83	60.59	57.33-67.00	52.67-73.00	5.36	7.89	3.45	7.26	41.40	84.60	4.57	13.75
Aerial biomass/plant (g)	62.29	68.69	57.00-69.43	63.32-75.75	7.24	6.49	7.06	6.30	95.20	94.20	14.19	12.61

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Traits	General Mean		Range		PCV		GCV		Heritability (%)		Genetic advance (%)	
	2002	2003	2002	2003	2002	2003	2002	2003	2002	2003	2002	2003
Yield/day to maturity (g)	0.07	0.07	0.05-0.10	0.06-0.10	22.96	18.50	21.93	17.04	91.20	84.80	42.85	28.57
Yield/day to seed fill (g)	0.15	0.17	0.12-0.22	0.13-0.24	23.53	19.85	22.49	18.96	91.30	91.20	46.66	35.29
Biomass/day to plant growth(g)	0.46	0.50	0.42-0.50	0.45-0.54	5.71	4.85	5.27	4.56	85.10	88.60	10.86	8.02
Harvest index (%)	14.56	14.92	12.35-19.69	12.60-19.68	15.69	13.87	14.93	13.19	90.50	90.50	29.26	25.87
Stem girth (cm)	6.85	8.48	6.13-7.73	7.81-9.28	8.68	6.91	5.79	4.48	44.30	42.10	7.88	6.01
Plant height (cm)	171.97	172.82	156.33-198.33	154.10-200.35	10.22	10.45	7.13	7.35	48.70	49.50	10.26	10.65
Panicle length (cm)	48.46	59.10	46.14-55.23	56.39-65.27	5.55	4.68	5.37	3.44	93.70	54.10	10.69	5.21
Panicle girth (cm)	19.43	20.71	16.78-24.87	17.97-26.37	14.15	13.82	13.97	13.66	97.50	97.70	28.41	27.81
10ml seed weight (g)	7.73	7.99	7.02-8.47	7.26-8.71	5.18	5.63	4.54	5.01	76.90	79.10	8.26	9.18
Protein content (%)	14.72	15.07	13.23-15.83	13.57-16.17	6.15	5.96	4.37	4.19	50.30	49.50	6.39	6.10
Leaf area (dm ²)	92.56	94.57	87.16-96.29	89.15-98.33	3.69	3.63	2.66	2.63	51.70	52.20	3.93	3.91
Seed yield/plant (g)	9.15	10.32	7.05-13.67	8.15-14.91	22.70	19.99	22.26	19.60	96.20	96.10	45.03	39.53

Table 9: Estimate of genotypic mean values of growth parameters, yield system and other traits in grain amaranth during 2002

Traits		AGR	GGR	RGR	NAR	LAR	SLA	SLW	LWR	RLGR	LAI	LAD	Days to flowering	Days to maturity	Days to seed fill(g)	Aerial Biomass/ plant (g)	Yield/ day to maturity (g)
Genotypes		(g/day)	(g/dm ² / day)	(g/g/ day)	(g/dm ² / day)	(g/dm ² / day)	(dm ² /g)	(g/dm ²)		(dm ² /dm ² / day)		(day)					
1.	Sangla A1	1.02	0.12	0.03	0.03	0.94	1.20	0.87	0.67	0.01	3.94	49.07	72.33	136.33	64.00	64.13	0.07
2.	Sangla A2	1.10	0.14	0.03	0.02	0.98	1.20	0.84	0.68	0.00	4.23	51.53	73.00	138.00	65.00	64.71	0.07
3.	Sangla A3	0.66	0.08	0.02	0.03	0.78	1.02	1.01	0.66	0.00	3.20	39.43	71.33	134.00	62.67	57.68	0.06
4.	Sangla A4	0.74	0.09	0.02	0.02	0.96	1.21	0.86	0.69	0.01	4.18	51.59	70.33	129.00	58.67	57.37	0.05
5.	Sangla A5	0.60	0.07	0.01	0.03	0.65	1.05	1.00	0.55	0.01	3.48	43.06	70.00	132.00	62.00	57.46	0.06
6.	Sangla A6	0.62	0.07	0.01	0.02	0.65	1.12	0.89	0.51	0.00	3.83	46.76	71.00	134.33	63.33	61.74	0.06
7.	Sangla A7	0.67	0.08	0.01	0.03	0.59	1.06	0.96	0.49	0.00	3.84	46.86	72.67	137.67	65.00	64.24	0.07
8.	Sangla A8	0.72	0.09	0.02	0.03	0.69	1.04	0.97	0.57	0.00	3.72	45.74	71.00	133.00	62.00	61.67	0.06
9.	Sangla A9	0.83	0.10	0.02	0.02	0.77	1.04	0.96	0.64	0.00	4.08	50.11	77.33	137.67	60.33	61.73	0.06
10.	Sangla A10	0.70	0.09	0.01	0.01	0.63	1.13	0.92	0.50	0.00	4.54	57.42	79.33	141.67	62.33	69.43	0.10
11.	Sangla A11	0.73	0.09	0.02	0.03	0.72	1.20	0.85	0.53	0.00	4.05	49.85	69.00	129.33	60.33	57.00	0.05
12.	Shimla A1	0.45	0.05	0.01	0.02	0.57	1.08	0.93	0.48	0.01	3.89	47.60	75.00	137.67	62.67	57.33	0.06
13.	JRS 502	0.67	0.08	0.01	0.03	0.57	1.08	0.94	0.47	0.00	3.85	47.24	77.00	139.33	62.33	62.63	0.06
14.	JRS 503	0.97	0.12	0.02	0.02	0.72	1.20	0.85	0.53	0.00	4.99	60.74	77.67	141.00	63.33	68.14	0.09
15.	JRS 504	1.26	0.14	0.02	0.04	0.64	1.15	0.87	0.49	0.01	4.80	58.98	77.33	138.33	61.00	68.50	0.09
16.	JRS 505	0.66	0.08	0.01	0.02	0.53	1.10	0.93	0.44	0.00	4.01	49.27	73.00	140.00	67.00	61.69	0.06
17.	JRS 506	0.54	0.06	0.01	0.01	0.57	1.09	0.93	0.48	0.01	3.93	48.25	73.33	133.00	59.67	58.20	0.06
18.	JRS 507	0.65	0.08	0.01	0.02	0.70	1.32	0.79	0.48	0.01	4.56	56.56	73.67	132.33	58.67	57.10	0.05
19.	JRS 508	0.73	0.08	0.01	0.03	0.61	1.21	0.83	0.46	0.01	4.61	56.91	78.67	136.00	57.33	67.89	0.09
20.	PRA 9101	0.79	0.09	0.01	0.01	1.04	2.22	0.45	0.42	0.00	9.01	108.93	76.67	135.33	58.67	67.80	0.09
21.	IC35407	0.73	0.09	0.02	0.02	0.92	1.13	0.90	0.72	0.01	4.15	51.46	71.00	129.67	58.67	57.03	0.05
22.	Annapurna	1.21	0.16	0.02	0.02	0.49	1.12	0.91	0.38	0.00	4.07	49.84	78.00	143.33	65.33	66.80	0.08
	Mean	0.77	0.09	0.02	0.02	0.72	1.18	0.88	0.54	0.01	4.32	53.06	74.03	135.86	61.83	62.29	0.07
	SE ± (d)	0.40 x10 ⁻¹	0.86 x10 ⁻²	0.81 x10 ⁻³	0.17 x10 ⁻²	0.29 x10 ⁻¹	0.35 x10 ⁻¹	0.39 x10 ⁻¹	0.78 x10 ⁻²	0.18 x10 ⁻²	0.13	1.55	1.41	1.48	2.07	0.81	0.31 x10 ⁻²
	CD (5%)	0.08	1.69 x10 ⁻²	1.63 x10 ⁻³	0.33 x10 ⁻²	0.57 x10 ⁻¹	0.69 x10 ⁻¹	0.76 x10 ⁻¹	1.53 x10 ⁻²	0.35 x10 ⁻²	0.25	3.04	2.76	2.90	4.06	1.59	0.61 x10 ⁻²

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Traits		Yield/day to seed fill (g)	Biomass/ day to plant growth (g)	Harvest index (%)	Stem girth (cm)	Plant height (cm)	Panicle length (cm)	Panicle girth (cm)	10 ml seed weight (g)	Protein content (%)	Leaf area (dm ²)	Seed yield/plant (g)
Genotypes												
1.	Sangla A1	0.14	0.47	14.26	7.34	181.87	46.43	17.72	7.91	13.92	96.19	9.14
2.	Sangla A2	0.14	0.47	14.68	7.37	178.47	48.69	20.51	7.98	13.63	95.59	9.50
3.	Sangla A3	0.12	0.43	13.22	6.17	163.77	47.31	17.59	7.96	13.23	94.78	7.62
4.	Sangla A4	0.12	0.44	12.52	6.13	157.00	46.23	17.08	7.34	13.72	89.52	7.18
5.	Sangla A5	0.12	0.43	12.94	6.43	159.60	47.16	17.16	7.17	15.41	92.86	7.44
6.	Sangla A6	0.13	0.46	13.38	6.73	163.47	47.52	17.53	8.10	15.83	95.20	8.26
7.	Sangla A7	0.15	0.47	14.71	6.53	173.20	48.41	20.15	7.14	14.50	92.51	9.44
8.	Sangla A8	0.13	0.46	13.08	7.20	169.00	47.34	18.03	7.74	14.41	96.01	8.07
9.	Sangla A9	0.14	0.45	13.29	7.33	177.00	47.29	18.31	7.54	13.68	91.61	8.20
10.	Sangla A10	0.22	0.49	19.69	6.50	165.00	48.63	24.87	7.02	14.71	91.63	13.67
11.	Sangla A11	0.12	0.44	12.74	6.83	161.13	46.20	17.27	7.05	15.45	94.19	7.26
12.	Shimla A1	0.12	0.42	13.33	6.23	161.20	46.79	17.33	7.85	15.44	91.01	7.61
13.	JRS 502	0.14	0.45	13.52	6.80	158.60	47.21	18.48	7.58	15.00	90.06	8.47
14.	JRS 503	0.20	0.48	18.42	6.53	190.00	55.23	24.40	8.47	15.22	95.05	12.55
15.	JRS 504	0.20	0.50	17.67	7.23	189.67	53.43	24.03	8.19	14.38	92.47	12.10
16.	JRS 505	0.12	0.44	13.42	6.70	169.67	46.85	18.14	7.72	15.02	91.00	8.28
17.	JRS 506	0.13	0.44	12.98	6.47	156.33	46.96	17.40	7.49	15.25	87.29	7.55
18.	JRS 507	0.12	0.43	12.35	6.47	157.93	46.14	17.30	7.60	15.12	90.15	7.05
19.	JRS 508	0.21	0.50	17.45	7.57	198.33	51.90	22.40	8.17	14.72	95.37	11.85
20.	PRA 9101	0.20	0.50	17.27	7.13	197.87	52.30	22.66	7.84	14.20	87.16	11.71
21.	IC35407	0.13	0.44	12.75	7.17	159.67	46.55	16.78	8.03	15.63	90.40	7.26
22.	Annapurna	0.17	0.47	16.60	7.73	194.67	51.47	22.37	8.05	15.35	96.29	11.09
	Mean	0.15	0.46	14.56	6.85	171.97	48.46	19.43	7.73	14.72	92.56	9.15
SE ± (d)		0.84 x10 ⁻²	0.82 x10 ⁻²	0.58	0.36	10.28	0.55	0.35	0.16	0.52	1.94	0.33
CD (5%)		1.65x10 ⁻²	1.61x10 ⁻²	1.14	0.71	20.15	1.08	0.69	0.31	1.02	3.80	0.65

♦ Leaf area measured at maximum leaf weight stage

Table 10: Estimate of genotypic mean values of growth parameters, yield system and other traits in grain amaranth during 2003

Traits	AGR (g/day)	CGR (g/dm ² /day)	RGR (g/g/day)	NAR (g/dm ² /day)	LAR	SLA (dm ² /g)	SLW (g/dm ²)	LWR	RLGR (dm ² /dm ² /day)	LAI	LAD (day)	Days to flowering	Days to maturity	Days to seed fill
Genotypes														
1. Sangla A1	0.61	0.08	0.02	0.02	0.94	1.04	0.96	0.84	0.01	3.06	36.99	71.33	138.33	67.00
2. Sangla A2	0.67	0.09	0.02	0.02	0.95	1.09	0.91	0.79	0.01	3.38	40.94	74.00	140.00	66.00
3. Sangla A3	0.44	0.06	0.01	0.02	0.90	1.07	0.93	0.77	0.01	2.88	35.47	75.33	136.00	60.67
4. Sangla A4	0.48	0.06	0.01	0.01	0.95	1.05	0.95	0.84	0.01	3.30	39.60	73.00	131.00	58.00
5. Sangla A5	0.50	0.07	0.01	0.02	0.89	1.13	0.89	0.73	0.01	3.27	40.42	79.67	133.67	54.00
6. Sangla A6	0.57	0.08	0.02	0.02	0.81	1.14	0.87	0.65	0.01	3.36	40.89	74.67	136.33	61.67
7. Sangla A7	0.61	0.08	0.02	0.02	0.76	1.11	0.89	0.63	0.01	3.46	42.53	75.67	136.67	61.00
8. Sangla A8	0.51	0.07	0.01	0.02	0.85	1.21	0.84	0.65	0.01	3.55	43.70	74.00	135.00	61.00
9. Sangla A9	0.55	0.07	0.01	0.02	0.83	1.07	0.93	0.73	0.01	3.51	42.54	81.00	142.33	61.33
10. Sangla A10	0.73	0.10	0.02	0.02	0.73	1.24	0.84	0.55	0.01	4.07	51.06	82.33	143.67	61.33
11. Sangla A11	0.49	0.07	0.01	0.02	0.75	1.14	0.87	0.62	0.01	3.42	41.50	69.67	129.33	59.67
12. Shimla A1	0.48	0.06	0.01	0.02	0.68	1.11	0.91	0.58	0.01	3.36	40.83	78.00	139.67	61.67
13. JRS 502	0.55	0.07	0.01	0.02	0.64	1.08	0.92	0.55	0.01	3.40	41.37	80.67	142.67	62.00
14. JRS 503	0.72	0.10	0.01	0.02	0.73	1.13	0.89	0.60	0.01	3.90	47.67	80.67	143.00	62.33
15. JRS 504	0.76	0.10	0.01	0.02	0.70	1.20	0.84	0.55	0.01	3.96	47.77	80.00	141.67	61.67
16. JRS 505	0.61	0.08	0.01	0.03	0.53	1.09	0.92	0.46	0.01	3.33	40.48	69.00	142.00	73.00
17. JRS 506	0.51	0.07	0.01	0.02	0.54	1.01	0.98	0.50	0.01	3.22	38.95	82.33	135.00	52.67
18. JRS 507	0.47	0.06	0.01	0.02	0.66	1.24	0.81	0.51	0.01	3.75	45.24	81.67	136.67	55.00
19. JRS 508	0.66	0.09	0.01	0.03	0.63	1.16	0.86	0.51	0.01	3.63	43.73	80.33	137.67	57.33
20. PRA 9101	0.75	0.10	0.01	0.02	0.97	1.97	0.55	0.47	0.02	6.63	81.75	79.67	137.33	57.67
21. IC35407	0.50	0.07	0.02	0.02	0.91	1.09	0.91	0.79	0.01	3.32	39.90	74.00	129.33	55.33
22. Annapurna	0.91	0.12	0.01	0.02	0.53	1.18	0.84	0.42	0.01	3.61	43.86	82.67	145.33	62.67
Mean	0.59	0.08	0.01	0.02	0.77	1.16	0.88	0.63	0.01	3.61	43.96	77.26	137.85	60.59
SE±(d)	0.11 x10 ⁻¹	0.23 x10 ⁻²	0.23 x10 ⁻²	0.14 x10 ⁻²	0.14 x10 ⁻¹	0.18 x10 ⁻¹	0.15 x10 ⁻¹	0.84 x10 ⁻²	0.15 x10 ⁻²	0.65 x10 ⁻¹	0.78	1.00	1.20	1.53
CD (5%)	0.02	0.45 x10 ⁻²	0.45 x10 ⁻²	0.27 x10 ⁻²	0.27 x10 ⁻²	0.35 x10 ⁻¹	0.29 x10 ⁻¹	1.65 x10 ⁻²	0.29 x10 ⁻²	0.13	1.53	1.96	2.35	2.99

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Traits		Aerial biomass/plant (g)	Yield/day to maturity (g)	Yield/day to seed fill (g)	Biomass/day to plant growth (g)	Harvest index (%)	Stem girth (cm)	Plant height (cm)	Panicle length (cm)	Panicle girth (cm)	10 ml seed weight (g)	Protein content (%)	Leaf area (dm ²)	Seed yield/plant (g)
Genotypes														
1.	Sangla A1	68.46	0.07	0.15	0.50	15.08	9.02	169.85	56.39	17.97	8.02	15.47	98.33	10.31
2.	Sangla A2	64.00	0.08	0.16	0.51	15.11	8.05	169.97	57.63	21.40	8.09	13.97	97.73	10.73
3.	Sangla A3	63.69	0.07	0.15	0.47	13.84	8.85	169.27	57.03	18.48	8.07	13.57	97.92	8.86
4.	Sangla A4	71.03	0.06	0.14	0.48	13.22	7.81	168.50	56.93	18.97	7.78	13.76	91.51	8.41
5.	Sangla A5	60.21	0.06	0.16	0.48	13.61	8.11	161.10	59.07	18.17	7.63	15.75	94.89	8.69
6.	Sangla A6	68.06	0.07	0.16	0.50	13.96	8.41	164.97	59.27	18.76	7.54	16.17	97.19	9.50
7.	Sangla A7	70.55	0.08	0.17	0.52	15.15	8.51	170.93	59.72	21.16	8.58	14.88	94.50	10.66
8.	Sangla A8	67.99	0.07	0.15	0.50	13.68	8.97	174.23	58.79	19.08	8.18	14.75	97.00	9.31
9.	Sangla A9	70.53	0.07	0.15	0.50	13.39	9.28	176.27	58.61	19.32	7.78	14.02	93.60	9.44
10.	Sangla A10	75.75	0.10	0.24	0.53	19.68	8.45	173.30	57.62	26.37	7.26	15.01	93.62	14.91
11.	Sangla A11	63.32	0.06	0.14	0.49	13.43	8.78	156.70	56.46	18.77	7.29	15.75	96.14	8.50
12.	Shimla A1	63.66	0.06	0.14	0.45	13.73	8.88	154.10	57.69	18.80	8.12	15.78	93.00	8.72
13.	JRS 502	68.95	0.07	0.15	0.48	13.88	8.75	160.62	60.25	19.98	7.82	15.34	92.28	9.57
14.	JRS 503	74.45	0.10	0.22	0.52	18.34	8.18	192.02	65.27	25.90	8.71	15.59	97.04	13.65
15.	JRS 504	74.85	0.09	0.21	0.53	17.64	8.58	191.69	62.25	25.53	8.43	14.72	94.46	13.20
16.	JRS 505	68.01	0.06	0.13	0.48	13.79	8.77	161.39	57.00	19.67	7.96	15.36	92.99	9.38
17.	JRS 506	64.52	0.07	0.16	0.48	13.41	7.83	158.35	57.43	18.82	7.73	15.49	89.15	8.65
18.	JRS 507	64.68	0.06	0.15	0.47	12.60	7.82	159.95	58.78	18.80	7.84	15.46	92.14	8.15
19.	JRS 508	74.21	0.10	0.23	0.54	17.45	8.93	200.35	62.47	23.90	8.41	15.06	97.36	12.96
20.	PRA 9101	74.10	0.09	0.22	0.54	17.29	8.48	199.39	61.13	24.26	8.05	14.64	89.35	12.81
21.	IC35407	63.35	0.06	0.15	0.49	13.21	8.52	171.69	58.18	18.28	8.25	15.97	92.39	8.36
22.	Annapurna	73.13	0.08	0.19	0.50	16.67	9.08	196.69	62.21	23.87	8.30	15.69	98.28	12.19
Mean		62.29	0.07	0.17	0.50	14.92	8.48	172.82	59.10	20.71	7.99	15.07	94.57	10.32
SE ± (d)		0.87	0.44 x10 ⁻²	0.82 x10 ⁻²	0.67 x10 ⁻²	0.51	0.36	10.48	1.53	0.35	0.16	0.52	1.94	0.33
CD (5%)		1.71	0.86 x10 ⁻²	1.61 x10 ⁻²	1.31 x10 ⁻²	0.99	0.71	20.54	2.99	0.69	0.31	1.02	3.80	0.65

♦ Leaf area measured at maximum leaf weight stage

Table 11: Mean performance of growth parameters at different stages of growth in grain amaranth during 2002 and 2003

		2002			2003					
		GS ₄ 73-85 days	GS ₅ 86-98 days	GS ₆ 99-days to harvesting	GS ₁ 35-47 days	GS ₂ 48-60 days	GS ₃ 61-73 days	GS ₄ 74-86 days	GS ₅ 87-99 days	GS ₆ 100-days to harvesting
Growth parameters										
AGR (g/day)		0.78	0.71	0.84	0.25	0.42	0.62	0.79	0.68	0.81
CGR (g/dm ² /day)		0.10	0.94x10 ⁻¹	0.11	0.33x10 ⁻¹	0.56x10 ⁻¹	0.83x10 ⁻¹	0.11	0.91x10 ⁻¹	0.11
RGR (g/g/day)		0.58x10 ⁻²	0.14x10 ⁻¹	0.14x10 ⁻¹	0.94x10 ⁻²	0.14x10 ⁻¹	0.17x10 ⁻¹	0.19x10 ⁻¹	0.14x10 ⁻¹	0.13x10 ⁻¹
NAR (g/dm ² /day)		0.25x10 ⁻¹	0.22x10 ⁻¹	-	0.13x10 ⁻¹	0.18x10 ⁻¹	0.22x10 ⁻¹	0.24x10 ⁻¹	0.21x10 ⁻¹	-
LAR		0.76	0.67	-	0.78	0.82	0.82	0.78	0.65	-
LWR		0.68	0.55	0.39	0.67	0.74	0.74	0.67	0.55	0.39
SLA (dm ² /g)		1.15	1.21	-	1.17	1.13	1.13	1.17	1.20	-
SLW (g/dm ²)		0.96	0.85	0.84	0.86	0.87	0.95	0.88	0.87	0.84
RLGR(dm ² /dm ² /day)		0.19x10 ⁻¹	-0.73x10 ⁻²	-	0.16x10 ⁻¹	0.15x10 ⁻¹	0.17x10 ⁻¹	0.99x10 ⁻²	-0.62x10 ⁻²	-
LAI		3.85	4.74	4.36	2.30	2.81	3.38	4.15	4.65	4.34
LAD (day)		51.54	54.57	-	30.66	37.14	45.22	52.85	53.95	-

Table 12: Mean, coefficient of variation (PCV, GCV), heritability and genetic advance values of growth parameters at S₂ stage during 2003 and S₄ stage during 2002 and 2003 in grain amaranth

S₂ stage									
Growth Parameters	Mean		PCV (%)	GCV (%)	Heritability (%)		Genetic advance (%)		
	2002	2003			2002	2003	2002	2002	2003
CGR (g/dm ² /day)	0.06		44.95	44.41	97.60			83.33	
RGR (g/g/day)	0.01		29.33	28.95	97.40			99.68	
NAR (g/dm ² /day)	0.02		36.12	35.46	96.30			49.67	
LAR	0.80		19.06	18.89	98.30			38.75	
RLGR (dm ² /dm ² /day)	0.02		33.99	31.12	83.80			49.89	
LAI	2.83		16.15	15.88	96.70			32.16	
LAD (day)	37.67		18.97	18.80	98.20			38.39	
AGR (g/day)	0.43		44.21	43.52	96.90			88.37	
SLA (dm ² /g)	1.14		15.80	15.62	97.80			31.58	
LWR	0.01		23.06	22.98	99.30			42.88	
SLW (g/dm ²)	0.89		11.39	11.08	94.60			22.47	
S₄ stage									
Growth Parameters	Mean		PCV (%)	GCV (%)	Heritability (%)		Genetic advance (%)		
	2002	2003			2002	2003	2002	2002	2003
CGR (g/dm ² /day)	0.09	0.10	30.43	27.78	83.40	27.62	55.55	59.78	
RGR (g/g/day)	0.02	0.15	42.38	41.65	96.60	33.20	50.00	65.67	
NAR (g/dm ² /day)	0.02	0.02	34.24	32.05	87.60	27.00	49.67	49.83	
LAR	0.71	0.71	22.62	22.10	95.40	22.54	45.07	46.48	
RLGR (dm ² /dm ² /day)	0.01	0.002	100.68	92.52	84.40	201.95	99.89	98.67	
LAI	4.32	4.38	26.31	29.06	98.10	24.95	53.01	51.14	
LAD (day)	53.06	53.40	25.63	25.38	98.10	24.44	51.77	50.17	
AGR (g/day)	0.77	0.76	27.68	26.94	94.80	27.71	54.55	56.58	
SLA (dm ² /g)	1.18	1.18	20.79	20.46	96.90	19.82	41.53	40.68	
LWR	0.54	0.54	18.23	18.14	98.90	18.89	37.04	38.89	
SLW (g/dm ²)	0.89	0.86	13.57	12.42	83.80	11.78	23.59	24.42	

4.1.2.2 Crop growth rate (CGR, g/dm²/day): CGR estimated during 2002 ranged from 0.05 to 0.16 with mean of 0.09, and during 2003 its range was 0.06-0.12 and mean performance was 0.08. Highest mean performance (0.11) was record at GS₆ during 2002 and at GS₄ (74-86 days) and GS₆ during 2003. PCV and GCV were 30.11, 21.08 and 27.87, 20.77 per cent, respectively. Heritability was 85.70 per cent with 55.55 per cent of genetic advance during 2002 and in 2003 heritability was 97.10 with corresponding genetic advance of 37.50. The highest CGR of 0.16 and 0.12 during 2002 and 2003, respectively was recorded in Annapurna. General mean at S₂ was 0.06 and PCV and GCV were 44.95 per cent and 44.41 per cent, respectively. High heritability (97.60%) and high genetic advance (83.33%) was observed at this stage during 2003. At S₄, mean was 0.09 during 2002 and 0.10 during 2003. PCV, GCV, heritabilities and genetic advances were 30.43, 27.78, 83.40 and 55.55 and 28.18, 27.62, 96.00 and 59.78 per cent during the years 2002 and 2003, respectively.

4.1.2.3 Relative growth rate (RGR, g/g/day): The general means were 0.02 during 2002 and 0.01 during 2003 and ranged from 0.01 to 0.03 and 0.01 to 0.02, respectively. Highest mean values (0.14×10^{-1} , 0.19×10^{-1}) were obtained at GS₅ (87-99 days) and GS₄ stages during 2002 and 2003. PCV and GCV were 32.86, 34.56 and 32.24, 27.46 per cent. Heritability was high (96.30 %) during 2002 and 63.10 per cent during 2003. Genetic advance was 55.62 per cent during 2002 and 97.67 per cent during 2003. Genotypes Sangla A1 and Sangla A2 had the highest (0.03) RGR during 2002. Sangla A1, Sangla A2, Sangla A6, Sangla A7, Sangla A10 and IC 35407 had the highest (0.02) RGR during 2003.

At S_2 mean was 0.01, PCV, GCV were 29.33 and 28.95 per cent, respectively. High heritability (97.40%) alongwith high genetic advance (99.68%) was obtained during 2003. At S_4 the means were 0.02, during 2002 and 0.15 during 2003. The PCV and GCV were 42.38, 41.65 and 33.52, 33.20 per cent while heritabilities were 96.60 and 98.10 per cent during 2002 and 2003, respectively.

4.1.2.4 Net assimilation rate (NAR, $\text{g/dm}^2/\text{day}$): The general mean value of 0.02 was obtained during both the years and the ranges were 0.01 to 0.04 and 0.01 to 0.03, respectively. Maximum NAR (0.25×10^{-1} , 0.24×10^{-1}) was recorded at GS_4 during both the years. PCV and GCV were 27.86, 26.46 and 18.24, 16.19 per cent. Heritabilities estimated were 90.20 and 78.80 per cent. High genetic advance i.e. 52.00 per cent was recorded during 2002 and 50.00 per cent during 2003. During 2002 JRS 504 had the highest of 0.04 while JRS 505 and JRS 508 had the highest of 0.03 NAR during 2003. Mean value obtained during 2002 at S_2 stage was 0.02 with PCV and GCV of 36.12 per cent and 35.46 per cent, respectively. High heritability (96.30%) accompanied with high genetic advance (49.67%) was obtained at this stage. The mean, PCV, GCV and heritability at S_4 stage were 0.02, 34.24, 32.05 and 87.60 during 2002 and 0.02, 28.07, 27.00 and 92.50 during 2003.

4.1.2.5 Leaf area ratio (LAR): LAR ranged from 0.49 to 1.04 and 0.53 to 0.97 with mean value of 0.72 and 0.77 during 2002 and 2003, respectively. LAR had maximum value of 0.76 at the GS_4 during 2002 and the value of 0.82 at GS_2 (48-60 days) and GS_3 (61-73 days) during 2003. PCV and GCV estimated were 22.73, 18.79 and 22.20, 18.65 per cent, respectively. Heritabilities estimated

were 95.40 and 98.60 per cent and genetic advances were 44.44 and 37.66 per cent during 2002 and 2003, respectively. The genotype PRA 9101 recorded the highest LAR of 1.04 and of 0.97 during 2002 and 2003, respectively. During 2003, at S_2 stage mean was 0.80. PCV, GCV, heritability and genetic advance were 19.06, 18.89, 98.30 and 38.75 per cent, respectively. Mean obtained at S_4 was 0.71 during both the years. PCV, GCV, heritability and genetic advance values were 22.62, 22.10, 95.40 and 45.07 per cent during 2002 and 22.67, 22.54, 98.80 and 46.48 per cent during 2003.

4.1.2.6 Specific leaf area (SLA, dm^2/g): The general mean values were recorded as 1.18 and 1.16 with maximum at GS_5 (1.21 during 2002 and 1.20 during 2003). The values of SLA ranged between 1.02 to 2.22 during 2002 and 1.01 to 1.97 during 2003. PCV and GCV were 20.79, 16.46 and 20.47, 16.35 per cent, respectively. Heritabilities were 96.90 and 98.70 per cent with genetic advances of 41.52 and 33.62 per cent, respectively. The highest SLA (2.22) was recorded for PRA9101 followed by JRS507 (1.32) during 2002 and PRA9101 had highest (1.97) during 2003. During 2002 at S_2 stage mean was 1.14. PCV, GCV, heritability and genetic advance values were 15.80, 15.62, 97.80 and 31.58 per cent, respectively. General mean obtained at S_4 was 1.18 during both the years. PCV, GCV, heritability and genetic advance values were 20.79, 20.46, 96.90 and 41.53 per cent during 2002 and 19.89, 19.82, 99.30 and 40.68 per cent during 2003.

4.1.2.7 Specific leaf weight (SLW, g/dm^2): The ranges obtained were between 0.45 to 1.01 during 2002 and 0.55 to 0.98 during 2003 and general

mean values of 0.88 during both the years. The highest mean performances of 0.96 at GS₄ during 2002 and 0.95 at GS₃ during 2003 were observed. The respective PCV and GCV were 13.56, 12.41 and 9.95, 9.74 per cent during 2002 and 2003. Heritabilities recorded were 83.30 and 95.70 per cent and genetic advances were 23.86 and 19.32 per cent. Sangla A3 (1.01) and JRS506 (0.98) had the highest value of SLW during 2002 and 2003, respectively. During 2002 at S₂ stage mean was 0.89. PCV, GCV, heritability and genetic advance values were 11.39, 11.08, 94.60 and 22.47 per cent, respectively. Mean obtained at S₄ was 0.89 during 2002 and 0.86 during 2003. PCV, GCV, heritability and genetic advance values were 13.57, 12.42, 83.80 and 23.59 per cent during 2002 and 11.99, 11.78, 96.60 and 24.42 per cent during 2003.

4.1.2.8 Leaf weight ratio (LWR): LWR had general mean values of 0.54 and 0.63 during 2002 and 2003, respectively and ranges observed during the two years were between 0.38 to 0.72 and 0.42 to 0.84. Highest values (0.68, 0.74) were recorded at GS₄ and GS₃ stages during 2002 and 2003, respectively. PCV and GCV were 18.26, 20.59 and 18.18, 20.53 per cent, respectively. Heritability estimated was high (99.10 and 99.40) during 2002 and 2003 and genetic advances were 37.03 and 41.27 per cent, respectively. Highest value of LWR was observed in variety IC35407 (0.72) during the year 2002 and in Sangla A1 and Sangla A4 (0.84) during 2003.

4.1.2.9 Relative leaf growth rate (RLGR, dm²/dm²/day): RLGR had the mean value of 0.01 for both the years and it ranged from 0.00 to 0.01 and 0.01 to 0.02. Highest RLGR were observed at GS₄ (0.19x10⁻¹) and GS₃ (0.17x10⁻¹)

during 2002 and 2003, respectively. PCV and GCV were 79.79, 26.58 and 69.84, 20.39 per cent, respectively. Heritabilities estimated were 76.60 and 58.90 per cent during 2002 and 2003. During 2002, at S_2 stage mean was 0.02. PCV, GCV, heritability and genetic advance were 33.99, 31.12, 83.80 and 49.89 per cent, respectively. At S_4 means were 0.01 during 2002 and 0.002 during 2003. PCV and GCV were 100.68, 225.70 and 92.52, 201.95 per cent. Heritabilities and corresponding genetic advances at this stage were 84.40, 79.90 and 99.89, 98.67 per cent during 2002 and 2003, respectively.

4.1.2.10 Leaf area index (LAI): LAI had the mean value of 4.32 and 3.61 during 2002 and 2003 ranging from 3.20 to 9.01 and 2.88 to 6.33, respectively. The respective PCV and CGV estimated were 26.32, 20.36 and 26.06, 20.25. High heritabilities (98.00, 98.80) were observed during both the years. The line PRA 9101 had the highest LAI with mean value of 9.01 during 2002 and of 6.63 during 2003. During 2002 at S_2 stage mean was 2.83. PCV, GCV, heritability and genetic advance values were 16.15, 15.88, 96.70 and 32.16 per cent, respectively. Mean obtained at S_4 was 4.32 during 2002 and 4.38 during 2003. PCV, GCV, heritability and genetic advance values were 26.31, 29.06, 98.10 and 53.10 per cent during 2002 and 25.05, 24.95, 99.20 and 51.14 per cent during 2003.

4.1.2.11 Leaf area duration (LAD, day): The general means values recorded were 53.06 and 43.96 during 2002 and 2003 with corresponding range of 39.43 to 108.93 and 35.47 to 81.75, respectively. Highest LAD of 54.57 and 53.95 days at GS_5 stage were observed during 2002 and 2003. High heritabilities of

98.10 per cent during 2002 and 98.90 per cent during 2003 were observed and the genetic advances were 51.77 and 42.58 per cent, respectively. During 2002, at S_2 stage mean was 37.67. PCV, GCV, heritability and genetic advances were 18.97, 18.80, 98.20 and 38.39 per cent, respectively. LAD at S_4 had mean value of 53.06 during 2002 and 53.40 during 2003. PCV, GCV, heritabilities and genetic advances estimated were 25.63, 25.38, 98.10, 51.77 and 24.53, 24.44, 99.30 and 50.17 during 2002 and 2003, respectively.

4.1.2.12 Days to flowering: Days to flowering varied from 69.00 to 79.33 days with an average of 74.03 days during 2002. During 2003, the range was 69.00 to 82.67 days with mean of 77.26. PCV were 4.72 and 5.73 per cent during 2002 and 2003, respectively whereas the corresponding GCV were 4.10 and 5.51 per cent. Heritabilities of 75.50 and 92.30 per cent were recorded and genetic advances were 7.34 and 10.90 per cent for the corresponding years. The longest days to flowering was recorded in Sangla A10 (79.33) whereas shortest in Sangla A11 (69.00), during 2002. During second year, the genotype Annapurna showed the longest (82.67) and JRS 505 the shortest (69.00) days to flowering.

4.1.2.13 Days to maturity: The average days to maturity were recorded as 135.86 with range from 129.00 to 143.33 days during 2002. This average was 137.85 days during 2003, and the value varied from 129.33 to 145.33 days. The PCV and GCV were 3.17 and 2.88 per cent during 2002 and 3.41 and 3.24 per cent during 2003. Heritabilities values were 82.40 and 90.30 per cent during 2002 and 2003, respectively. During 2002, the shortest days to maturity

(129.00) was recorded for Sangla A4 whereas Annapurna recorded the longest (143.33) days. Sangla A11 and IC35407 had the shortest (129.33) while Annapurna had the longest days to maturity (145.33) during 2003.

4.1.2.14 Days to seed fill: Days to seed fill varied from 57.33 to 67.00 and 52.67 to 73.00 with mean of 61.83 and 60.59 during 2002 and 2003, respectively. PCV and GCV during 2002 and 2003 were 5.36 and 7.89 per cent and 3.45 and 7.26 per cent. Heritabilities estimated were 41.40 and 84.60 per cent with corresponding genetic advances of 4.57 and 13.75 per cent during 2002 and 2003, respectively. The genotypes JRS505 (67.00 and 73.00) recorded the longest and JRS508 (57.33) and JRS506 (52.67) the shortest days to seed fill during 2002 and 2003, respectively.

4.1.2.15 Aerial biomass/plant at harvest maturity (g): During 2002 and 2003, the mean values observed were 62.29 and 68.69, which varied from 57.00 to 69.43 and 63.32 to 75.75, respectively. The PCV values recorded were 7.24 and 6.49 per cent and corresponding GCV was 7.06 and 6.30 per cent during 2002 and 2003. In both the years high heritabilities were observed i.e. 95.20 and 94.20 per cent and genetic advance was 14.19 and 12.61 per cent. The entry Sangla A10 (69.43) during 2002 and Sangla A10 (75.75) during 2003 exhibited the highest aerial biomass/plant. These values were followed by JRS504 (68.50 and 74.85) and JRS503 (68.14 and 74.45) during 2002 and 2003, respectively.

4.1.2.16 Seed yield/plant at harvest maturity (g): The mean values ranged from 7.05 to 13.67 and 8.15 to 14.91 with general mean of 9.15 and 10.32 during

2002 and 2003, respectively. The PCV, GCV, heritabilities and genetic advances were 22.70, 22.26, 96.20 and 45.03 per cent during 2002 and 19.99, 19.60, 96.10 and 39.53 per cent during 2003. During 2002, Sangla A10 gave the highest seed yield (13.67), followed by JRS503 (12.55). During 2003 also, Sangla A10 yielded highest (14.91) followed by JRS 503 (13.65).

4.1.2.17 Seed yield/day to maturity (g): During 2002 and 2003, the average values were observed to be as 0.07 for both the years and the range was recorded from 0.05 to 0.10 and 0.06 to 0.10, respectively. The PCV and GCV values were 22.96, 18.50 and 21.93, 17.04 per cent, respectively. High heritabilities (91.20 and 84.80) and high to medium genetic advances (42.85, 28.57) were observed during 2002 and 2003, respectively. Genotypes Sangla A10 (0.10) during 2002 and Sangla A10, JRS503 and JRS508 during 2003 (0.10) recorded the highest seed yield per day to maturity.

4.1.2.18 Seed yield/day to seed fill (g): The treatment means varied from 0.12 to 0.22 and 0.13 to 0.24 with average of 0.15 and 0.17 during 2002 and 2003. PCV and GCV values were 23.53 and 22.49 per cent during 2002 and 19.85 and 18.96 per cent during 2003. Heritabilities were 91.30 and 91.20 per cent with genetic advances of 46.66 and 35.29 per cent during the two years. Sangla A10 showed highest value of 0.22 during 2002 and the value of 0.24 during 2003 for this trait. These values were followed by JRS508 (0.21 and 0.23) and JRS503 (0.20 and 0.22) during 2002 and 2003, respectively.

4.1.2.19 Biomass/day to plant growth (g): The average values obtained for aerial biomass/day to plant growth were 0.46 and 0.50 with treatment means

ranging from 0.42 to 0.50 and 0.45 to 0.54 during 2002 and 2003, respectively. PCV and GCV values were 5.71, 5.27 per cent during 2002 and 4.85, 4.56 per cent during 2003. Heritabilities and corresponding genetic advances were 85.10, 10.86 and 88.60, 8.02 per cent during 2002 and 2003, respectively. Genotypes JRS504, JRS508 and PRA9101 showed the highest mean value of 0.50 during 2002 whereas genotypes JRS508 and PRA9101 showed the highest of 0.54 during 2003.

4.1.2.20 Harvest index (%): Mean harvest index obtained was 14.56 during 2002 and 14.92 during 2003. The ranges were between 12.35 to 19.69 and 12.60 to 19.68, respectively. The values for PCV and GCV were 15.69, 13.87 and 14.93, 13.19 per cent during 2002 and 2003. Heritabilities estimated were 90.50 per cent for both the years with genetic advances of 29.26 and 25.85 per cent during 2002 and 2003, respectively. Sangla A10 (19.69) followed by JRS503 (18.42) showed the highest harvest index during 2002 and Sangla A10 (19.68) followed by JRS503 (18.34) during 2003.

4.1.2.21 Stem girth (cm): The mean values obtained were 6.85 and 8.48, which ranged from 6.13 to 7.73 and 7.81 to 9.28 during 2002 and 2003, respectively. The PCV values were 8.68 and 6.91 per cent and corresponding GCV values were 5.79 and 4.48 per cent. Heritabilities and genetic advances were 44.30, 42.10 per cent and 7.88, 6.01 per cent during 2002 and 2003. Line Annapurna (7.73) and Sangla A9 (9.28) showed the maximum stem girth during the respective years.

4.1.2.22 Plant height (cm): The average values obtained were 171.97 and 172.82 ranging from 156.33 to 198.33 and 154.10 to 200.35 during 2002 and 2003, respectively. The PCV and GCV values were 10.22, 10.45 and 7.13, 7.35 per cent. Heritabilities estimated were 48.70 and 49.50 per cent with corresponding genetic advances of 10.26 and 10.65 per cent during 2002 and 2003, respectively. The genotype JRS508 (198.33 during 2002 and 200.35 during 2003) had the highest plant height.

4.1.2.23 Panicle length (cm): The treatment means ranged from 46.14 to 55.23 and 56.39 to 65.27 cm with mean of 48.46 and 59.10 during 2002 and 2003, respectively. PCV and GCV values during 2002 and 2003 were 5.55, 4.68 and 5.37 and 3.44 per cent, respectively. Heritabilities were 93.70 and 54.10 per cent with corresponding genetic advances of 10.69 and 5.21 per cent. JRS503 showed highest panicle length of 55.23 cm and 65.27 cm during 2002 and 2003, respectively.

4.1.2.24 Panicle girth (cm): The range obtained for panicle girth was 16.78 to 24.87 and 17.97 to 26.37 with average of 19.43 and 20.71 during 2002 and 2003, respectively. PCV and GCV were 14.15, 13.82 and 13.97, 13.66 per cent. Heritabilities were 97.50 and 97.70 per cent with genetic advances of 28.41 and 27.81 per cent during 2002 and 2003, respectively. Genotype Sangla A10 (24.87) had the highest panicle girth followed by JRS503 (24.40) during 2002, whereas, during 2003, Sangla A10 (26.37) had the highest panicle girth.

4.1.2.25 10 ml seed weight (g): The average values obtained were 7.73 and 7.99 ranging from 7.02 to 8.47 and 7.26 to 8.71 during 2002 and 2003,

respectively. PCV and GCV obtained were 5.18 and 5.63 per cent and 4.54 and 5.01 per cent. Heritabilities and genetic advances were 76.90, 79.10 per cent and 8.26, 9.18 per cent during first and second year, respectively. The highest mean value of 10 ml seed weight was obtained in JRS503 (8.47) during 2002 and the same genotype viz., JRS503 (8.71) during 2003.

4.1.2.26 Protein content (%): Protein content ranged from 13.23 to 15.83 and 13.57 to 16.17 with mean values of 14.72 and 15.07 during the two years. Values for PCV and GCV were 6.15 and 5.96 per cent and 4.37 and 4.19 per cent. Heritabilities were 50.30 and 49.50 per cent with genetic advances of 6.39 and 6.10 during 2002 and 2003, respectively. Genotype Sangla A6 had the highest per cent of protein 15.83 during 2002 and 16.17 during the year 2003.

4.1.2.27 Leaf area at maximum leaf weight stage (dm^2): Leaf area was recorded at maximum leaf weight stage i.e. GS_5 , which corresponds to 86-98 days have also been taken as one specific trait in this study. The average values of leaf area were 92.56 and 94.57 with ranges from 87.16 to 96.29 and 89.15 to 98.33 during 2002 and 2003, respectively. PCV and GCV values were 3.69 and 2.66 per cent and 3.63 and 2.63 per cent during first and second year. Heritability values of 51.70 and 52.20 and genetic advances of 3.93 and 3.91 were obtained during the respective years. Genotype Annapurna (96.29) followed by Sangla A1 (96.19) during 2002 and Sangla A1 (98.33) followed by Annapurna (98.28) during 2003 showed the highest leaf area.

4.2 Association Among Traits

The associations of grain yield with other observed traits have been studied by calculating the phenotypic and genotypic correlations by forming three different groups of traits *viz.*,

- i) correlations of growth parameters with yield, yield components and protein content,
- ii) correlations of yield system and other traits with yield, and
- iii) correlations of growth parameters with yield, yield system and other traits at some specific stages/intervals of growth during crop season.

4.2.1 Correlations of growth parameters with yield, yield components and protein content

The phenotypic and genotypic correlations of different growth parameters with yield and with panicle length, panicle girth and 10 ml seed weight and protein content have been undertaken (Table 13 and 14).

4.2.1.1 Absolute Growth Rate (AGR): AGR showed significant high positive phenotypic and high genotypic correlations with CGR, panicle length, panicle girth and seed yield/plant during 2002 and 2003. Significant high positive phenotypic and high genotypic correlations of AGR with RGR during 2002 and with LAI and LAD during 2003 were also observed. High significant phenotypic and high genotypic correlations with SLW and LWR were observed during 2003 but were negative.

4.2.1.2 Crop growth rate (CGR): CGR exhibited positive phenotypic correlations with seed yield per plant, panicle girth and panicle length during both

Table13: Phenotypic and genotypic correlations of growth parameters and some other traits with yield in grain amaranth during 2002

Growth parameters		CGR (g/dm ² /day)	RGR (g/g/day)	NAR (g/dm ² /day)	LAR	SLA (dm ² /g)	SLW (g/dm ³)	LWR	LAI	LAD (day)	RLGR (dm ² /dm ² /day)	Panicle length (cm)	Panicle girth (cm)	10 ml seed weight (g)	Protein content (%)	Yield/ plant (g)
AGR (g/day)	P	0.945*	0.679*	0.200	0.226	0.107	-0.181	0.077	0.184	0.184	0.086	0.568*	0.555*	0.368	-0.223	0.515*
	G	1.003	0.670	0.170	0.226	0.108	-0.205	0.069	0.188	0.188	0.096	0.597	0.570	0.435	-0.384	0.540
CGR (g/dm ² /day)	P		0.639*	0.100	0.212	0.066	-0.137	0.087	0.129	0.130	-0.001	0.496*	0.516*	0.316	-0.208	0.474*
	G		0.674	0.069	0.223	0.071	-0.166	0.088	0.142	0.142	0.020	0.559	0.559	0.389	-0.366	0.527
RGR (g/g/day)	P			0.391	0.610*	-0.095	0.045	0.722*	-0.143	-0.143	0.375	0.010	-0.015	0.142	-0.470*	-0.007
	G			0.374	0.630	-0.097	0.042	0.728	-0.148	-0.147	0.430	0.003	-0.025	0.183	-0.699	-0.009
NAR (g/dm ² /day)	P				-0.139	-0.395	0.402	0.175	-0.413	-0.417	0.369	-0.059	-0.135	0.152	-0.164	-0.150
	G				-0.123	-0.389	0.374	0.174	-0.412	-0.416	0.430	-0.059	-0.157	0.206	-0.329	-0.172
LAR	P					0.536*	-0.535*	0.677*	0.442*	0.444*	0.191	-0.039	-0.094	-0.013	-0.440*	-0.077
	G					0.525	-0.521	0.687	0.433	0.433	0.251	-0.061	-0.101	-0.005	-0.616	-0.076
SLA (dm ² /g)	P						-0.951*	-0.241	0.962*	0.960*	-0.151	0.348	0.297	0.024	-0.122	0.305
	G						-0.981	-0.245	0.963	0.961	-0.170	0.359	0.307	0.033	-0.133	0.321
SLW (g/dm ³)	P							0.230	-0.918*	-0.917*	0.078	-0.383	-0.317	-0.053	0.102	-0.320
	G							0.250	-0.958	-0.957	0.049	-0.418	-0.362	-0.074	0.031	-0.371
LWR	P								-0.307	-0.304	0.350	-0.374	-0.400	-0.050	-0.387	-0.381
	G								-0.313	-0.310	0.405	-0.400	-0.413	-0.054	-0.574	-0.393

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Growth parameters		CGR (g/dm ² /day)	RGR (g/g/day)	NAR (g/dm ² /day)	LAR	SLA (dm ² /g)	SLW (g/dm ²)	LWR	LAI	LAD (day)	RLGR (dm ² /day)	Panicle length (cm)	Panicle girth (cm)	10 ml seed weight (g)	Protein content (%)	Yield/ plant (g)
LAI	P									0.999*	-0.210	0.515*	0.482*	0.117	-0.095	0.478*
	G									0.999	-0.248	0.533	0.492	0.138	-0.108	0.494
LAD (day)	P										-0.213	0.511*	0.490*	0.106	-0.095	0.488*
	G										-0.244	0.529	0.501	0.124	-0.107	0.505
RLGR (dm ² /dm ² /day)	P											-0.155	-0.327	0.230	-0.032	-0.295
	G											-0.164	-0.402	0.274	-0.095	-0.364
Panicle length (cm)	P												0.856*	0.533*	0.020	0.810*
	G												0.890	0.641	-0.038	0.855
Panicle girth (cm)	P													0.325	-0.054	0.963*
	G													0.393	-0.122	0.989
10 ml seed weight (g)	P														-0.067	0.307
	G														-0.189	0.334
Protein content (%)	P															-0.050
	G															-0.116

* Significant at 5% level

Table14: Phenotypic and genotypic correlations of growth parameters and some other traits with yield in grain amaranth during 2003

Growth parameters		CGR (g/dm ² / day)	RGR (g/g/ day)	NAR (g/dm ² / day)	LAR	SLA (dm ² /g)	SLW (g/dm ³)	LWR	LAI	LAD	RLGR (dm ² /dm ² / day)	Panicle length (cm)	Panicle girth (cm)	10 ml seed weight (g)	Protein content (%)	Yield/ plant (g)
AGR (g/day)	P	0.985*	0.140	0.192	-0.228	0.391	-0.436*	-0.466*	0.482*	0.482*	0.172	0.529*	0.842*	0.352	-0.008	0.836*
	G	0.994	0.163	0.221	-0.231	0.393	-0.444	-0.467	0.486	0.485	0.219	0.695	0.857	0.397	0.005	0.863
CGR (g/dm ² /day)	P		0.156	0.176	-0.215	0.377	-0.426*	-0.450*	0.459*	0.460*	0.137	0.525*	0.838*	0.335	0.039	0.836*
	G		0.198	0.219	-0.222	0.382	-0.438	-0.457	0.464	0.464	0.182	0.704	0.861	0.375	0.058	0.868
RGR (g/g/day)	P			-0.033	0.347	-0.175	0.190	0.419	-0.174	-0.161	-0.128	-0.092	0.087	0.006	-0.120	0.202
	G			-0.244	0.479	-0.200	0.196	0.542	-0.190	-0.176	-0.210	0.168	0.136	0.011	-0.140	0.304
NAR (g/dm ² /day)	P				-0.489*	0.015	-0.052	-0.475*	0.003	0.002	-0.021	0.089	0.200	0.209	0.122	0.218
	G				-0.544	0.020	-0.061	-0.529	0.013	0.012	-0.031	0.252	0.248	0.203	0.126	0.260
LAR	P					0.234	-0.152	0.791*	0.167	0.172	0.249	-0.220	-0.236	-0.077	-0.401	-0.127
	G					0.226	-0.137	0.796	0.158	0.164	0.337	-0.290	-0.244	-0.082	-0.591	-0.131
SLA (dm ² /g)	P						-0.972*	-0.401	0.968*	0.969*	0.674*	0.250	0.412	0.026	-0.054	0.394
	G						-0.978	-0.403	0.968	0.970	0.904	0.350	0.420	0.033	-0.082	0.407
SLW (g/dm ³)	P							0.473*	-0.935*	-0.935*	-0.590*	-0.324	-0.465*	-0.048	-0.024	-0.433*
	G							0.481	-0.941	-0.941	-0.830	-0.450	-0.485	-0.050	-0.006	-0.453
LWR	P								-0.437*	-0.436*	-0.171	-0.379	-0.492*	-0.085	-0.358	-0.378
	G								-0.440	-0.439	-0.227	-0.509	-0.504	-0.087	-0.515	-0.390

Contd....

Contd...14

Growth parameters		CGR (g/dm ² /day)	RGR (g/g/day)	NAR (g/dm ² /day)	LAR	SLA (dm ² /g)	SLW (g/dm ²)	LWR	LAI	LAD	RLGR (dm ² /dm ² /day)	Panicle length (cm)	Panicle girth (cm)	10 ml seed weight (g)	Protein content (%)	Yield/plant (g)
LAI	P									0.999*	0.647*	0.328	0.538*	0.075	-0.052	0.509*
	G									0.999	0.872	0.461	0.548	0.085	-0.085	0.521
LAD (day)	P										0.645*	0.321	0.545*	0.060	-0.055	0.518*
	G										0.858	0.452	0.554	0.069	-0.087	0.532
RLGR (dm ² /dm ² /day)	P											0.147	0.113	0.162	-0.110	0.076
	G											0.311	0.129	0.280	-0.215	0.129
Panicle length (cm)	P												0.596*	0.437*	0.084	0.545*
	G												0.803	0.679	0.290	0.723
Panicle girth (cm)	P													0.350	-0.013	0.954*
	G													0.414	-0.063	0.979
10 ml seed weight (g)	P														-0.120	0.327
	G														-0.269	0.354
Protein content (%)	P															-0.062
	G															-0.135

* Significant at 5% level

the years. During 2002 CGR also showed significant high positive correlations with RGR and in 2003, with LAI and LAD. Their corresponding genotypic correlations were positive and high. Significant negative phenotypic correlations of CGR with SLW and LWR were observed during 2003 and their genotypic correlations were also negative and high.

4.2.1.3 Relative growth rate (RGR): RGR exhibited positive phenotypic and high genotypic correlations with LWR and LAR during 2002. Its genotypic correlation with LWR and LAR were positive and of high magnitudes. This trait showed significant negative phenotypic and high negative genotypic correlations with protein content during 2002 only. But, during 2003 no correlation of RGR was shown with any of the trait.

4.2.1.4 Net assimilation rate (NAR): NAR elicited significant negative phenotypic correlations with LAR and LWR during 2003. Its genotypic correlations with LAR and LWR were also negative and high.

4.2.1.5 Leaf area ratio (LAR): LAR exhibited significant high positive phenotypic correlation with LWR during both the years. During 2002, LAR also showed significant positive phenotypic correlations with SLA, LAD and LAI. Its genotypic correlations with these growth parameters were also positive and high. This trait showed high and negative phenotypic and genotypic correlations with SLW and protein content during 2002 only.

4.2.1.6 Specific leaf area (SLA): SLA elicited high significant positive phenotypic correlations with LAI and LAD during both the years. The genotypic correlations with these parameters were also high and positive for both the

years. Also during 2003, high positive phenotypic and genotypic correlation was found with RLGR. Phenotypic correlation of SLA with SLW was significantly high and negative during 2002 and 2003 and the correlation was also high and negative at genotypic level.

4.2.1.7 Specific leaf weight (SLW): Significant high negative phenotypic correlations of SLW were found with LAI and LAD during 2002 and 2003. The corresponding genotypic correlation values were high and negative. During 2003, SLW showed significant negative phenotypic correlations with RLGR, panicle girth and seed yield/plant and their corresponding genotypic correlations were also negative and high, but positive and high phenotypic and genotypic correlations were observed with LWR.

4.2.1.8 Leaf Weight Ratio (LWR): LWR exhibited significant negative phenotypic correlations with LAI, LAD and panicle girth during 2003. The corresponding genotypic correlation values were also high and negative.

4.2.1.9 Leaf area index (LAI): Significant positive phenotypic correlations of LAI were observed with LAD, panicle girth and seed yield per plant during both the years. Also LAI showed positive phenotypic correlation with panicle length during 2002 and with RLGR during 2003. The corresponding genotypic correlations were observed to be positive and high.

4.2.1.10 Leaf area duration (LAD): During 2002, LAD exhibited significant positive phenotypic correlations with panicle length, panicle girth and seed yield per plant, and during 2003, significant positive phenotypic correlations of LAD

with RLGR, panicle girth and seed yield per plant were observed. Their genotypic correlations were also positive and high.

4.2.1.11 Relative Leaf Growth Rate (RLGR): This trait has not shown correlation with remaining other traits, except with above discussed growth parameter.

4.2.2 Correlation of yield system and other traits with yield

Correlation of nine yield system traits including seed yield and seven other traits including protein content have been given in table 15, 16, 17 and 18 for the year 2002 and 2003.

4.2.2.1 Days of flowering: During 2002, significant positive and high phenotypic correlations of days to flowering with yield per day to seed fill, seed yield per plant, panicle girth, harvest index, aerial biomass per plant, days to maturity, yield per day to maturity, panicle length, biomass per day to plant growth and with plant height were observed. During 2003, significant positive phenotypic correlations of days to flowering with yield per day to seed fill, days to maturity, panicle girth, panicle length and seed yield per plant were observed. The corresponding genotypic correlations were also positive and high.

4.2.2.2 Days to maturity: Days to maturity showed significant positive phenotypic correlations with aerial biomass per plant, panicle girth, seed yield per plant, days to seed fill, harvest index and yield per day to maturity which also showed positive and high values at genotypic level during 2002 and 2003. Significant positive phenotypic correlation with yield per day to seed fill, plant

Table15: Phenotypic correlations of yield system and other traits in grain amaranth during 2002

Traits	Days to maturity	Days to seed fill	Aerial biomass/plant (g)	Yield/day to maturity (g)	Yield/day to seed fill (g)	Biomass/day to plant growth (g)	Harvest index (%)	Stem girth (cm)	Plant height (cm)	Panicle length (cm)	Panicle girth (cm)	10 ml seed weight (g)	Protein content (%)	♦Leaf area (dm ²)	Yield/plant (g)
Days to flowering	0.658*	-0.200	0.681*	0.656*	0.741*	0.532*	0.701*	0.228	0.484*	0.604*	0.708*	0.272	-0.028	-0.023	0.717*
Days to maturity		0.606*	0.684*	0.559*	0.459*	0.342	0.571*	0.205	0.486*	0.477*	0.625*	0.283	-0.019	0.133	0.616*
Days to seed fill			0.170	0.035	-0.185	-0.117	0.003	0.025	0.121	-0.016	0.065	0.080	0.005	0.198	0.044
Aerial biomass/ plant (g)				0.893*	0.863*	0.915*	0.857*	0.406	0.671*	0.776*	0.902*	0.344	-0.171	0.198	0.925*
Yield/day to maturity (g)					0.956*	0.841*	0.979*	0.275	0.610*	0.782*	0.932*	0.293	-0.068	0.184	0.983*
Yield/day to seed fill (g)						0.856*	0.968*	0.283	0.571*	0.807*	0.929*	0.289	-0.054	0.089	0.969*
Biomass/day to plant growth (g)							0.783*	0.408	0.602*	0.736*	0.814*	0.304	-0.221	0.186	0.848*
Harvest index (%)								0.239	0.567*	0.790*	0.943*	0.292	0.002	0.146	0.988*
Stem girth (cm)									0.427*	0.287	0.244	0.174	-0.113	0.214	0.290
Plant height (cm)										0.668*	0.582*	0.422	-0.150	0.213	0.610*
Panicle length (cm)											0.856*	0.533*	0.020	0.144	0.810*
Panicle girth (cm)												0.325	-0.054	0.119	0.963*
10 ml seed weight (g)													-0.067	0.216	0.307
Protein content (%)														0.003	-0.050
♦Leaf area (dm ²)															0.159

Significant at 5% level

♦ Leaf area measured at maximum leaf weight stage

Table16: Genotypic correlations of yield system and other traits in grain amaranth during 2002

Traits	Days to maturity	Days to seed fill	Aerial biomass/ plant (g)	Yield/ day to maturity (g)	Yield/ day to seed fill (g)	Biomass/ day to plant growth (g)	Harvest index (%)	Stem girth (cm)	Plant height (cm)	Panicle length (cm)	Panicle girth (cm)	10 ml seed weight (g)	Protein content (%)	Leaf area (dm ²)	Yield/ plant (g)
Days to flowering	0.841	0.117	0.805	0.797	0.824	0.652	0.825	0.449	0.715	0.705	0.831	0.292	-0.049	-0.113	0.826
Days to maturity		0.636	0.767	0.696	0.626	0.522	0.706	0.343	0.567	0.561	0.705	0.344	-0.040	0.305	0.720
Days to seed fill			0.259	0.140	-0.026	0.028	0.120	-0.011	0.022	0.024	0.109	0.215	-0.003	0.720	0.143
Aerial biomass/ plant (g)				0.969	0.934	0.948	0.949	0.610	0.935	0.812	0.932	0.395	-0.170	0.314	0.967
Yield/day to maturity (g)					0.985	0.937	0.996	0.441	0.892	0.854	0.987	0.344	-0.163	0.216	1.000
Yield/day to seed fill (g)						0.928	0.989	0.418	0.884	0.865	0.978	0.324	-0.111	0.099	0.986
Biomass/day to plant growth (g)							0.906	0.647	0.977	0.801	0.887	0.374	-0.229	0.257	0.924
Harvest Index (%)								0.361	0.851	0.865	0.998	0.320	-0.103	0.181	0.998
Stem girth (cm)									0.963	0.425	0.399	0.401	-0.060	0.597	0.426
Plant height (cm)										0.973	0.868	0.740	-0.314	0.474	0.872
Panicle length (cm)											0.890	0.641	-0.038	0.238	0.855
Panicle girth (cm)												0.393	-0.122	0.184	0.989
10 ml seed weight (g)													-0.189	0.266	0.334
Protein content (%)														-0.175	-0.116
Leaf area (dm ²)															0.214

♦ Leaf area measured at maximum leaf weight stage

Table17: Phenotypic correlations of yield system and other traits in grain amaranth during 2003

Traits	Days to maturity	Days to seed fill (g)	Aerial biomass/ plant (g)	Yield/ day to maturity (g)	Yield/ day to seed fill (g)	Biomass/ Harvest Index (%)	Stem girth (cm)	Plant height (cm)	Panicle length (cm)	Panicle girth (cm)	10 ml seed weight (g)	Protein content (%)	♦Leaf area (dm ²)	Yield/ plant (g)
Days to flowering	0.453*	-0.480*	0.402	0.418	0.587*	0.231	0.404	0.269	0.443*	0.487*	0.115	0.090	-0.221	0.426*
Days to maturity		0.564*	0.687*	0.428*	0.366	0.248	0.511*	0.398	0.365	0.597*	0.289	-0.067	0.128	0.581*
Days to seed fill			0.304	0.034	-0.184	0.030	0.129	0.142	-0.051	0.135	0.179	-0.149	0.331	0.177
Aerial biomass/ plant (g)				0.848*	0.790*	0.868*	0.826*	0.668*	0.585*	0.890*	0.350	-0.177	0.164	0.911*
Yield/day to maturity (g)					0.947*	0.844*	0.959*	0.672*	0.541*	0.898*	0.340	-0.050	0.130	0.960*
Yield/day to seed fill (g)						0.806*	0.933*	0.629*	0.568*	0.897*	0.260	-0.009	0.047	0.928*
Biomass/day to plant growth (g)							0.760*	0.637*	0.542*	0.776*	0.278	-0.198	0.146	0.823*
Harvest index (%)							0.222	0.638*	0.498*	0.926*	0.312	-0.012	0.170	0.984*
Stem girth (cm)								0.344	0.097	0.207	0.101	-0.136	0.298	0.274
Plant height (cm)									0.626*	0.634*	0.435*	-0.088	0.245	0.667*
Panicle length (cm)										0.596*	0.437*	0.084	0.175	0.545*
Panicle girth (cm)											0.350	-0.013	0.081	0.954*
10 ml seed weight (g)												-0.120	0.223	0.327
Protein content (%)													0.007	0.062
♦Leaf area (dm ²)														0.167

* Significant at 5% level

♦ Leaf area measured at maximum leaf weight stage

Table18: Genotypic correlations of yield system and other traits in grain amaranth during 2003

Traits	Days to maturity	Days to seed fill	Aerial biomass/ plant (g)	Yield/ day to maturity (g)	Yield/day to seed fill (g)	Biomass/ day to plant growth (g)	Harvest index (%)	Stem girth (cm)	Plant height (cm)	Panicle length (cm)	Panicle girth (cm)	10 ml seed weight (g)	Protein content (%)	Leaf area (dm ²)	Yield/ plant (g)
Days to flowering	0.493	-0.467	0.438	0.445	0.593	0.262	0.420	0.016	0.391	0.667	0.515	0.103	0.158	-0.283	0.439
Days to maturity		0.546	0.729	0.543	0.455	0.324	0.587	0.404	0.606	0.510	0.631	0.334	-0.124	0.190	0.632
Days to seed fill			0.316	0.122	-0.111	0.076	0.190	0.395	0.237	-0.127	0.142	0.239	-0.279	0.467	0.218
Aerial biomass/ plant (g)				0.945	0.864	0.884	0.923	0.606	1.011	0.738	0.924	0.398	-0.188	0.254	0.956
Yield/day to maturity (g)					0.973	0.919	0.990	0.432	0.957	0.774	0.977	0.394	-0.164	0.254	0.994
Yield/day to seed fill (g)						0.869	0.949	0.260	0.868	0.788	0.949	0.284	-0.014	0.052	0.944
Biomass/day to plant growth (g)							0.857	0.588	0.994	0.666	0.833	0.316	-0.172	0.244	0.876
Harvest index (%)								0.349	0.868	0.704	0.978	0.341	-0.121	0.224	0.995
Stem girth (cm)									0.614	0.399	0.352	0.279	-0.108	0.776	0.419
Plant height (cm)										0.850	0.938	0.705	-0.395	0.341	0.920
Panicle length (cm)											0.803	0.679	0.290	0.170	0.723
Panicle girth (cm)												0.414	-0.063	0.129	0.979
10 ml seed weight (g)													-0.269	0.277	0.354
Protein content (%)														-0.168	-0.135
Leaf area (dm ²)															0.225

♦ Leaf area measured at maximum leaf weight stage

height and panicle length was also observed during 2002. The corresponding genotypic correlations were also positive and high.

4.2.2.3 Aerial biomass per plant (g): Aerial biomass per plant exhibited significant high positive phenotypic and high genotypic correlations with seed yield per plant, biomass per day to plant growth, panicle girth, yield per day to maturity, yield per day to seed fill, harvest index, panicle length and plant height during both the years.

4.2.2.4 Yield per day to maturity (g): Significant positive and high phenotypic correlations were observed with seed yield per plant, harvest index, yield per day to seed fill, panicle girth, biomass per day to plant growth, panicle length and plant height during 2002 and 2003. The corresponding genotypic correlations were also high and positive.

4.2.2.5 Yield per day to seed fill (g): Yield/day to seed fill showed significant high positive phenotypic and high positive genotypic correlations with yield per plant, harvest index, panicle girth, biomass per day to plant growth, panicle length and plant height during 2002 and 2003.

4.2.2.6 Biomass per day to plant growth (g): Significant positive phenotypic and high positive genotypic correlations of biomass per day to plant growth with seed yield per plant, panicle girth, harvest index, panicle length and plant height were exhibited during 2002 and 2003.

4.2.2.7 Harvest index (%): Harvest index exhibited significant high positive phenotypic correlations and high genotypic correlations with seed yield per plant, panicle girth, panicle length and plant height for both the years.

4.2.2.8 Stem girth (cm): Stem girth showed significant positive phenotypic and high genotypic correlations with plant height during 2002 only.

4.2.2.9 Plant height (cm): At phenotypic level, during both the years correlations of plant height were significant and positive with panicle length, seed yield per plant and panicle girth. Also during 2003, significant positive correlation of plant height with 10 ml seed weight was observed. The corresponding genotypic correlations were also positive and high.

4.2.2.10 Panicle length (cm): High positive phenotypic and genotypic correlations were observed with panicle girth and seed yield per plant during 2002 and 2003. Also, in addition to correlation with panicle girth and seed yield per plant significant positive phenotypic correlation with 10 ml seed weight was observed, and the genotypic correlation was also positive and high during both the years.

4.2.2.11 Panicle girth (cm): Panicle girth exhibited high positive significant phenotypic correlation with seed yield per plant during 2002 and 2003. The genotypic correlations were also positive and high.

Of the remaining traits comparatively moderately high and positive genotypic correlations of grain yield were observed with days to seed fill during 2003 and for 10 ml seed weight and leaf area during both the year, protein content exhibited negative but low genotypic correlation with seed yield during 2002 only.

4.2.3 Correlation of growth parameters with yield, yield system and other traits at some specific stages of growth during crop season

The correlation patterns of various growth parameters with seed yield calculated over a long duration of growth period on the basis of average of several stages might be different than that of the correlations of these growth parameters with seed yield at some specific stages of plant growth. So, for understanding the importance of growth parameters, correlations of the eleven growth parameters viz. CGR, RGR, NAR, LAR, RLGR, LAD, LAI, AGR, SLA, SLW and LWR with yield, yield system and other traits at different selected growth period of crop growth were calculated. These stages were active vegetative growth stage, S_1 (35-47 days); average of duration from active growth stage upto pre flowering stage, S_2 (35-73 days); initial post flowering stage, S_3 (74-86 days); and average of duration from initial post flowering stage to harvesting, S_4 (74-days to harvesting).

In the year 2002, the data was not recorded on the initial consecutive three stages and hence statistical analysis was done consisting of only two specific stages (S_3 and S_4) rather than the above mentioned four. These stages have been considered as individual traits for the sake of calculation of correlations. The phenotypic and genotypic correlations of the growth parameters with yield, yield system, basic yield components and other traits at the above said four stages of growth have been tabulated in table 19 for the year

2002 and in table 20 and table 21 for the year 2003, the main accounts of which are described as under.

4.2.3.1 Absolute growth rate (g/day): During 2003, AGR at S_1 stage did not show any correlation with yield system or other traits and with seed yield. At S_2 stage, AGR showed significant positive phenotypic and high positive genotypic correlations with aerial biomass per plant, yield per day to maturity, yield per day to seed fill, biomass per day to plant growth, harvest index, panicle girth and seed yield per plant.

During 2002 AGR at S_3 stage showed significant positive correlation with biomass per day to plant growth, its genotypic correlation was also high and positive.

Significant positive phenotypic correlations of AGR at S_4 stage with aerial biomass per plant, stem girth, plant height, panicle girth and seed yield per plant were observed for both the years. AGR at S_4 stage also showed positive phenotypic correlations with yield/day to maturity, yield/day to seed fill, biomass/day to plant growth, harvest index and panicle length during 2002; and during 2003 with 10 ml seed weight. All the corresponding genotypic correlations were positive and of high magnitudes.

4.2.3.2 Crop growth rate ($\text{g}/\text{dm}^2/\text{day}$): No correlation was exhibited by CGR at S_1 stage. At S_2 stage, CGR exhibited significant positive phenotypic correlations with yield per day to seed fill, seed yield per plant, harvest index, panicle girth, yield per day to maturity, aerial biomass per plant and biomass per day to plant

Table 19: Phenotypic and genotypic correlations of growth parameters with yield, yield system and other traits at S₃ and S₄ stages of growth in grain amaranth during 2002

Traits	S ₃ stages	S ₄	Days to flowering	Days to maturity	Days to seed fill	Aerial biomass plant (g)	Yield/day to maturity (g)	Yield/day to seed fill (g)	Biomass/day to plant growth (g)	Harvest index (%)	Stem girth (cm)	Plant height (cm)	Panicle length (cm)	Panicle girth (cm)	10 ml seed weight (g)	Protein content (%)	Leaf area (dm ²)	Yield/plant (g)	
AGR (g/day)	S ₃	P	0.410	0.161	-0.024	-0.202	0.315	0.331	0.348	0.437*	0.271	0.300	0.351	0.360	0.289	0.261	-0.139	0.097	0.292
		G	0.434	0.292	0.018	-0.382	0.378	0.349	0.409	0.512	0.308	0.533	0.597	0.429	0.317	0.355	-0.329	0.042	0.330
	S ₄	P		0.307	0.377	0.166	0.584*	0.528*	0.454*	0.545*	0.476*	0.486*	0.528*	0.570*	0.557*	0.368	-0.221	0.376	0.518*
		G		0.380	0.452	0.287	0.624	0.548	0.480	0.595	0.509	0.809	0.823	0.599	0.572	0.437	-0.386	0.490	0.543
CGR (g/dm ² /day)	S ₃	P	0.230	0.162	-0.018	-0.195	0.317	0.334	0.350	0.435*	0.276	0.297	0.345	0.363	0.295	0.255	-0.137	0.099	0.296
		G	0.275	0.300	0.025	-0.381	0.386	0.356	0.416	0.519	0.314	0.535	0.602	0.437	0.324	0.354	-0.330	0.045	0.338
	S ₄	P		0.262	0.385	0.224	0.527*	0.467*	0.383	0.462*	0.422	0.460*	0.423*	0.482*	0.503*	0.299	-0.218	0.342	0.461*
		G		0.349	0.498	0.416	0.597	0.516	0.423	0.531	0.480	0.730	0.770	0.539	0.552	0.386	-0.392	0.519	0.514
RGR (g/g/day)	S ₃	P	0.519*	-0.175	-0.259	-0.152	0.023	0.021	-0.001	0.191	-0.061	0.266	0.127	-0.019	-0.078	0.206	-0.319	0.189	-0.041
		G	0.632	-0.143	-0.265	-0.281	0.018	-0.040	-0.023	0.168	-0.106	0.439	0.267	-0.009	-0.116	0.246	-0.632	0.180	-0.074
	S ₄	P		-0.205	-0.060	0.138	0.036	-0.001	-0.086	0.070	-0.053	0.302	0.155	0.005	-0.033	0.185	-0.409	0.405	-0.033
		G		-0.240	-0.098	0.163	0.040	-0.001	-0.081	0.096	-0.060	0.446	0.236	0.013	-0.035	0.186	-0.621	0.570	-0.035
NAR (g/dm ² /day)	S ₃	P	0.762*	-0.027	-0.110	-0.114	0.088	0.099	0.096	0.195	0.046	0.217	0.154	0.104	0.040	0.200	-0.165	0.242	0.056
		G	0.845	0.034	-0.074	-0.184	0.119	0.072	0.094	0.215	0.023	0.392	0.293	0.144	0.027	0.285	-0.305	0.267	0.050
	S ₄	P		-0.158	-0.102	0.034	0.018	-0.042	-0.056	0.101	-0.082	0.110	0.073	0.045	-0.046	0.224	-0.163	0.462*	-0.060
		G		-0.178	-0.077	0.113	0.041	-0.055	-0.065	0.118	-0.087	0.299	0.109	0.027	-0.050	0.307	-0.310	0.575	-0.054
LAR	S ₃	P	0.994*	-0.254	-0.379	-0.224	-0.033	-0.029	-0.020	0.143	-0.079	0.098	0.070	-0.032	-0.080	-0.019	-0.463*	-0.040	-0.067
		G	0.996	-0.309	-0.409	-0.309	-0.044	-0.029	-0.031	0.137	-0.076	0.155	0.145	-0.060	-0.088	-0.009	-0.673	-0.052	-0.066
	S ₄	P		-0.250	-0.397	-0.252	-0.049	-0.038	-0.022	0.130	-0.084	0.089	0.069	-0.040	-0.093	-0.013	-0.437*	-0.078	-0.075
		G		-0.300	-0.432	-0.364	-0.063	-0.036	-0.030	0.123	-0.081	0.140	0.133	-0.062	-0.099	-0.006	-0.615	-0.099	-0.074
SLA (dm ² /g)	S ₃	P	0.990*	0.210	-0.047	-0.282	0.319	0.333	0.396	0.424*	0.319	0.147	0.337	0.356	0.321	0.002	-0.095	-0.331	0.332
		G	0.992	0.239	-0.041	-0.414	0.321	0.361	0.419	0.447	0.354	0.189	0.510	0.368	0.334	0.006	-0.104	-0.464	0.349
	S ₄	P		0.176	-0.074	-0.281	0.299	0.304	0.363	0.412	0.287	0.135	0.339	0.345	0.294	0.024	-0.122	-0.325	0.302
		G		0.205	-0.070	-0.422	0.299	0.331	0.387	0.431	0.321	0.190	0.515	0.356	0.304	0.033	-0.136	-0.453	0.319

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Traits	Stages	S4	Days to flowering	Days to maturity	Days to seed fill	Aerial biomass plant (g)	Yield/day to maturity (g)	Yield/day to seed fill (g)	Biomass/day to growth (g)	Harvest index (%)	Stem girth (cm)	Plant height (cm)	Panicle length (cm)	Panicle girth (cm)	10 ml seed weight (g)	Protein content (%)	Leaf area (dm ²)	Yield/plant (g)
SLW (g/dm ²)	S ₃	P	0.910*	-0.315	-0.011	0.318	-0.376	-0.363	-0.455*	-0.356	-0.276	-0.331	-0.417	-0.377	-0.032	0.029	0.255	-0.377
		G	0.909	-0.373	-0.055	0.429	-0.424	-0.473	-0.539	-0.477	-0.322	-0.619	-0.485	-0.464	-0.060	-0.107	0.370	-0.467
	S ₄	P		-0.213	0.075	0.323	-0.324	-0.307	-0.384	-0.294	-0.209	-0.340	-0.379	-0.313	-0.055	0.096	0.279	-0.316
		G		-0.242	-0.057	0.449	-0.337	-0.374	-0.432	-0.370	-0.262	-0.587	-0.413	-0.357	-0.074	0.026	0.388	-0.365
LWR	S ₃	P	0.972*	-0.462*	-0.389	-0.018	-0.305	-0.304	-0.347	-0.349	-0.023	-0.188	-0.328	-0.356	-0.021	-0.460*	0.217	-0.348
		G	0.973	-0.529	-0.420	-0.016	-0.314	-0.328	-0.374	-0.376	-0.001	-0.250	-0.360	-0.373	-0.015	-0.683	0.300	-0.361
	S ₄	P		-0.457*	-0.451*	-0.103	-0.371	-0.336	-0.356	-0.371	-0.056	-0.247	-0.377	-0.402	-0.053	-0.390	0.136	-0.382
		G		-0.518	-0.491	-0.161	-0.380	-0.359	-0.378	-0.396	-0.056	-0.335	-0.402	-0.414	-0.061	-0.572	0.186	-0.393
LAI	S ₃	P	0.981*	0.347	0.130	-0.198	0.457*	0.466*	0.517*	0.459*	0.161	0.407	0.505*	0.486*	0.086	-0.078	-0.327	0.474*
		G	0.983	0.404	0.151	-0.300	0.465	0.493	0.546	0.493	0.218	0.611	0.522	0.497	0.101	-0.097	-0.455	0.490
	S ₄	P		0.347	0.073	-0.272	0.456*	0.474*	0.537*	0.463*	0.175	0.426*	0.515*	0.482*	0.117	-0.095	0.339	0.478*
		G		0.410	0.090	-0.420	0.463	0.502	0.568	0.499	0.254	0.640	0.533	0.493	0.138	-0.109	-0.469	0.494
LAD (day)	S ₃	P	0.996*	0.367	0.102	-0.255	0.470*	0.492*	0.553*	0.484*	0.168	0.409	0.505*	0.502*	0.079	-0.087	-0.339	0.499*
		G	0.996	0.426	0.122	-0.383	0.478	0.523	0.584	0.522	0.235	0.616	0.522	0.514	0.092	-0.101	-0.474	0.516
	S ₄	P		0.356	0.072	-0.282	0.462*	0.484*	0.549*	0.473*	0.175	0.421	0.511*	0.490*	0.106	-0.095	-0.341	0.488*
		G		0.419	0.090	-0.431	0.469	0.513	0.580	0.510	0.254	0.632	0.529	0.501	0.124	-0.107	-0.474	0.505
RLGR (dm ² /dm ² /day)	S ₃	P	0.631*	-0.150	-0.289	-0.217	-0.209	-0.143	-0.128	-0.146	-0.064	-0.189	-0.249	-0.237	-0.146	-0.001	0.068	-0.160
		G	0.693	-0.197	-0.387	-0.427	-0.255	-0.173	-0.144	-0.192	-0.027	-0.356	-0.372	-0.284	-0.212	-0.030	0.107	-0.201
	S ₄	P		-0.223	-0.385	-0.265	-0.205	-0.183	-0.153	-0.213	0.114	0.060	-0.119	-0.234	0.315	-0.021	0.074	-0.217
		G		-0.245	-0.467	-0.507	-0.225	-0.247	-0.186	-0.282	0.291	0.086	-0.153	-0.280	0.358	-0.136	0.081	-0.266

* Significant at 5 % level

S₃ = Initial post flowering stage andS₄ = average of duration from initial post flowering to harvesting stages.

♦ Leaf area measured at maximum leaf weight stage

Table 20: Phenotypic correlations of growth parameters with yield, yield system and other traits at S₁, S₂, S₃, and S₄ stages of growth in grain amaranth during 2003

Traits	Stages	S ₂	S ₃	S ₄	Days to 50% flowering	Days to 75% maturity	Days to seed fill	Aerial biomass /plant (g)	Yield/ day to maturity (g)	Yield/ day to seed fill (g)	Biomass/ day to plant growth (g)	Harvest Index (%)	Stem girth (cm)	Plant height (cm)	Panicle length (cm)	Panicle girth (cm)	10 ml seed weight (g)	Protein content (%)	Leaf area (dm ²)	Yield/ plant (g)
AGR (g/day)	S ₁	0.406*	-0.370	-0.205	-0.073	0.247	0.311	0.122	0.083	0.063	-0.015	0.152	-0.161	-0.080	-0.225	0.166	-0.272	0.125	-0.246	0.156
	S ₂		-0.157	-0.268	0.404	0.405	0.024	0.532*	0.561*	0.611*	0.439*	0.585*	-0.056	0.282	0.278	0.585*	-0.085	0.246	-0.184	0.595*
	S ₃			0.464*	0.087	0.113	0.030	0.354	0.295	0.308	0.404	0.279	0.277	0.414	0.331	0.324	0.372	-0.089	0.060	0.309
	S ₄				0.048	0.392	0.341	0.511*	0.367	0.284	0.422	0.393	0.447*	0.506*	0.345	0.454*	0.457*	-0.225	0.375	0.438*
CGR (g/dm ² /day)	S ₁	0.400	-0.376	-0.222	-0.075	0.249	0.315	0.117	0.076	0.055	-0.023	0.146	-0.169	-0.085	-0.225	0.162	-0.265	0.121	-0.238	0.149
	S ₂		-0.157	-0.302	0.381	0.396	0.037	0.513*	0.539*	0.595*	0.423*	0.575*	-0.065	0.266	0.263	0.569*	-0.110	0.256	-0.163	0.582*
	S ₃			0.481*	0.073	0.102	0.033	0.341	0.282	0.292	0.393	0.266	0.269	0.405	0.315	0.310	0.378	-0.090	0.054	0.295
	S ₄				0.043	0.368	0.322	0.485*	0.339	0.264	0.403	0.362	0.436*	0.490*	0.337	0.431*	0.461*	-0.230	0.344	0.408
RGR (g/g/day)	S ₁	0.299	-0.355	-0.104	-0.163	0.194	0.342	0.119	0.094	0.047	0.016	0.158	-0.059	-0.093	-0.284	0.130	-0.269	0.050	-0.119	0.156
	S ₂		-0.459*	-0.558*	0.186	0.211	0.035	0.413	0.475*	0.496*	0.407	0.493*	-0.045	0.160	0.138	0.399	-0.161	0.175	-0.028	0.487*
	S ₃			0.706*	-0.249	-0.138	0.095	0.042	0.000	-0.046	0.156	-0.012	0.319	0.166	0.011	-0.060	0.294	-0.274	0.220	-0.003
	S ₄				0.373	-0.079	0.268	0.007	-0.064	-0.183	0.061	-0.065	0.331	0.121	-0.098	-0.115	0.276	-0.425*	0.392	-0.054
NAR (g/dm ² /day)	S ₁	0.460*	-0.378	-0.378	-0.169	0.204	0.357	0.040	-0.016	-0.054	-0.091	0.045	-0.165	-0.114	-0.266	0.063	-0.223	0.107	-0.226	0.049
	S ₂		-0.261	-0.465*	0.279	0.399	0.134	0.394	0.396	0.417	0.261	0.424*	-0.073	0.171	0.167	0.409	-0.054	0.304	-0.091	0.432*
	S ₃			0.761*	-0.032	0.064	0.093	0.145	0.070	0.062	0.160	0.076	0.277	0.224	0.195	0.088	0.317	-0.050	0.208	0.094
	S ₄				-0.249	-0.036	0.195	-0.090	-0.202	-0.263	-0.089	-0.202	0.169	-0.009	0.073	-0.177	0.209	-0.129	0.338	-0.183
LAR	S ₁	0.896*	0.518*	0.496*	-0.281	-0.339	-0.073	-0.122	-0.050	-0.099	0.061	-0.076	0.175	-0.091	-0.186	-0.251	-0.119	-0.246	0.335	-0.097
	S ₂		0.706*	0.682*	-0.296	-0.373	-0.093	-0.140	-0.067	-0.095	0.063	-0.087	0.088	-0.087	-0.186	-0.233	-0.151	-0.315	0.182	-0.111
	S ₃			0.994*	-0.388	-0.396	-0.031	-0.136	-0.068	-0.130	0.079	-0.117	0.084	0.006	-0.230	-0.194	0.060	-0.476*	0.008	-0.129
	S ₄				-0.369	-0.419	-0.071	-0.148	-0.066	-0.116	0.077	-0.118	0.058	0.005	-0.235	-0.200	0.043	-0.447*	-0.036	-0.133
SLA (dm ² /g)	S ₁	0.803*	0.465*	0.385	0.503*	0.336	-0.136	0.477*	0.469*	0.536*	0.410	0.464*	0.120	0.427*	0.468*	0.535*	0.093	0.167	0.044	0.492*
	S ₂		0.838*	0.776*	0.301	0.156	-0.125	0.447*	0.454*	0.514*	0.499*	0.427*	0.072	0.413	0.311	0.477*	0.013	0.009	-0.174	0.453*
	S ₃			0.989*	0.121	-0.051	-0.162	0.301	0.362	0.409	0.443*	0.308	-0.007	0.350	0.184	0.331	0.033	-0.096	-0.321	0.320
	S ₄				0.083	-0.081	-0.157	0.260	0.321	0.364	0.411	0.265	-0.021	0.337	0.150	0.282	0.041	-0.127	-0.320	0.275

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Traits	Stages	Days to 75% flowering maturity				Days to seed fill	Aerial biomass /plant (g)	Yield/ day to maturity (g)	Yield/ day to seed fill (g)	Biomass/ day to plant growth (g)	Harvest Index (%)	Stem girth (cm)	Plant height (cm)	Panicle length (cm)	Panicle girth (cm)	10 ml seed weight (g)	Protein content (%)	Leaf area (dm ²)	Yield/ plant (g)
		S2	S3	S4	50% flowering maturity	Days to seed fill													
SLW (g/dm ³)	S ₁	0.522*	0.272	0.155	-0.377	-0.356	-0.002	-0.392	-0.315	-0.335	-0.292	-0.316	-0.280	-0.397	-0.449*	-0.394	-0.139	-0.157	-0.356
	S ₂		0.703*	0.451*	-0.387	-0.298	0.065	-0.484*	-0.449*	-0.513*	-0.454*	-0.450*	-0.121	-0.357	-0.525*	-0.021	-0.126	0.024	-0.483*
	S ₃			0.851*	-0.172	0.070	0.228	-0.336	-0.394	-0.449*	-0.496*	-0.321	-0.080	-0.285	-0.383	-0.044	-0.018	0.254	-0.341
	S ₄				-0.045	0.141	0.180	-0.231	-0.304	-0.349	-0.411	-0.240	0.012	-0.258	-0.147	-0.049	0.087	0.269	-0.248
LWR	S ₁	0.949*	0.818*	0.817*	-0.471*	-0.442*	0.001	-0.303	-0.236	-0.310	-0.109	-0.254	0.107	-0.248	-0.367	-0.121	-0.330	0.270	-0.286
	S ₂		0.885*	0.879*	-0.457*	-0.419	0.011	-0.379	-0.320	-0.387	-0.229	-0.321	0.046	-0.303	-0.356	-0.121	-0.329	0.245	-0.357
	S ₃			0.974*	-0.481*	-0.378	0.073	-0.348	-0.319	-0.416	-0.222	-0.336	0.088	-0.224	-0.363	0.044	-0.443*	0.222	-0.357
	S ₄				-0.444*	-0.439*	-0.020	-0.392	-0.334	-0.406	-0.244	-0.353	0.055	-0.274	-0.382	-0.006	-0.378	0.140	-0.380
LAI	S ₁	0.576*	0.335	0.316	0.463*	0.414	-0.021	0.416	0.328	0.365	0.274	0.322	0.259	0.373	0.455*	0.103	0.303	-0.106	0.368
	S ₂		0.795*	0.740*	0.448*	0.323	-0.097	0.544*	0.513*	0.584*	0.512*	0.512*	0.117	0.396	0.363	-0.066	0.086	-0.209	0.547*
	S ₃			0.981*	0.236	0.124	-0.096	0.462*	0.482*	0.521*	0.537*	0.438*	0.049	0.436*	0.307	0.110	-0.084	-0.318	0.464*
	S ₄				0.216	0.069	-0.132	0.444*	0.482*	0.526*	0.547*	0.431*	0.043	0.444*	0.288	0.128	-0.107	-0.337	0.454*
LAD (day)	S ₁	0.777*	0.481*	0.442*	0.543*	0.374	-0.134	0.526*	0.497*	0.575*	0.447*	0.507*	0.175	0.343	0.381	-0.093	0.226	-0.062	0.540*
	S ₂		0.888*	0.858*	0.379	0.250	-0.104	0.530*	0.522*	0.585*	0.543*	0.507*	0.083	0.407	0.337	-0.025	0.013	-0.254	0.537*
	S ₃			0.995*	0.243	0.106	-0.120	0.475*	0.513*	0.559*	0.564*	0.471*	0.044	0.444*	0.298	0.113	-0.097	-0.329	0.493*
	S ₄				0.223	0.073	-0.135	0.453*	0.496*	0.542*	0.556*	0.447*	0.041	0.445*	0.286	0.125	-0.108	-0.337	0.469*
RLGR (dm ² /dm ² /day)	S ₁	0.506*	-0.110	-0.314	0.048	-0.110	-0.153	0.063	0.144	0.194	0.159	0.161	-0.154	-0.083	-0.139	-0.227	-0.138	0.105	0.140
	S ₂		-0.257	-0.160	-0.045	-0.105	-0.062	0.249	0.319	0.332	0.407	0.284	-0.122	0.213	0.031	0.063	-0.300	-0.210	0.284
	S ₃			0.635*	-0.112	-0.221	-0.114	-0.156	-0.039	-0.015	-0.068	-0.009	-0.055	-0.142	-0.216	-0.038	-0.070	0.013	-0.047
	S ₄				-0.256	-0.389	-0.146	-0.321	-0.267	-0.264	-0.169	-0.320	-0.030	-0.061	-0.170	0.101	-0.089	-0.039	-0.336

* Significant at 5% level

S₁ = Active vegetative stage,

S₂ = average of duration from active vegetative upto preflowering stages,

S₃ = initial post flowering stage, and

S₄ = average of duration from initial post flowering to harvesting stages.

♦ Leaf area measured at maximum leaf weight stage

Table 21: Genotypic correlations of growth parameters with yield, yield system and other traits at S₁, S₂, S₃, and S₄ stages of growth in grain amaranth during 2003

Traits	Stages	S ₂	S ₃	S ₄	Days to 50% flower	Days to 75% maturity	Days to seed fill	Aerial plant (g)	Yield/ day to maturity (g)	Yield/ day to seed (g)	Biomass / day to plant (g)	Harvest index (%)	Stem girth (cm)	Plant height (cm)	Panicle length (cm)	Panicle girth (cm)	10 ml seed weight (g)	Protein content (%)	Leaf area (dm ²)	Yield/ plant (g)
AGR (g/day)	S ₁	0.422	-0.399	-0.215	0.075	0.253	0.329	0.128	0.101	0.076	-0.010	0.163	-0.277	-0.137	-0.314	0.170	-0.312	0.196	-0.324	0.161
	S ₂		-0.115	-0.253	0.426	0.439	0.033	0.549	0.614	0.648	0.460	0.634	-0.084	0.424	0.374	0.601	-0.091	0.389	-0.246	0.619
	S ₃			0.452	0.095	0.114	0.024	0.393	0.348	0.343	0.473	0.297	0.433	0.587	0.491	0.341	0.429	-0.184	0.067	0.327
	S ₄				0.053	0.403	0.359	0.541	0.424	0.316	0.478	0.421	0.721	0.721	0.461	0.466	0.515	-0.339	0.515	0.457
CGR (g/dm ² /day)	S ₁	0.413	-0.409	-0.234	-0.072	0.259	0.333	0.122	0.098	0.071	-0.023	0.161	-0.287	-0.135	-0.314	0.167	-0.303	0.202	-0.329	0.158
	S ₂		-0.124	-0.295	0.402	0.484	0.041	0.524	0.593	0.630	0.440	0.621	-0.099	0.395	0.344	0.581	-0.128	0.403	-0.230	0.603
	S ₃			0.477	0.082	0.103	0.026	0.381	0.337	0.331	0.462	0.286	0.417	0.581	0.490	0.329	0.434	-0.191	0.067	0.314
	S ₄				0.051	0.380	0.336	0.519	0.404	0.302	0.464	0.400	0.686	0.710	0.465	0.447	0.525	-0.352	0.489	0.435
RGR (g/g/day)	S ₁	0.311	-0.379	-0.108	-0.172	0.196	0.366	0.125	0.110	0.058	0.022	0.169	-0.117	-0.150	-0.393	0.133	-0.311	0.088	-0.136	0.162
	S ₂		-0.447	-0.555	0.201	0.231	0.040	0.421	0.521	0.527	0.424	0.534	-0.070	0.242	0.186	0.405	-0.165	0.271	-0.028	0.506
	S ₃			0.706	-0.267	-0.157	0.098	0.054	0.013	-0.043	0.190	-0.020	0.496	0.217	0.028	-0.063	0.335	-0.441	0.295	-0.005
	S ₄				-0.398	-0.091	0.287	0.012	-0.060	-0.188	0.080	-0.073	0.535	0.155	-0.145	-0.119	0.309	-0.639	0.537	-0.056
NAR (g/dm ² /day)	S ₁	0.476	-0.413	-0.404	-0.178	0.212	0.388	0.042	-0.011	-0.053	-0.096	0.048	-0.278	-0.176	-0.369	0.061	-0.255	0.170	-0.294	0.051
	S ₂		-0.223	-0.450	0.293	0.432	0.155	0.399	0.431	0.438	0.263	0.462	-0.126	0.256	0.216	0.422	-0.054	0.491	-0.113	0.450
	S ₃			0.744	-0.036	0.060	0.096	0.172	0.098	0.077	0.207	0.077	0.442	0.299	0.292	0.095	0.369	-0.132	0.280	0.101
	S ₄				-0.270	-0.052	0.208	-0.089	-0.211	-0.278	-0.079	-0.226	0.244	-0.057	0.101	-0.185	0.248	-0.220	0.482	-0.195
LAR	S ₁	0.906	0.529	0.505	-0.286	-0.377	-0.106	-0.116	-0.055	-0.094	0.090	-0.089	0.283	-0.152	-0.250	-0.255	-0.127	-0.381	0.453	-0.102
	S ₂		0.705	0.681	-0.302	-0.402	-0.116	-0.139	-0.069	-0.092	0.078	-0.095	0.149	-0.115	-0.239	-0.240	-0.163	-0.472	0.236	-0.113
	S ₃			0.996	-0.402	-0.421	-0.038	-0.137	-0.072	-0.135	0.089	-0.126	0.132	0.024	-0.302	-0.201	0.070	-0.691	0.012	-0.133
	S ₄				-0.388	-0.442	-0.074	-0.150	-0.078	-0.128	0.085	-0.132	0.097	0.009	-0.306	-0.207	0.051	-0.651	-0.052	-0.140
SLA (dm ² /g)	S ₁	0.817	0.486	0.398	0.578	0.342	-0.212	0.540	0.572	0.639	0.509	0.532	0.235	0.623	0.690	0.587	0.104	0.226	0.021	0.548
	S ₂		0.843	0.781	0.330	0.153	-0.164	0.466	0.511	0.562	0.546	0.460	0.117	0.602	0.430	0.490	0.013	0.012	0.267	0.472
	S ₃			0.990	0.129	-0.055	-0.181	0.312	0.398	0.433	0.476	0.328	-0.007	0.501	0.258	0.335	0.040	-0.143	-0.452	0.329
	S ₄				0.085	-0.087	-0.170	0.271	0.348	0.380	0.443	0.278	-0.034	0.469	0.214	0.286	0.050	-0.189	-0.449	0.281

Contd....

Cont....21

Traits	Stage	S ₁	S ₂	S ₃	S ₄	Days to 50% flower in maturity	Days to 75% seed fill	Days to Aerial plant (g)	Yield/ day to maturity (g)	Yield/ day to seed (g)	Biomass / day to plant (g)	Harvest index (%)	Stem girth (cm)	Plant height (cm)	Panicle length (cm)	Panicle girth (cm)	10 ml seed weight (g)	Protein content (%)	Leaf area (dm ²)	Yield/ plant (g)
SLW (g/dm ²)	S ₁	0.551	0.340	0.180	-0.512	-0.406	0.082	-0.556	-0.491	-0.512	-0.489	-0.434	-0.565	-0.562	-0.768	-0.531	-0.180	-0.264	-0.168	-0.482
	S ₂		0.712	0.457	-0.432	-0.300	0.113	-0.517	-0.521	-0.578	-0.517	-0.496	-0.191	-0.564	-0.551	-0.552	-0.015	-0.177	0.063	-0.514
	S ₃			0.859	-0.184	0.076	0.255	-0.352	-0.433	-0.477	-0.535	-0.341	-0.133	-0.474	-0.368	-0.388	-0.042	-0.009	0.361	-0.352
	S ₄				-0.038	0.150	0.189	-0.250	-0.327	-0.359	-0.456	-0.249	0.015	-0.369	-0.220	-0.272	-0.058	0.159	0.393	-0.255
LWR	S ₁	0.953	0.823	0.825	-0.494	-0.462	0.009	-0.313	-0.270	-0.335	-0.121	-0.280	0.150	-0.364	-0.502	-0.448	-0.125	-0.469	0.387	-0.300
	S ₂		0.886	0.881	-0.479	-0.438	0.019	-0.388	-0.352	-0.411	-0.243	-0.345	0.071	-0.433	-0.478	-0.496	-0.124	-0.474	0.344	-0.369
	S ₃			0.975	-0.499	-0.396	0.080	-0.359	-0.350	-0.438	-0.238	-0.360	0.142	-0.312	-0.495	-0.447	0.047	-0.642	0.313	-0.368
	S ₄				-0.460	-0.462	-0.024	-0.402	-0.366	-0.427	-0.260	-0.378	0.087	-0.377	-0.510	-0.471	-0.009	-0.553	0.194	-0.391
LAI	S ₁	0.603	0.387	0.364	0.558	0.451	-0.081	0.523	0.413	0.467	0.400	0.374	0.415	0.492	0.685	0.562	0.122	0.490	-0.152	0.431
	S ₂		0.803	0.747	0.484	0.332	-0.131	0.579	0.574	0.636	0.574	0.546	0.171	0.575	0.520	0.604	-0.075	0.118	-0.307	0.569
	S ₃			0.983	0.253	0.129	-0.114	0.479	0.529	0.552	0.575	0.462	0.075	0.639	0.415	0.501	0.122	-0.134	-0.447	0.475
	S ₄				0.224	0.073	-0.143	0.462	0.521	0.550	0.588	0.451	0.065	0.634	0.402	0.484	0.146	0.163	-0.474	0.463
LAD (day)	S ₁	0.788	0.495	0.454	0.605	0.385	-0.193	0.585	0.571	0.651	0.537	0.551	0.262	0.478	0.556	0.630	-0.115	0.318	-0.115	0.578
	S ₂		0.890	0.860	0.407	0.259	-0.131	0.556	0.577	0.628	0.593	0.537	0.123	0.594	0.477	0.580	-0.027	0.009	-0.368	0.555
	S ₃			0.996	0.257	0.111	-0.136	0.493	0.561	0.590	0.605	0.497	0.068	0.644	0.414	0.525	0.127	-0.143	-0.462	0.506
	S ₄				0.232	0.077	-0.147	0.471	0.537	0.567	0.598	0.470	0.063	0.633	0.402	0.498	0.142	-0.160	-0.474	0.480
RLGR (dm ² /dm ² /day)	S ₁	0.404	-0.123	-0.399	0.067	-0.103	-0.170	0.052	0.185	0.224	0.154	0.213	-0.229	0.007	-0.153	0.061	-0.289	-0.249	0.093	0.168
	S ₂		-0.272	-0.179	-0.050	-0.096	-0.049	0.258	0.384	0.370	0.431	0.343	-0.159	0.448	0.066	0.272	0.074	-0.472	-0.338	0.320
	S ₃			0.696	-0.132	-0.232	-0.108	-0.157	-0.050	-0.024	-0.065	0.013	-0.096	-0.216	-0.243	-0.118	-0.031	-0.062	0.028	-0.048
	S ₄				-0.354	-0.448	-0.113	-0.362	-0.388	-0.381	-0.190	0.421	-0.062	-0.263	-0.239	-0.432	0.136	-0.197	-0.073	-0.411

S₁ = Active vegetative stage,
S₂ = average of duration from active vegetative upto preflowering stages,
S₃ = initial post flowering stage, and
S₄ = average of duration from initial post flowering to harvesting stages
♦ Leaf area measured at maximum leaf weight stage

growth during 2003. The corresponding genotypic correlations were also positive and high.

At initial post flowering stage (S_3) significant positive phenotypic and high positive genotypic correlation of CGR was observed with biomass per day to plant growth during 2002.

At duration from post flowering to harvesting stages (S_4) positive and significant phenotypic correlations were illustrated with aerial biomass per plant, stem girth, plant height and panicle girth during both the years. During 2002, S_4 stage also showed significant positive phenotypic correlation with seed yield per plant, panicle length, yield/day to maturity and biomass/day to plant growth. All the corresponding genotypic correlations were positive and high.

4.2.3.3 Relative growth rate (g/g/day): Like CGR, RGR at S_1 stage did not show any correlation with yield, yield system or other traits. At S_2 stage, significant positive phenotypic correlations of RGR were observed with yield per day to maturity, yield per day to seed fill, harvest index and seed yield per plant and these were positive and high at genotypic level, during 2003.

At S_4 stage, RGR exhibited significant negative correlation with protein content during 2003. The corresponding genotypic correlation was high and negative.

4.2.3.4 Net assimilation rate ($\text{g}/\text{dm}^2/\text{day}$): No correlation of NAR at S_1 stage was observed. At S_2 , NAR showed significant positive phenotypic and high positive genotypic correlations with harvest index and seed yield per plant during 2003. During 2002, NAR at S_4 stage exhibited significant positive phenotypic and

high genotypic correlations with leaf area measured at maximum leaf weight stage.

4.2.3.5 Leaf area ratio: LAR at S_1 and S_2 stages showed no correlation with any of the yield system or other traits and with yield. However, negative significant phenotypic correlations were found to exist between LAR and protein content at S_3 and S_4 stages for both the year. The corresponding genotypic correlations were also high and negative.

4.2.3.6 Specific leaf area (dm^2/g): Positive significant phenotypic and high positive genotypic correlations of SLA at S_1 were exhibited with days to flowering, aerial biomass per plant, yield per day to maturity, yield per day to seed fill, harvest index, plant height, panicle length, panicle girth and yield per plant; and at S_2 with aerial biomass per plant, yield per day to maturity, yield per day to seed fill, biomass per day to plant growth, harvest index, panicle girth and seed yield per plant during 2003.

SLA at S_3 exhibited positive phenotypic and high genotypic correlations with biomass per day to plant growth during both the years. No significant correlation of SLA was observed at S_4 stage during both the years.

4.2.3.7 Specific leaf weight (g/dm^2): Significant negative phenotypic correlation of SLW at S_1 were observed with panicle length and at S_2 stage with aerial biomass per plant, yield per day to maturity, yield per day to seed fill, biomass per day to plant growth, harvest index, panicle girth and seed yield per plant during 2003. The genotypic correlations of these characters were also negative and high.

At S_3 , SLW showed significant negative phenotypic correlations with yield per day to seed fill and biomass per day to plant growth during both the years and with biomass per day to plant growth at S_4 stage (only during 2002). The genotypic correlations with these growth parameters were negative and of high magnitude.

4.2.3.8 Leaf weight ratio: LWR exhibited significant negative phenotypic correlations with days to flowering, days to maturity and panicle girth at S_1 stage; and with days to flowering and panicle girth at S_2 stage during 2003.

At S_3 stage, LWR showed significant negative phenotypic and high negative genotypic correlations with days to flowering and protein content during both the years and with panicle girth during 2003 only.

Significant negative phenotypic and high negative genotypic correlations of LWR at S_4 were observed with days to flowering, days to maturity during both the years and with panicle girth only during 2003. High and negative genotypic correlations with these traits were also observed.

4.2.3.9 Leaf area index: At S_1 stage, LAI showed significant positive correlations with panicle length, days to flowering and panicle girth. The genotypic correlations with these characters were also high and positive. LAI at stage S_2 showed significant positive phenotypic and high genotypic correlations with days to flowering, aerial biomass per plant, yield per day to maturity, yield per day to seed fill, biomass per day to plant growth, harvest index, panicle girth and seed yield per plant during 2003.

Significant positive phenotypic correlations of stage S_3 with aerial biomass per plant, yield per day to maturity, yield per day to seed fill, biomass per day to plant growth, harvest index, panicle girth and seed yield per plant were observed during 2002 and 2003. During 2002, LAI also exhibited significant positive correlation with panicle length. All the corresponding genotypic correlations were positive and of high magnitude.

Positive significant phenotypic correlations at S_4 with aerial biomass per plant, yield per day to maturity, yield per day to seed fill, biomass per day to plant growth, harvest index, plant height, panicle girth and seed yield per plant were observed during both the years. The genotypic correlations with these characters were also high and positive. During 2002, LAI at this stage also showed significant positive phenotypic and high genotypic correlation with panicle length.

4.2.3.10 Leaf area duration (day): At S_1 , S_2 , S_3 and S_4 , LAD exhibited significant positive phenotypic correlations with aerial biomass per plant, yield per day to maturity, yield per day to seed fill, biomass per day to plant growth, harvest index, panicle girth and yield per plant. The genotypic correlations with these characters were also high and positive. LAD during 2003 also exhibited significant positive phenotypic and high genotypic correlations with days to flowering at S_1 stage and with plant height at S_3 and S_4 stage. During 2002, LAD at S_4 stage showed positive phenotypic and high genotypic correlations with panicle length.

4.3 Path Coefficient Analysis

4.3.1 Path coefficient analysis of growth parameters, components of yield (seed weight, panicle length and panicle girth) and protein content

The partitioning of the phenotypic and genotypic correlations of various growth parameters into direct and indirect effect following path coefficient analysis is given in table 22 and table 23.

In general, magnitudes of phenotypic and genotypic correlation of different traits during 2002 and 2003 have a general similarity and the trend of correlations between various growth parameters specifically with grain yield is also similar. The path coefficient analysis of different growth parameters, yield component and protein content during both the years have also revealed a similar trend, in general, with respect to phenotypic and genotypic correlations and the character wise account of which is being given here as under.

4.3.1.1 Absolute Growth Rate (AGR): Though the phenotypic correlation of AGR with yield was significant during both the years with high magnitudes of genotypic correlation coefficient, the direct contribution of this trait, however, was high and negative at genotypic level. The positive correlation has been shown to be because of its indirect effect through LAD and panicle girth during both the years. However, during 2002 AGR has also contributed positively through RGR, and through CGR during 2003.

4.3.1.2 Crop Growth Rate (CGR): Like AGR, high and significant correlation of CGR with grain yield during both the years was because of its indirect effect

Table 22: Estimate of direct and indirect phenotypic and genotypic effects of growth parameters and some other traits on yield in grain amaranth during 2002

Traits	AGR (g/day)	CGR (g/dm ² /day)	RGR (g/g/day)	NAR (g/dm ² /day)	LAR	SLA (dm ² /g)	SLW (g/dm ²)	LWR	LAI	LAD (day)	RLGR (dm ² /dm ² /day)	Panicle length (cm)	Panicle girth (cm)	10 ml seed weight (g)	Protein content (%)	Correlation
AGR (g/day)	P -0.542 G -0.715	0.018 -0.011	0.559 0.781	-0.026 -0.028	-0.065 -0.160	-0.018 0.005	-0.005 0.016	-0.019 -0.004	-0.523 -0.781	0.600 0.848	-0.002 -0.009	0.047 0.162	0.476 0.439	0.024 0.012	-0.010 -0.016	0.515* 0.540
CGR (g/dm ² /day)	P -0.513 G -0.718	0.019 -0.011	0.526 0.786	-0.013 -0.011	-0.061 -0.158	-0.011 0.003	-0.003 0.013	-0.021 -0.005	-0.368 -0.588	0.423 0.639	0.000 0.002	0.041 0.152	0.443 0.430	0.021 0.010	-0.009 -0.016	0.474* 0.527
RGR (g/g/day)	P -0.368 G -0.479	0.012 -0.007	0.824 1.166	-0.050 -0.061	-0.176 -0.446	0.016 -0.005	0.001 -0.003	-0.177 -0.041	0.407 0.613	-0.466 -0.662	-0.008 -0.039	0.001 0.001	-0.013 -0.019	0.009 0.005	-0.020 -0.030	-0.007 -0.009
NAR (g/dm ² /day)	P -0.108 G -0.122	0.002 -0.001	0.322 0.435	-0.128 -0.163	0.040 0.087	0.068 -0.019	0.010 -0.030	-0.043 -0.010	1.172 1.712	-1.360 -1.878	-0.008 -0.039	-0.005 -0.016	-0.116 -0.121	0.010 0.005	-0.007 -0.014	-0.150 -0.172
LAR	P -0.123 G -0.162	0.004 -0.002	0.503 0.734	0.018 0.020	-0.288 -0.707	-0.092 0.026	-0.014 0.042	-0.166 -0.039	-1.257 -1.797	1.446 1.953	-0.004 -0.023	-0.003 -0.017	-0.081 -0.078	-0.001 0.000	-0.019 -0.026	-0.077 -0.076
SLA (dm ² /g)	P -0.058 G -0.077	0.001 -0.001	-0.078 -0.113	0.051 0.063	-0.154 -0.371	-0.172 0.049	-0.024 0.079	0.059 0.014	-2.733 -3.998	3.131 4.333	0.003 0.015	0.029 0.097	0.255 0.236	0.002 0.001	-0.005 -0.006	0.305 0.321
SLW (g/dm ²)	P 0.098 G 0.147	-0.003 0.002	0.037 0.049	-0.051 -0.061	0.154 0.368	0.164 -0.048	0.025 -0.080	-0.056 -0.014	2.608 3.978	-2.991 -4.314	-0.002 -0.004	-0.032 -0.113	-0.272 -0.278	-0.004 -0.002	0.004 0.001	-0.320 -0.371
LWR	P -0.042 G -0.050	0.002 -0.001	0.595 0.849	-0.022 -0.028	-0.195 -0.486	0.041 -0.012	0.006 -0.020	-0.245 -0.057	0.874 1.300	-0.993 -1.399	-0.007 -0.037	-0.031 -0.108	-0.343 -0.318	-0.003 -0.001	-0.017 -0.024	-0.381 -0.393

Contd...

Contd....22

Traits	AGR (g/day)	CGR (g/dm ² /day)	RGR (g/g/day)	NAR (g/dm ² /day)	LAR	SLA (dm ² /g)	SLW (g/dm ²)	LWR	LAI	LAD (day)	RLGR (dm ² /dm ² /day)	Panicle length (cm)	Panicle girth (cm)	10 ml seed weight (g)	Protein content (%)	Correlation
LAI	P -0.100	0.002	-0.118	0.053	-0.127	-0.165	-0.023	0.075	-2.841	3.258	0.004	0.042	0.414	0.008	-0.004	0.478*
	G -0.134	-0.001	-0.172	0.067	-0.306	0.047	0.077	0.018	-4.154	4.508	0.023	0.145	0.379	0.004	-0.005	0.494
LAD (day)	P -0.100	0.002	-0.118	0.053	-0.128	-0.165	-0.023	0.074	-2.839	3.261	0.004	0.042	0.421	0.007	-0.004	0.488*
	G -0.134	-0.001	-0.171	0.068	-0.306	0.047	0.077	0.018	-4.151	4.511	0.022	0.143	0.385	0.003	-0.005	0.505
RLGR (dm ² /dm ² /day)	P -0.046	0.000	0.309	-0.047	-0.055	0.026	0.002	-0.086	0.597	-0.694	-0.021	-0.013	-0.281	0.015	-0.001	-0.295
	G -0.069	0.000	0.501	-0.070	-0.178	-0.008	-0.004	-0.023	1.028	-1.099	-0.091	-0.045	-0.309	0.007	-0.004	-0.364
Panicle length (cm)	P -0.308	0.009	0.008	0.008	0.011	-0.060	-0.010	0.092	-1.463	1.667	0.003	0.082	0.735	0.035	0.001	0.810*
	G -0.427	-0.006	0.004	0.010	0.043	0.017	0.033	0.023	-2.214	2.384	0.015	0.271	0.685	0.017	-0.002	0.855
Panicle girth (cm)	P -0.301	0.010	-0.012	0.017	0.027	-0.051	-0.008	0.098	-1.369	1.597	0.007	0.071	0.859	0.022	-0.002	0.963*
	G -0.408	-0.006	-0.029	0.026	0.071	0.015	0.029	0.024	-2.045	2.259	0.037	0.242	0.770	0.010	-0.005	0.989
10 ml seed weight (g)	P -0.199	0.006	0.117	-0.019	0.004	-0.004	-0.001	0.012	-0.334	0.344	-0.005	0.044	0.279	0.067	-0.003	0.307
	G -0.311	-0.004	0.213	-0.034	0.003	0.002	0.006	0.003	-0.574	0.560	-0.025	0.174	0.302	0.027	-0.008	0.334
Protein content (%)	P 0.121	-0.004	-0.387	0.021	0.127	0.021	0.003	0.095	0.269	-0.309	0.001	0.002	-0.046	-0.004	0.043	-0.050
	G 0.274	0.004	-0.815	0.054	0.436	-0.006	-0.002	0.033	0.450	-0.484	0.009	-0.010	-0.094	-0.005	0.043	-0.116

* Significant at 5% level

Residual value P = 0.0496

G = -0.0033

Table23: Estimate of direct and indirect phenotypic and genotypic effects of growth parameters and some other traits on yield in grain amaranth during 2003

Traits	AGR (g/day)	CGR (g/dm ² /day)	RGR (g/g/day)	NAR (g/dm ² /day)	LAR	SLA (dm ² /g)	SLW (g/dm ²)	LWR	LAI	LAD (day)	RLGR (dm ³ /dm ² /day)	Panicle length (cm)	Panicle girth (cm)	10 ml seed weight (g)	Protein content (%)	Correlation
AGR (g/day)	P 0.059 G -0.465	0.111 0.701	0.006 0.011	0.022 0.037	0.047 -0.001	0.045 -0.441	-0.018 0.209	-0.181 -0.079	-0.644 -0.865	0.750 1.368	-0.019 -0.030	0.019 -0.155	0.636 0.501	0.002 0.072	0.000 0.000	0.836* 0.863
CGR (g/dm ² /day)	P 0.058 G -0.463	0.113 0.705	0.007 0.014	0.020 0.036	0.044 -0.001	0.043 -0.429	-0.018 0.207	-0.174 -0.077	-0.612 -0.826	0.716 1.310	-0.015 -0.025	0.019 -0.157	0.633 0.504	0.002 0.068	0.000 0.001	0.836* 0.868
RGR (g/g/day)	P 0.008 G -0.076	0.018 0.140	0.044 0.069	-0.004 -0.041	-0.072 0.002	-0.020 0.224	0.008 -0.092	0.162 0.092	0.232 0.338	-0.251 -0.496	0.014 0.029	-0.003 0.038	0.066 0.079	0.000 0.002	0.000 -0.003	0.202 0.304
NAR (g/dm ² /day)	P 0.011 G -0.103	0.020 0.155	-0.001 -0.017	0.115 0.166	0.101 -0.002	0.002 -0.023	-0.002 0.029	-0.184 -0.089	-0.004 -0.023	0.003 0.034	0.002 0.004	0.003 -0.056	0.151 0.145	0.001 0.037	0.000 0.003	0.218 0.260
LAR	P -0.014 G 0.108	-0.024 -0.156	0.015 0.033	-0.056 -0.090	-0.206 0.003	0.027 -0.253	-0.006 0.065	0.307 0.135	-0.223 -0.282	0.268 0.461	-0.027 0.046	-0.008 -0.065	-0.179 -0.143	0.000 0.015	0.000 -0.015	-0.127 -0.131
SLA (dm ² /g)	P 0.023 G -0.183	0.043 0.270	-0.008 -0.014	0.002 0.003	-0.048 0.001	0.115 -1.121	-0.041 0.461	-0.155 -0.068	-1.293 -1.726	1.510 2.735	-0.074 -0.123	0.009 -0.078	0.311 0.246	0.000 0.006	0.000 -0.002	0.394 0.407
SLW (g/dm ²)	P -0.026 G 0.206	-0.048 -0.309	0.008 0.014	-0.006 -0.010	0.031 0.000	-0.112 1.096	0.042 -0.471	0.183 0.081	1.249 1.676	-1.456 -2.655	0.065 0.113	-0.012 0.100	-0.351 -0.284	0.000 -0.009	0.000 0.000	-0.433* -0.453
LWR	P -0.028 G 0.218	-0.051 -0.322	0.018 0.038	-0.055 -0.088	-0.163 0.002	-0.046 0.452	0.020 -0.227	0.387 0.169	0.583 0.784	-0.678 -1.237	0.019 0.031	-0.014 0.114	-0.372 -0.295	0.000 -0.016	0.000 -0.013	-0.378 -0.390

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Traits		AGR (g/day)	CGR (g/dm ² /day)	RGR (g/g/day)	NAR (g/dm ² /day)	LAR	SLA (dm ² /g)	SLW (g/dm ³)	LWR	LAI	LAD (day)	RLGR (dm ² /dm ² /day)	Panicle length (cm)	Panicle girth (cm)	10 ml seed weight (g)	Protein content (%)	Correlation
LAI	P	0.029	0.052	-0.008	0.000	-0.034	0.112	-0.039	-0.169	-1.335	1.555	-0.071	0.012	0.406	0.000	0.000	0.509*
	G	-0.226	0.327	-0.013	0.002	0.000	-1.086	0.443	-0.074	-1.782	2.817	-0.118	-0.103	0.321	0.015	-0.002	0.521
LAD (day)	P	0.028	0.052	-0.007	0.000	-0.035	0.112	-0.039	-0.169	-1.333	1.557	-0.071	0.011	0.412	0.000	0.000	0.518*
	G	-0.226	0.328	-0.012	0.002	0.001	-1.087	0.444	-0.074	-1.780	2.820	-0.117	-0.101	0.324	0.012	-0.002	0.532
RLGR (dm ² /dm ² /day)	P	0.010	0.015	-0.006	-0.002	-0.051	0.078	-0.025	-0.066	-0.864	1.005	-0.109	0.005	0.086	0.001	0.000	0.076
	G	-0.102	0.128	-0.015	-0.005	0.001	-1.014	0.391	-0.038	-1.553	2.421	-0.136	-0.069	0.075	0.051	-0.005	0.129
Panicle length (cm)	P	0.031	0.059	-0.004	0.010	0.045	0.029	-0.014	-0.147	-0.437	0.499	-0.016	0.036	0.450	0.002	0.000	0.545*
	G	-0.324	0.497	-0.012	0.042	-0.001	-0.392	0.212	-0.086	-0.821	1.274	-0.042	-0.223	0.470	0.123	0.007	0.723
Panicle girth (cm)	P	0.050	0.094	0.004	0.023	0.049	0.047	-0.020	-0.190	-0.718	0.848	-0.012	0.021	0.756	0.002	0.000	0.954*
	G	-0.399	0.607	0.009	0.041	-0.001	-0.471	0.229	-0.085	-0.977	1.563	-0.017	-0.179	0.585	0.075	-0.002	0.979
10 ml seed weight (g)	P	0.021	0.038	0.000	0.024	0.016	0.003	-0.002	-0.033	-0.100	0.093	-0.018	0.016	0.264	0.005	0.000	0.327
	G	-0.185	0.264	0.001	0.034	0.000	-0.037	0.023	-0.015	-0.152	0.193	-0.038	-0.151	0.242	0.181	-0.007	0.354
Protein content (%)	P	0.000	0.004	-0.005	0.014	0.083	-0.006	-0.001	-0.139	0.070	-0.086	0.012	0.003	-0.010	-0.001	0.000	-0.062
	G	-0.002	0.041	-0.010	0.021	-0.002	0.092	0.003	-0.087	0.151	-0.245	0.029	-0.065	-0.037	-0.049	0.025	-0.135

* Significant at 5% level

Residual value P = 0.0539

G = 0.0085

through LAD and panicle girth, while its direct genotypic effect was high and positive during 2003 only. Its indirect effect through LAI was also high and negative during both the years.

4.3.1.3 Relative Growth Rate (RGR): Though no correlation was shown between this trait and yield during both the years, RGR showed high direct phenotypic and genotypic contribution during 2002. Its indirect contribution through LAI was high during both the years whereas it was high and negative through LAD.

4.3.1.4 Net Assimilation Rate (NAR): NAR contributed positively through RGR and LAI and negatively through LAD during 2002 only, otherwise it showed no correlation with grain yield during both the years.

4.3.1.5 Leaf Area Ratio (LAR): Correlation between LAR and yield was not shown during both the years, however it contributed through LAD during both the years and through RGR during 2002 only. Its indirect contribution through LAI however was high and negative in both the years.

4.3.1.6 Specific Leaf Area (SLA): High and positive indirect contribution of SLA through LAD and panicle girth and, high negative contribution through LAI have been shown during both the years, though no correlation between this trait and yield was observed.

4.3.1.7 Specific Leaf Weight (SLW): Significant correlation was shown between SLW and yield during 2003 only. Its indirect contribution through LAI was high and positive and through LAD and panicle girth it was high and

negative during both the years. During 2002, the magnitude of indirect genotypic contribution through LAR was also considerable.

4.3.1.8 Leaf Weight Ratio (LWR): Low magnitudes of correlations between LWR and yield were shown during both the years, however, its indirect contribution through LAI was high and positive and through LAD and panicle girth was high and negative during both the years. Its contribution through LAR was high and negative whereas through RGR it was high and positive during 2002 only. During 2003, its indirect genotypic contribution through SLA and AGR was considerably moderate high and positive, whereas, through CGR was considerably moderately high and negative.

4.3.1.9 Leaf Area Index (LAI): Significant phenotypic and high genotypic correlations between LAI and grain yield is attributable to its indirect contribution through LAD and panicle girth, though its direct contribution is highly negative during both the years. During 2003, its genotypic contribution through CGR and SLW was also considerable, and through SLA it was high and negative.

4.3.1.10 Leaf Area Duration (LAD): High correlation between LAD and grain yield during both the years is attributable to the high direct positive effect and high indirect positive effect through panicle girth, though, indirect effect through LAI was high and negative. During 2002, its genotypic effect through LAR and during 2003, through AGR and SLA were comparatively high and negative, and through CGR and SLW was considerable and positive.

4.3.1.11 Relative Leaf Growth Rate (RLGR): High and positive indirect contribution of RLGR through LAI during 2002 and through LAD during 2003

have been shown, though no correlation between this trait and yield was observed.

4.3.1.12 Panicle Length: High correlation between panicle length with yield could be explained by the indirect high positive contribution through LAD and panicle girth during both the years. However, its indirect contribution through LAI and AGR was high and negative during 2002. During 2003, genotypic contribution through CGR was moderately high and positive and through SLA it was negative.

4.3.1.13 Panicle Girth: Panicle girth showed high direct effects and high indirect effects through LAD during both the years contributing to the significant relationship between this trait and yield. Its indirect contributions through LAI and AGR were high and negative during both the years, and through CGR it was high and positive at genotypic level only during 2003.

Path coefficient analysis had revealed no additional information for 10 ml seed weight and protein content (%) than revealed by their association with grain yield.

4.3.2 Path coefficient analysis of yield system and other traits on yield (Table 24 and Table 25)

4.3.2.1 Days to flowering: High correlation between day to flowering and yield could be attributable to aerial biomass/plant during both the years. At phenotypic level days to maturity, days to seed fill and harvest index contributed indirectly and positively towards this correlation during both the years whereas, yield/day to maturity and yield/day to seed fill contributed indirectly at genotypic

Table24: Estimate of direct and indirect phenotypic and genotypic effects of yield system and other traits on yield in grain amaranth during 2002

Traits		Days to flowering	Days to maturity	Days to seed fill	Aerial biomass /plant (g)	Yield/ day to maturity (g)	Yield/day to seed fill (g)	Biomass/ day to plant growth (g)	Harvest index (%)	Stem girth (cm)	Plant height (cm)	Panicle length (cm)	Panicle girth (cm)	10 ml seed weight (g)	Protein content (%)	Leaf area (dm ²)	Correlation
Days to flowering	P	-4.960	3.999	0.942	0.229	-0.001	0.039	-0.026	0.463	-0.001	0.001	-0.005	0.041	-0.002	0.000	0.000	0.717*
	G	-0.281	0.090	-0.020	0.558	0.955	0.238	-0.494	-0.082	0.014	0.019	-0.004	-0.169	0.003	-0.001	-0.001	0.826
Days to maturity	P	-3.261	6.083	-2.847	0.230	-0.001	0.024	-0.017	0.377	-0.001	0.001	-0.004	0.036	-0.002	0.000	0.000	0.616*
	G	-0.236	0.107	-0.109	0.531	0.834	0.181	-0.396	-0.071	0.010	0.015	-0.004	-0.143	0.004	-0.001	-0.003	0.720
Days to seed fill	P	0.995	3.688	-4.696	0.057	0.000	-0.010	0.006	0.002	0.000	0.000	0.000	0.004	-0.001	0.000	0.000	0.044
	G	-0.033	0.068	-0.172	0.180	0.167	-0.008	-0.021	-0.012	0.000	0.001	0.000	-0.022	0.002	0.000	-0.007	0.143
Aerial biomass/ plant (g)	P	-3.378	4.158	-0.798	0.336	-0.001	0.045	-0.045	0.566	-0.001	0.001	-0.007	0.052	-0.003	0.000	0.000	0.925*
	G	-0.226	0.082	-0.045	0.693	1.161	0.270	-0.719	-0.095	0.018	0.025	-0.005	-0.189	0.004	-0.004	-0.003	0.967
Yield/day to maturity(g)	P	-3.254	3.402	-0.164	0.300	-0.001	0.050	-0.041	0.646	-0.001	0.001	-0.007	0.053	-0.002	0.000	0.000	0.983*
	G	-0.224	0.074	-0.024	0.671	1.198	0.285	-0.711	-0.100	0.013	0.024	-0.005	-0.200	0.004	-0.003	-0.002	1.000
Yield/day to seed fill (g)	P	-3.677	2.792	0.871	0.290	-0.001	0.053	-0.042	0.639	-0.001	0.001	-0.007	0.053	-0.002	0.000	0.000	0.969*
	G	-0.231	0.067	0.004	0.647	1.180	0.289	-0.704	-0.099	0.013	0.024	-0.006	-0.198	0.003	-0.002	-0.001	0.986
Biomass/day to plant growth(g)	P	-2.640	2.082	0.550	0.307	-0.001	0.045	-0.049	0.517	-0.001	0.001	-0.006	0.047	-0.002	0.000	0.000	0.848*
	G	-0.183	0.056	-0.005	0.657	1.123	0.269	-0.759	-0.091	0.020	0.026	-0.005	-0.180	0.004	-0.005	-0.002	0.924
Harvest index (%)	P	-3.476	3.473	-0.012	0.288	-0.001	0.051	-0.039	0.660	-0.001	0.001	-0.007	0.054	-0.002	0.000	0.000	0.988*
	G	-0.232	0.075	-0.021	0.658	1.193	0.286	-0.687	-0.100	0.011	0.023	-0.006	-0.202	0.003	-0.002	-0.002	0.998

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Traits		Days to flowering	Days to maturity	Days to seed fill	Aerial biomass/ plant (g)	Yield/ day to maturity	Yield/day to seed fill (g)	Biomass/ day to plant growth (g)	Harvest index (%)	Stem girth (cm)	Plant height (cm)	Panicle length (cm)	Panicle girth (cm)	10 ml seed weight (g)	Protein content (%)	Leaf area (dm ²)	Correl- ation
Stem girth (cm)	P	-1.132	1.245	-0.119	0.136	0.000	0.015	-0.020	0.158	-0.003	0.001	-0.002	0.014	-0.001	0.000	0.000	0.290
	G	-0.126	0.037	0.002	0.422	0.528	0.121	-0.494	-0.036	0.030	0.026	-0.003	-0.081	0.004	-0.001	-0.005	0.426
Plant height (cm)	P	-2.402	2.956	-0.567	0.225	-0.001	0.030	-0.030	0.374	-0.001	0.002	-0.006	0.033	-0.003	0.000	0.000	0.610*
	G	-0.201	0.061	-0.004	0.647	1.068	0.256	-0.741	-0.085	0.029	0.027	-0.006	-0.176	0.008	-0.006	-0.004	0.872
Panicle length (cm)	P	-2.994	2.904	0.076	0.261	-0.001	0.043	-0.036	0.522	-0.001	0.001	-0.008	0.049	-0.004	0.000	0.000	0.810*
	G	-0.198	0.060	-0.004	0.563	1.023	0.250	-0.608	-0.086	0.013	0.026	-0.006	-0.181	0.007	-0.001	-0.002	0.855
Panicle girth (cm)	P	-3.511	3.799	-0.306	0.303	-0.001	0.049	-0.040	0.623	-0.001	0.001	-0.007	0.057	-0.002	0.000	0.000	0.963*
	G	-0.233	0.075	-0.019	0.646	1.183	0.283	-0.673	-0.100	0.012	0.023	-0.006	-0.203	0.004	-0.003	-0.002	0.989
10 ml seed weight (g)	P	-1.350	1.720	-0.378	0.116	0.000	0.015	-0.015	0.193	-0.001	0.001	-0.004	0.019	-0.008	0.000	0.000	0.307
	G	-0.082	0.037	-0.037	0.274	0.412	0.094	-0.284	-0.032	0.012	0.020	-0.004	-0.080	0.010	-0.004	-0.002	0.334
Protein content (%)	P	0.139	-0.114	-0.024	-0.058	0.000	-0.003	0.011	0.001	0.000	0.000	0.000	0.003	0.001	0.000	0.000	-0.050
	G	0.014	-0.004	0.000	-0.118	-0.195	-0.032	0.174	0.010	-0.002	-0.008	0.000	0.025	-0.002	0.021	0.002	-0.116
Leaf area (dm ²)	P	0.116	0.809	-0.928	0.067	0.000	0.005	-0.009	0.096	-0.001	0.000	-0.001	0.007	-0.002	0.000	-0.001	0.159
	G	0.032	0.033	-0.124	0.217	0.258	0.029	-0.195	-0.018	0.018	0.013	-0.002	-0.037	0.003	-0.004	-0.009	0.214

* Significant at 5% level

Residual value $P = 0.0004$

$G = 0.0001$

♦ Leaf area measured at maximum leaf weight stage

Table25: Estimate of direct and indirect phenotypic and genotypic effects of yield system and other traits on yield in grain amaranth during 2003

Traits	Days to flowering	Days to maturity	Days to seed fill	Aerial biomass/plant (g)	Yield/day to maturity (g)	Yield/day to seed fill (g)	Biomass/day to plant growth (g)	Harvest index (%)	Stem girth (cm)	Plant height (cm)	Panicle length (cm)	Panicle girth (cm)	10 ml seed weight (g)	Protein content (%)	Leaf area (dm ²)	Correlation
Days to flowering	P -0.509 G 0.023	0.237 0.030	0.263 0.005	0.132 0.059	-0.013 -0.058	0.019 -0.021	-0.004 0.039	0.285 0.354	0.000 0.000	-0.001 -0.003	-0.001 -0.003	0.019 0.017	-0.001 0.000	0.000 0.000	0.000 -0.002	0.426* 0.439
Days to maturity	P -0.231 G -0.011	0.522 0.061	-0.309 -0.005	0.225 0.097	-0.013 -0.071	0.012 -0.016	-0.005 0.048	0.361 0.495	-0.001 -0.004	-0.001 -0.005	0.000 -0.002	0.023 0.021	-0.002 0.001	0.000 0.000	0.000 0.001	0.581* 0.632
Days to seed fill	P 0.245 G -0.011	0.295 0.033	-0.548 -0.010	0.100 0.042	-0.001 -0.016	-0.006 0.004	-0.001 0.011	0.091 0.160	-0.001 -0.004	-0.001 -0.002	0.000 0.001	0.005 0.005	-0.001 0.001	0.000 0.000	0.000 0.003	0.177 0.218
Aerial biomass/plant (g)	P -0.205 G 0.010	0.359 0.044	-0.166 -0.003	0.328 0.134	-0.026 -0.124	0.025 -0.030	-0.016 0.131	0.583 0.778	-0.001 -0.006	-0.002 -0.008	-0.001 -0.003	0.034 0.031	-0.003 0.001	0.001 0.000	0.000 0.002	0.911* 0.956
Yield/day to maturity (g)	P -0.213 G 0.010	0.223 0.033	-0.019 -0.001	0.278 0.126	-0.030 -0.131	0.031 -0.034	-0.015 0.136	0.677 0.833	0.000 -0.005	-0.002 -0.007	-0.001 -0.003	0.035 0.033	-0.002 0.001	0.000 0.000	0.000 0.002	0.960* 0.994
Yield/day to seed fill (g)	P -0.299 G 0.014	0.191 0.028	0.101 0.001	0.259 0.115	-0.029 -0.128	0.032 -0.035	-0.015 0.129	0.658 0.800	0.000 -0.003	-0.002 -0.007	-0.001 -0.003	0.035 0.032	-0.002 0.001	0.000 0.000	0.000 0.000	0.928* 0.944
Biomass/day to plant growth (g)	P -0.117 G 0.006	0.129 0.020	-0.016 -0.001	0.285 0.118	-0.025 -0.121	0.026 -0.031	-0.018 0.148	0.536 0.722	-0.001 -0.006	-0.002 -0.008	-0.001 -0.003	0.030 0.028	-0.002 0.001	0.001 0.000	0.000 0.002	0.823* 0.876
Harvest index (%)	P -0.206 G 0.010	0.267 0.036	-0.071 -0.002	0.271 0.123	-0.029 -0.130	0.030 -0.034	-0.014 0.127	0.706 0.843	0.000 -0.004	-0.002 -0.007	-0.001 -0.003	0.036 0.033	-0.002 0.001	0.000 0.000	0.000 0.000	0.984* 0.995

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Traits		Days to flowering	Days to maturity	Days to seed fill	Aerial biomass/ plant (g)	Yield/ day to maturity	Yield/ day to seed fill (g)	Biomass/ day to plant growth (g)	Harvest index (%)	Stem girth (cm)	Plant height (cm)	Panicle length (cm)	Panicle girth (cm)	10 ml seed weight (g)	Protein content (%)	♦ Leaf area (dm ²)	Correlation
Stem girth (cm)	P	-0.001	0.139	-0.143	0.125	-0.007	0.005	-0.006	0.157	-0.002	-0.001	0.000	0.008	-0.001	0.000	0.000	0.274
	G	0.000	0.025	-0.004	0.081	-0.057	-0.009	0.087	0.294	-0.011	-0.005	-0.002	0.012	0.001	0.000	0.006	0.419
Plant height (cm)	P	-0.137	0.208	-0.008	-0.219	-0.020	0.020	0.099	0.719	-0.001	-0.004	-0.001	0.024	-0.003	0.000	0.000	0.667*
	G	0.009	0.037	-0.002	0.135	-0.126	-0.031	0.148	0.731	-0.006	-0.008	-0.003	0.032	0.002	0.001	0.003	0.920
Panicle length (cm)	P	-0.226	0.191	0.028	0.192	-0.016	0.018	-0.010	0.352	0.000	-0.002	-0.001	0.023	-0.003	0.000	0.000	0.545*
	G	0.015	0.031	0.001	0.099	-0.102	-0.028	0.099	0.593	-0.004	-0.007	-0.004	0.027	0.002	0.000	0.001	0.723
Panicle girth (cm)	P	0.248	-0.312	-0.074	0.292	-0.027	0.029	0.134	0.653	0.000	-0.002	-0.001	0.038	0.003	0.000	0.000	0.954*
	G	0.012	0.031	-0.001	0.123	-0.128	-0.034	0.124	0.824	-0.004	-0.007	-0.003	0.034	0.001	0.000	0.001	0.979
10 ml seed weight (g)	P	-0.058	0.151	-0.098	0.115	-0.010	0.008	-0.005	0.220	0.000	-0.002	-0.001	0.013	-0.007	0.000	0.000	0.327
	G	0.002	0.020	-0.002	0.053	-0.052	-0.010	0.047	0.287	-0.003	-0.005	-0.003	0.014	0.002	0.000	0.002	0.354
Protein content (%)	P	-0.046	-0.035	0.081	-0.058	0.002	0.000	0.004	-0.008	0.000	0.000	0.000	0.000	0.001	0.000	0.000	-0.062
	G	0.004	-0.008	0.003	-0.025	0.021	0.001	-0.026	-0.102	0.001	0.003	-0.001	-0.002	-0.001	0.000	-0.001	-0.135
♦ Leaf area (dm ²)	P	0.112	0.067	-0.181	0.054	-0.004	0.002	-0.003	0.120	-0.001	-0.001	0.000	0.003	-0.002	0.000	0.000	0.167
	G	-0.006	0.012	-0.005	0.034	-0.033	-0.002	0.036	0.189	-0.008	-0.003	-0.001	0.004	0.001	0.000	0.007	0.225

* Significant at 5% level

Residual value P = 0.0011

G = -0.0015

♦ Leaf area measured at maximum leaf weight stage

Table 26: Top high yielding and low yielding genotypes of grain amaranth during kharif 2002 and 2003

Genotypes	Traits		Yield/plant (g)		Days to maturity		AGR (g/day)		CGR (g/dm ² /day)		LAI		LAD		Aerial biomass /plant (g)		Yield/day to maturity (g)		Yield/day to seed fill (g)		Biomass/day to plant growth (g)		Harvest index (%)	
	2002	2003	2002	2003	2002	2003	2002	2003	2002	2003	2002	2003	2002	2003	2002	2003	2002	2003	2002	2003	2002	2003	2002	2003
High yielding genotypes																								
1. Sangla A10	13.67	14.91	141.67	143.67	0.70	0.73	0.09	0.10	4.54	4.07	57.42	51.06	69.43	75.75	0.10	0.10	0.22	0.22	0.24	0.24	0.49	0.53	19.69	19.68
2. JRS503	12.55	13.65	141.00	143.00	0.97	0.72	0.12	0.10	4.99	3.90	60.74	47.67	68.14	74.45	0.09	0.10	0.20	0.20	0.22	0.22	0.48	0.52	18.42	18.34
3. JRS504	12.10	13.20	138.33	141.67	1.26	0.76	0.14	0.10	4.80	3.96	58.98	47.77	68.50	74.85	0.09	0.09	0.20	0.20	0.21	0.21	0.50	0.53	17.67	17.64
4. JRS508	11.85	12.96	136.00	137.67	0.73	0.66	0.08	0.09	4.61	3.63	56.91	43.73	67.89	74.21	0.09	0.10	0.21	0.21	0.23	0.23	0.50	0.54	17.45	17.45
5. PRA9101	11.71	12.81	135.33	137.36	0.79	0.75	0.09	0.10	9.01	6.63	108.93	81.75	67.80	74.10	0.09	0.09	0.20	0.20	0.22	0.22	0.50	0.54	17.27	17.29
6. Annapurna	11.09	12.19	143.33	145.33	1.21	0.91	0.16	0.12	4.07	3.61	49.84	43.86	66.80	73.13	0.08	0.08	0.17	0.17	0.19	0.19	0.47	0.50	16.60	16.67
Low yielding genotypes																								
1. JRS507	7.05	8.15	132.33	136.67	0.65	0.47	0.08	0.06	4.56	3.75	56.56	45.24	57.10	64.68	0.05	0.06	0.12	0.12	0.15	0.15	0.43	0.47	12.35	12.50
2. Sangla A4	7.18	8.41	129.00	131.00	0.74	0.48	0.09	0.06	4.18	3.30	51.59	39.60	57.37	63.60	0.05	0.06	0.12	0.12	0.14	0.14	0.44	0.48	12.52	13.22
3. IC35407	7.26	8.36	129.67	129.33	0.73	0.50	0.09	0.07	4.15	3.32	51.46	39.90	57.03	63.35	0.05	0.06	0.13	0.13	0.15	0.15	0.44	0.49	12.75	13.21
4. Sangla A11	7.26	8.50	129.33	129.33	0.73	0.49	0.09	0.07	4.05	3.42	49.85	41.50	57.00	63.32	0.05	0.06	0.12	0.12	0.14	0.14	0.44	0.49	12.74	13.43
5. Sangla A5	7.44	8.69	132.00	133.67	0.60	0.50	0.07	0.07	3.48	3.27	43.06	40.42	57.46	63.85	0.06	0.06	0.12	0.12	0.16	0.16	0.43	0.48	12.94	13.51

Table 27: Genotypic means of some high yielding early and late maturity grain amaranth genotypes for some important traits during 2002 and 2003

Traits		Yield/ plant (g)	AGR (g/day)	CGR	LAI	LAD	Aerial biomass/ plant (g)	Yield/ day to maturity (g)	Yield/day to seed fill (g)	Biomass/ day to plant growth (g)	Harvest index (%)	Days to maturity	Protein content (%)
Genotypes													
(A) 2002													
Early maturing													
1.	Sangla A4	7.18	0.74	0.09	4.18	51.59	57.37	0.05	0.12	0.44	12.52	129.00	13.72
2.	Sangla A11	7.26	0.73	0.09	4.05	49.85	57.00	0.05	0.12	0.44	12.74	129.33	15.45
3.	IC 35407	7.26	0.73	0.09	4.15	51.46	57.03	0.05	0.13	0.44	12.75	129.67	15.63
4.	Sangla A5	7.44	0.60	0.07	3.48	43.06	57.46	0.06	0.12	0.43	12.94	132.00	15.41
5.	JRS 507	7.05	0.65	0.08	4.56	56.56	57.10	0.05	0.12	0.43	12.35	132.33	15.12
Late maturing													
1.	JRS502	8.47	0.67	0.08	3.85	47.24	62.63	0.06	0.14	0.45	13.52	139.33	15.00
2.	JRS 503	12.55	0.97	0.12	4.99	60.74	68.14	0.09	0.20	0.48	18.42	141.00	15.22
3.	Sangla A10	13.67	0.70	0.09	4.54	57.42	69.43	0.10	0.22	0.49	19.69	141.67	14.71
4.	Annapurna	11.09	1.21	0.16	4.07	49.87	66.80	0.08	0.17	0.47	16.60	143.33	15.35
5.	JRS505	8.28	0.66	0.08	4.01	49.27	61.69	0.06	0.12	0.44	13.42	140.00	15.02
CD 5%		0.65	0.08	1.69	0.25	3.04	1.59	0.61x10⁻²	1.65x10⁻²	1.61x10⁻²	1.41	2.90	1.02
(B) 2003													
Early maturing													
1.	Sangla A4	8.41	0.48	0.06	3.30	39.60	63.60	0.06	0.14	0.48	13.22	131.00	14.06
2.	Sangla A11	8.50	0.49	0.07	3.42	41.50	63.32	0.06	0.14	0.49	13.43	129.33	15.79
3.	IC 35407	8.36	0.50	0.07	3.32	39.90	63.35	0.06	0.15	0.49	13.21	129.33	15.97
4.	Sangla A8	9.31	0.51	0.07	3.55	43.70	67.99	0.07	0.15	0.50	13.68	135.00	14.75
5.	JRS 506	8.65	0.51	0.07	3.22	38.95	64.52	0.07	0.16	0.48	13.41	135.00	15.59
Late maturing													
1.	JRS 502	9.57	0.55	0.07	3.40	41.37	68.95	0.07	0.15	0.18	13.88	142.67	15.34
2.	JRS 503	13.65	0.72	0.10	3.90	47.67	74.45	0.10	0.22	0.52	18.63	143.00	15.56
3.	Sangla A10	14.01	0.73	0.10	4.07	51.06	75.75	0.10	0.24	0.53	19.68	143.67	15.05
4.	Annapurna	12.19	0.91	0.12	3.61	43.86	73.13	0.08	0.19	0.50	16.67	145.33	15.69
5.	Sangla A9	9.44	0.55	0.07	3.51	42.54	70.53	0.07	0.15	0.50	13.39	142.33	14.02
CD 5%		0.65	0.02	0.45	0.13	1.53	1.71	0.86x10⁻²	1.61x10⁻²	1.31x10⁻²	0.99	2.35	1.02

level during 2002 only. Direct contribution of this trait at phenotypic and genotypic level was considerable and negative during 2002 while, it was high and negative at phenotypic level during 2003 only. At genotypic level indirect negative contribution through panicle girth had also been observed during 2002.

4.3.2.2 Days to maturity: Significant correlation between days to maturity and yield is attributable to its high direct phenotypic effect during both the years and considerable indirect positive phenotypic effect through aerial biomass and harvest index. While, at genotypic level indirect effect through yield/day to maturity and yield/day to seed fill was considerable during 2002 only. Both the phenotypic and genotypic contributions through days to flowering were high and negative during both the years. At genotypic level magnitudes of indirect effect through biomass/day to plant growth and panicle girth were negative and considerable during 2002 only.

4.3.2.3 Days to seed fill: Correlations had not been shown between days to seed fill and yield, however path coefficient had revealed negative direct contribution of this trait during both the years, both at genotypic and phenotypic level. However, at phenotypic level contribution through days to flowering and days to maturity were positive during both the years.

4.3.2.4 Aerial biomass/plant (g): The direct contribution of aerial biomass was high and positive during both the years. Though, its indirect contribution through days to flowering was high and negative during 2002, but considerable negative only at phenotypic level during 2003 and, through harvest index was high and positive during 2003 but it was high and positive at phenotypic level during 2002.

4.3.2.5 Yield/day to maturity (g): Significant correlation between yield/day to maturity and yield is attributable through aerial biomass during both the years but its indirect phenotypic contribution through day to flowering was high and negative. Its indirect contribution through harvest index both at phenotypic and genotypic level was high and positive during 2003, but high and positive only at phenotypic level during 2002. At phenotypic level its indirect contribution through days to maturity was high and positive during both the years, and, during 2002 at genotypic level considerably high and positive through yield/day to seed fill, whereas it was high and negative through biomass/day to plant growth during 2002 only.

4.3.2.6 Yield/day to seed fill (g): At genotypic level, direct contribution of yield/day to seed fill was high and positive during 2002. Its significant and high correlation with yield is attributable to contribution through aerial biomass/plant both at genotypic and phenotypic level during both the years and through harvest index during 2003. At phenotypic level high and positive contribution through days to maturity, days to seed fill and harvest index was observed during 2002, whereas at genotypic level it was positive and high through yield/day to maturity. Its contribution through days to flowering was high and negative both at genotypic and phenotypic level, and high and negative through biomass/day to plant growth during 2002, whereas it was negative through days to flowering at phenotypic level during 2003 only.

4.3.2.7 Biomass/day to plant growth (g): Significant and high correlations between biomass/day to plant growth and yield is because of its indirect

contribution through aerial biomass/plant during both the years and harvest index during 2003, whereas its contribution through days to flowering was negative at phenotypic level. At phenotypic level, it contributed positively through days to maturity, days to seed fill and harvest index and at genotypic level through yield/day to maturity and yield/day to seed fill during 2002. The magnitude of its contribution through yield/day to maturity was however low and negative during 2003.

4.3.2.8 Harvest index (%): The high correlation between harvest index and yield was because of its high direct positive effect both at genotypic and phenotypic level during 2003, but it was high and positive at phenotypic level only during 2002. Its phenotypic contribution through days to flowering was high and negative during both the years. During 2002, its contribution through aerial biomass/plant, yield/day to maturity and yield/day to seed fill was positive and through panicle girth and biomass/day to plant growth was negative at genotypic level. However, through yield/day to maturity the contribution was negative but of low magnitude during 2003.

4.3.2.9 Stem girth (cm): Aerial biomass/plant and harvest index contributed positively during 2003, whereas at phenotypic level it was high and positive through days to maturity during both the years, whereas positive with low magnitude through harvest index during 2002 only. During both the years its effect through days to seed fill was negative with low magnitude at phenotypic level. Its contribution through days to flowering was negative both at phenotypic and genotypic level during the two years. At genotypic level, its effect through

yield/day to maturity and aerial biomass/plant was positive and high and biomass/day to plant growth was high but negative during 2002 only.

4.3.2.10 Plant height (cm): High and significant association of plant height and yield both at phenotypic and genotypic level is attributable to its effect through aerial biomass during both the years and harvest index during 2003, however, it was high during 2002 at phenotypic level only. Its effect through days to flowering was negative during 2002 both at phenotypic and genotypic level. At phenotypic level contribution through days to maturity was also positive and high during both the years. At genotypic level its contribution was high and positive through yield/day to maturity during 2002 but negative with low magnitude during 2003.

4.3.2.11 Panicle length (cm): Indirect contribution through aerial biomass/plant and harvest index was responsible for high and significant positive correlation of panicle length with yield during 2003 both at genotypic and phenotypic levels, but it was high and positive through harvest index at phenotypic level during 2002 only. Panicle length contributed negatively through days to flowering at both the levels during 2002 and at phenotypic level during 2003. Its contribution at phenotypic level was also high and positive through days to maturity during both the years. At genotypic level, effect through yield/day to maturity was positive and high, biomass/day to plant growth was negative and high and panicle girth negative and low during 2002, and yield/day to maturity negative and low during 2003.

4.3.2.12 Panicle girth (cm): Positive contribution through aerial biomass/plant and harvest index was responsible for high correlations at phenotypic and genotypic level during 2003, whereas during 2002 these were high through aerial biomass/plant at both the level but through harvest index at phenotypic level only. At phenotypic level effect through days to maturity was high and positive, but considerable and negative through days to seed fill during 2002 only. Contribution through day to flowering was high and negative at both the levels during 2002 and was high and positive at phenotypic level during 2003 only. Effect through yield/day to maturity was high and positive during 2002 but low and negative during 2003 at genotypic level only. Contribution through biomass/day to plant growth at genotypic level was high and negative during 2002 but low and positive during 2003. Contribution through yield/day to seed fill at genotypic level was positive during 2002 only. During 2002, direct contribution of panicle girth was negative with low magnitude at genotypic level.

Path coefficient has not revealed any additional information than revealed by the correlation coefficient in case of 10 ml seed weight (g), protein content (%) and leaf area (dm^2) at maximum leaf weight stage during both the years.

DISCUSSION

DISCUSSION

Importance attributed to some of the traditional crops like grain amaranth because of their inherent high nutritional quality recently, and adaptation to unfavorable and water scarce conditions alongwith sustainability of production and diversification of agriculture, haunts the breeders to make efforts for the varietal improvement of such crops *vis-a-vis* the enhanced plant breeding activity. Of the several plant breeding strategies for crop improvement, selection is the most simple and is the culmination of all other activities including biotechnological or otherwise. Eye judgment has remained the criterion of selection since centuries, which is still used directly or indirectly by modern plant breeders at practical level. Later, emphasis was put on making selection on the basis of measured characters of plant by Engledow and Wadham (1923), who made selections from progeny of hybrids for improving yield in cereals. *Per se* selection for yield is unreliable because of, in general, its low heritability. Several indirect selection criteria based on heritability, correlations or path coefficients have been put forth, debated, advocated and used in different crops by different breeders throughout the world.

The use of selection index based on several yield contributing traits for making selection for yield was originally purposed by Smith (1936). After measurement of plant traits and their subjection to statistical procedures a quantitative description of morphological changes or differences within a single

genotype during different stages of growth is obtained but it throws little light directly on underlying physiological causes on which the development of these traits is based on. Subsequently, methods of developing selection index were modified, put to critical evaluation and compared to other methods of trait selections. On practical platform, however, Borojevic (1990) and Wallace *et al.* (1993) while reviewing the impact of indirect selection of yield stated that indirect selection through individual morphological, physiological, developmental and component traits or through selection indices based on components of yield or other attributes or ideotypes has remained as more of a matter of statistical estimates rather than impact on practical yield improvement in plants, though considerable success has been achieved in animal breeding programmes. Borojevic (1990) has attributed this failure to, of not identifying most suitable traits to be effective in getting the response to selection in plant species:

The yield of a crop is the cumulative consequence of various processes including assimilation, differentiation and development. The yield has been, therefore, considered as a holistic biological system by Wallace and co-workers and have presumed yield to be based upon yield system traits and these yield system traits have been identified to be subcomponents of three major genetically controlled physiological component of yield i.e. i) biomass, ii) harvest index and iii) days to harvest maturity (Wallace and Masaya, 1988; Wallace, 1991; Wallace *et al.*, 1993; Yan and Wallace, 1995). These yield system traits which are the sub-components of the three major genetically controlled physiological components are i) days to flowering, ii) days to harvest maturity, iii)

aerial biomass at harvest maturity, iv) days to seed fill (days to maturity – days to flowering), v) yield/day to maturity (measure average rate of yield accumulation/day to maturity and so economically relevant average partitioning of photosynthetic rate to reproductive growth), vi) yield/day to seed fill (average rate of yield accumulation/day to seed fill, measures physiological origin of economic product rate), vii) biomass/day to plant growth (the rate of accumulation of aerial biomass averaged across days to maturity, measuring average crop growth rate and net photosynthetic efficiency), viii) the harvest index, which is the yield biomass divided by aerial biomass (this ratio quantify the consummated partitioning of photosynthate to reproductive and vegetative parts).

As per by these authors selection made on these eight yield system traits which are based on major genetically controlled physiological components and have already integrated relevant gene actions, environmental fluctuations and GXE interaction effects will therefore be effective rather than those where gene actions occur in for advance of actual process of accumulation of yield. Because basic selection of such traits which are recorded far advance of actual yield accumulation, traits interact with too many gene, affects physiological processes causing their genetical influences to become unpredictable. This has also been supported by the absence of correlation between yield and early seedling traits in common bean (Thakur *et al.*, 1994).

Character observations and their statistical processings for making selections have been instrumental in estimating advances in traits, yield

components or yield but statistical manipulations are more amenable to observations than physiological mechanism, the actual metabolic process responsible for yield (Watson, 1952). Since actual yield is weight per unit area of land, it is therefore more logical to base an analysis of yield based on weight changes during growth rather than on morphological characters. The analysis of growth in term of dry weight changes made by Blackman (1919) has further been developed into a technique of investigating growth and yield by use of several growth parameters and that has been named as "growth analysis". Taking clues from Borojevic (1990), Wallace *et al.* (1993) and that from the concept of growth parameters we have studied yield system traits, traits of growth parameters and some other traits seemingly important for yield and quality in grain amaranth which possesses considerable genetic variability in Himalayan region for making selections for yield improvement. Discussion on some genetic parameters, associations and path coefficient analysis from the view point of making *per se* selection for yield or selection based on a suitable selection index which could act as an effective criterion for yield enhancement, therefore, has been discussed as under.

Genetic Variability, Heritability and Genetic Advance

Significant genetic differences for various growth parameters, yield system and other traits have been revealed by significance of means squares during both the years (Table 1 and Table 7), thus, indicting the material studied to be important for making effective selection for yield.

For the eleven growth parameter i.e. AGR, CGR, RGR, NAR, LAR, RLGR, SLA, SLW, LWR, LAI and LAD high range of means, high PCV, GCV, heritability in broad sense and genetic advances were observed during one or the other year (Table 8). But for SLW genetic advances were more than 30 per cent for all growth parameter during both the years. Variability studies, therefore, indicated all these growth parameters except SLW to be effective selection criterion.

Das *et al.* (2004) in ricebean have reported moderate to high PCV, GCV and heritabilities with high genetic advance (>30%) for AGR, CGR, RGR and NAR. Genetic advance for SLW, LWR, RLGR and SLA were low, for LAI and LAD PCV and GCV were moderate with high heritability and medium genetic advance. High heritability coupled with high to moderate genetic advances for NAR, LAI and LAD have also been reported by Singh *et al.* (1995) in lentil, Singh and Singh (1996) in mungbean, whereas for CGR and NAR in rice by Chauhan *et al.* (1994).

Of the nine yield system traits including seed yield/plant, PCV, GCV (during 2002) and heritabilities and genetic advances (during 2002 and 2003) were generally high for yield/day to maturity, yield/day to seed fill and seed yield/plant itself. Harvest index showed low PCV and GCV, high heritability and moderate genetic advances during both the years. Days to flowering, days to maturity, days to seed fill and aerial biomass/plant showed low values for PCV and GCV and heritabilities were quite high, in general. Genetic advances were low in case of days to flowering, days to maturity, days to seed fill and aerial

biomass/plant. Therefore, it could be seen that on the basis of studies of range, PCV, GCV, heritability and genetic advance, the traits yield/day to maturity, yield/day to seed fill, harvest index and seed yield/plant are quite important for making selection for the enhancement of yield. Yield/day to seed fill and yield/day to maturity are the two most important traits for yield enhancement alongwith harvest index which is the actual partitioning of photosynthate from total biomass to economic yield.

Of the other traits panicle girth showed low PCV and GCV, very high heritability and moderately high genetic advance during both the years, whereas panicle length showed low PCV and GCV, moderate to high heritability and low genetic advance during the two years. The two traits i.e. panicle length and panicle girth could be considered as the subtraits of number of seeds in a panicle and, therefore, could be considered the subtrait/sub-components of one of the direct component of yield i.e. seed number, the other being the seed weight. Though in 10 ml seed weight range was comparatively high, PCV and GCV were low, heritability was also very high but genetic advance was low. Of these yield sub-components panicle girth has come out to be one of the important trait for making selection for grain yield in amaranthus and the three traits out of the yield system traits. Protein content (%) and leaf area at maximum leaf weight stage seems to be of not much importance for making selection for yield on the basis of these genetic parameters.

Heritability was found to be high for days to flowering and days to maturity in amaranth (Sarma *et al.*, 2003). Joshi and Rana (1995) have also reported

high heritability and high genetic advance for grain yield; Joshi (1986) and Ghosh *et al.* (1999) showed high heritability for inflorescence length, plant height and seed yield. The present studies in respect to these traits are in line with these findings. But, Lohithasawa *et al.* (1996) have found high heritability and moderate genetic advance for plant height and days to 50 per cent flowering and moderate heritability with moderate genetic advance for stem girth, which is contrary to our results where specifically genetic advance was low.

Correlation Among Traits

In general, collation of phenotypic and genotypic correlations during both the years showed that magnitudes of genotypic values were, in general, higher than the phenotypic ones which suggest strong inherent association between various characters at genetic level for different growth parameters, yield system and other traits (Table 13, 14, 15, 16, 17 and 18).

Shukla and Singh (2003) have also reported similar tendency in amaranth species. Falconer (1981) assigned the prominence of additive and the additive x additive type of gene action for such higher correlations. However, Gadekar *et al.* (1990) argued that higher genotypic correlation could be due to effects of non-additive genetic components on the expression of these traits or due to large environment influences on the traits leading to reduced magnitudes of phenotypic correlations.

The perusal of table 13 and table 14 shows that AGR and CGR were significantly correlated with yield/plant alongwith their high magnitudes of genotypic positive correlations during both the year. Das *et al.* (2004) have also

shown significant phenotypic association of AGR and CGR with seed yield alongwith high magnitudes of genotypic correlations in rice bean.

The other two growth parameters are LAI and LAD which showed significant phenotypic and high genotypic positive correlations with yield during both the years (Table 13 and 14). LAI and LAD also showed positive significant phenotypic and high genotypic correlations with important yield components i.e. panicle length and panicle girth during 2002, whereas during 2003 these two parameters showed significant and high positive correlations with panicle girth only.

Both AGR and CGR have also shown significant phenotypic and high genotypic positive correlations with two traits that are panicle length and panicle girth which could be considered as the subtraits/sub-components of seed number per panicle, one of the basic component of yield, other being the seed weight. Both these growth parameters, however, have not shown any correlation with other basic component of yield i.e. 10 ml seed weight during both the years. Das *et al.* (2004) has also observed significant and high positive correlations of LAI and LAD with seed yield and significant phenotypic association and high genotypic association of AGR and CGR with seed number per plant only but not with seed weight (100 seed weight). Growth parameters NAR, LAR, SLA, SLW, RLGR and LWR showed no correlation with grain yield during both the years. These growth parameters have also not shown correlations with important yield components i.e. panicle length, panicle girth and 10 ml seed weight during both years except SLW and LWR which have shown

negative significant phenotypic and high negative genotypic correlations with panicle girth and, SLW with seed yield during 2003 only. Das *et al.* (2004) have also reported no correlation of these traits with seed yield in ricebean, however Pandey *et al.* (1981) have reported association of NAR with grain yield in cowpea.

Watson (1952) gave opinion that NAR, though seems important for yield is mostly governed by external factors and therefore may not show correlation with yield. The present study is in line with his arguments.

Taking into consideration correlations of different growth parameters among themselves it was found that AGR and CGR; LAR and LWR; SLA and LAI; SLA and LAD; and LAI and LAD showed significant positive phenotypic and high genotypic correlations whereas, SLA and SLW; SLW and LAI; and, SLW and LAD showed significant negative phenotypic and high negative genotypic correlations during both the years. While CGR and RGR; RGR and LAR; RGR and LWR; LAR and SLA; LAR and LAD; LAR and LAI during 2002, and CGR and LAI; CGR and LAD showed positive significant phenotypic and high genotypic correlations during 2003. Negative significant and high genotypic correlations were also shown between SLA and SLW; SLW and LAI; SLW and LAD during 2002 and AGR and SLW; AGR and LWR; CGR and SLW; CGR and LWR; NAR and LAR; NAR and LWR; SLA and SLW; SLW and RLGR; LWR and LAI; LWR and LAD during 2003.

From these accounts of correlation among growth parameters it can be inferred that AGR, CGR, LAI and LAD, in general, showed high correlations with

other growth parameters, thereby, indicating their importance as has been exhibited by their significant correlations with yield and yield components.

Das *et al.* (2004) have also reported such positive associations between AGR and CGR; CGR and LAI; CGR and LAD; LAI and LAD, and negative association between NAR and LAR; SLA and SLW, whereas association between LWR and LAD was positive in ricebean in comparison to the negative in our case. Singh and Singh (1996) in mungbean have reported positive correlation of LAI with LAD, and, LAD with yield and Gill *et al.* (1992) of LAD with CGR. Singh and Singh (1982) in mungbean have also not reported correlation between NAR and SLW as has been observed in our study. Positive and significant correlation of LAD (Chatterjee *et al.*, 1987) in ricebean; LAI (Turk and Hall, 1980) in cowpea and in soybean (Nelson and Schweitzer, 1988) with yield have been reported.

Thus, on the basis of the present association studies in grain amaranths and some other crops, it could be agreed upon that AGR, CGR, LAI and LAD are the most important growth parameters which could be used to isolate high yielding genotypes.

During both the years all the yield system traits showed significant positive phenotypic and high genotypic correlations with grain yield and aerial biomass/plant except days to seed fill which shows non-significant association with yield and biomass but genotypic correlation was quite high (Table 15,16,17 and 18). Plant height, panicle length and panicle girth showed significant positive and high genotypic positive correlations with yield during both the years,

however, stem girth showed comparatively high magnitudes of genotypic correlations during both the years. The presence of such correlations are on speculated lines as both seed yield and aerial biomass depends apparently on rate of their accumulation and other contributing component traits, in general.

Among associations between yield system and other traits days to flowering and yield/day to seed fill, panicle length, panicle girth; days to maturity and days to seed fill, aerial biomass/plant, yield/day to maturity, harvest index and panicle girth; biomass/plant with yield/day to maturity, yield/day to seed fill, biomass/day to plant growth, and harvest index; yield/day to maturity with yield/day to seed fill, biomass/day to plant growth, harvest index, plant height, panicle length and panicle girth; yield/day to seed fill with biomass/plant, harvest index, plant height, panicle length and panicle girth; biomass/day to plant growth with harvest index, plant height, panicle length and panicle girth; harvest index with plant height, panicle length and panicle girth; stem girth with plant height; plant height with panicle length and panicle girth; panicle length with panicle girth and 10 ml seed weight also showed positive significant phenotypic and high genotypic correlations during both the years. Some other trait combinations also showed positive significant phenotypic and high genotypic correlations during one or the other year, however, these all indicated towards the strength of associations between the yield system and other yield contributing traits with yield/plant and biomass/plant.

Bressani *et al.* (1987) in grain amaranth, however, have also reported positive association between plant height and grain yield but seed weight was

not correlated with yield; Ayiecho and Jain (1990) have also reported the importance of correlations between plant height, seed weight, harvest index and days to flowering with seed yield. Agong and Ayiecho (1992) have reported positive correlation of head length with plant height and seed yield and, days to flowering with days to maturity which corresponds with the present studies. Joshi and Rana (1995) and Sarma *et al.* (2003) observed significant positive correlation of plant height and panicle length with grain yield. However, Shukla and Singh (2003) found negative correlation between days to flowering with days to maturity, whereas correlation between plant height and grain yield was significant. These authors also observed significant and positive correlations between leaf area and grain yield, leaf area and days to seed fill and plant height which is contrary to the present studies where leaf area at maximum leaf weight was taken and no such correlation was observed. Whereas, Ghosh *et al.* (1999) reported significant correlations of plant height with days to flowering and panicle length which correspond with our studies.

Based on the results of association studies in our case it could be observed that all the yield system traits proposed by Wallace *et al.* (1993) have been speculated to be important traits for selection in plants and are suitable characters for indirect selection for yield in grain amaranth. Also the other two important traits outside the preview of yield system traits i.e. panicle length and panicle girth have been pointed out to be important indirect selection traits.

Conclusions for the suitability of different growth parameters, yield system and other traits for indirect selection for seed yield have been drawn on the basis

of statistical calculation based on averages of several stages. However, it could be thought of that correlations calculated between growth parameters, yield system and other yield component traits on the averaged data of several stages may differ from data taken on some specific crop growth durations. Therefore, correlations of eleven growth parameters with sixteen yield system and other plant traits have been calculated at four different growth periods i.e. S_1 , S_2 , S_3 and S_4 . However, during 2002 data on S_1 and S_2 have not been recorded.

The correlations of eleven growth parameters at two stages (S_3 and S_4) of growth with sixteen plant traits constituted 352 ($11 \times 16 \times 2$) values during 2002 and that of eleven growth parameters at four stages (S_1 , S_2 , S_3 and S_4) with sixteen plant traits constituted 704 values ($11 \times 16 \times 4$) during 2003.

Comparisons of correlation coefficient of 352 trait combination during 2002 and 704 during 2003 have shown S_4 stage (average of post flowering to harvesting) to be most significant stage whereby several growth parameters have shown significant phenotypic or high genotypic correlations with yield, yield system traits and basic yield component traits (Table 19, 20 and 21). During 2002, 40 trait combinations at S_4 stage in comparison to 24 at S_3 showed significant high genotypic correlations. Out of which 36 values were positive and high at S_4 and only 19 at S_3 . During 2003, these values were 32 and 23 and 27 and 17, respectively. During 2003 data on S_1 and S_2 stages in addition to S_3 and S_4 was also taken and 24 trait combinations at S_1 , 51 at S_2 , 23 at S_3 and 32 at S_4 stages showed high and significant correlations of growth parameters with yield

system and other traits. Second year data, therefore, revealed that S_2 stage is even more important than S_4 stage for growth parameters analysis.

It could, therefore, be concluded that growth parameters need not to be calculated at several stages of growth period but at S_2 i.e. 35-73 days and S_4 i.e. 74 – harvesting, are the two most crucial periods during which growth parameter analysis will be prudent.

Thakur *et al.* (2003) in ricebean have observed S_4 stage i.e. 83 days–harvesting as the most significant stage for growth parameter analysis for using them as an indirect selection parameter for grain yield. Singh *et al.* (2000) have also reported that growth indices recorded during reproductive phase have better association with yield and yield attributes than during vegetative phase in brassica.

Analysis of variance (Table 4 and Table 6) has shown significant treatment differences for all the growth parameters studied at S_2 and S_4 stage. PCV, GCV, heritabilities and genetic advances of these growth parameters were, in general, similar to the data obtained from the average of 35-days to maturity, during both the year. Growth parameters showing significant phenotypic and high genotypic correlations with other traits during S_4 and S_2 stages is being described as under.

The growth parameters AGR, CGR, LAI and LAD showed significant phenotypic and high genotypic positive correlations with seed yield and aerial biomass/plant during both the years, in general, both at S_2 or S_4 stage (Table 19 and Table 20). These estimates, however, are similar to, those as drawn from

the calculations made on the basis of average of several stages. Therefore, these four growth parameters could be used unequivocally as indirect selection criterion at these stages. Apart from this, growth parameter, RGR showed significant phenotypic and high genotypic correlations with yield/plant at S_2 stage only and SLA with both yield and biomass at this stage. However, SLW showed negative phenotypic and high negative genotypic correlations with yield and biomass at S_2 stage which was calculated only during 2003.

NAR have not shown any correlation with yield/plant and aerial biomass during both the years, when calculations were made on the basis of average of several stages. However, during 2003 at S_2 stage it showed significant phenotypic associations with yield/plant and harvest index. Though genotypic magnitudes were lower than the phenotypic ones, thereby, indicating the role of external factors in the expression of this trait as has been expounded by Watson (1952) and therefore, though, seems apparently important it could not be considered an indirect parameter for making selection for yield.

Similarly NAR has also not shown significant correlations with leaf area at four different stages (S_1 , S_2 , S_3 and S_4) during both the years except at S_4 stage during 2002. This poor association of these two traits over different stages may perhaps be explained by the fact that carbondioxide fixing enzyme ribulose biphosphate carboxylase on which NAR depends is, in general, having more concentration in thicker leaves De Wit *et al.* (1979) and therefore association of NAR with leaf area becomes irrelevant. This is, however, contrary to the findings here that NAR also showed no correlation with SLW, which measures leaf

thickness during both the years. This perhaps again indicated the expression of NAR to be more complicated in terms of its implication with external factors.

Path Coefficient Analysis

Path coefficient analysis of growth parameters with yield and yield component, in general, have not revealed any additional information than that revealed by their correlation studies. However, on basis of perusal of table 22 and 23 it could be concluded that path coefficient analysis have pointed towards LAI and LAD as the most significant growth parameters where several other growth parameters have contributed to yield indirectly through these traits. Similarly AGR and CGR are the other two growth parameters through which several other growth parameters and yield attributes/traits have indirectly contributed towards yield. On the basis of similar analogy panicle girth has shown to be one of most important sub-component of basic component (seed number) of yield, during two years studies. Whereas, RGR which has not shown any significant correlation with yield has also been revealed to be of some significance where it has shown very high positive direct effect and very high positive indirect effect through AGR, CGR, NAR, LAR, LWR and high and negative effect through protein content (%). Apart from this, additional information given by path coefficient is that the growth parameters AGR and LAI both showed significant phenotypic and high genotypic positive correlations with yield have high magnitudes of direct negative effects both at phenotypic and genotypic level. Therefore, while making use of these traits for making selection one has to be cautious about the negative direct component and in such case

selection for compromising intermediate values are required to be done than for the extreme values as has been suggested by Yan and Wallace (1995).

The path coefficient analysis of yield system and other traits has also not revealed much information in addition to whatever is revealed by the correlation studies during the two years. However, the perusal of table 24 and 25 illustrates that aerial biomass, harvest index, days to flowering and days to maturity were the most important traits through which several other traits contributed indirectly during both the years. Though, the correlation between days to flowering and yield was significant and positive, the direct component of this trait was high and negative indicating that selection for early flowering and high yield is possible. The direct effect of days to maturity and the indirect effects of several other traits through days to maturity were high and positive showing that selection for high yielding genotypes with early maturity may not be possible. Though, correlation between days to seed fill and grain yield was not found during both the years, path coefficient revealed additional information that its direct contribution is comparatively high and negative during both the years, therefore it is possible to make selection between high yielding genotypes with smallest number of days to seed fill. The direct genotypic contribution of biomass/day to plant growth was also negative and high during 2002 only. Similarly, the direct contribution of panicle girth was negative but of small magnitude during 2002 only. Several other traits have contributed either positively or negatively with high magnitudes (Table 24) through yield/day to maturity, yield/day to seed fill and biomass/day to

plant growth. These three traits are important from the view point of per day accumulation of yield or biomass and are, therefore, important.

The two years path coefficient analysis has revealed the importance of AGR, CGR, LAI and LAD to the highest extent and RGR to some extent and also the importance of panicle girth for yield improvement. The path analysis has also revealed the importance of aerial biomass, harvest index, days to flowering, days to maturity, days to seed fill, yield/day to maturity, yield/day to seed fill and biomass/day to plant growth as important traits for indirect selection.

Shukla and Singh (2003) have, however, found high direct effect through leaf area for higher genotypic correlations between this trait and seed yield which is contrary to the present result. These authors also reported small genotypic paths of days to flowering, days to maturity and panicle length which, however, also does not correlate with yield which does not tune with results of our study. However, it is pertinent to note that their material consisted of *Amaranthus* species and our is the different varieties of *Amaranthus hypochondriacus*.

The two years study on variability, correlations and path analysis allowed to conclude that AGR, CGR, LAI and LAD among the growth parameters; aerial biomass/plant, yield/day to maturity, yield/day to seed fill, biomass/day to plant growth, harvest index, days to flowering and days to maturity among the yield system traits and panicle length and panicle girth, subcomponent traits of the basic yield components are the most important traits for making selection for yield improvement.

Most of the yield system traits as defined by Wallace *et al.* (1993) have come out to be the most effective traits for indirect selection for yield, of which capacity to synthesize total biomass, rate of yield and biomass accumulation are particularly significant. Higher rate, however, is got with higher harvest index i.e. the partitioning of total photosynthate to economic yield.

Robertson and Frey (1987), Takeda and Frey (1987) and Frey (1988) have also considered higher rate of biomass accumulation to be only option for higher yield in oats, because the days to maturity of existing cultivars already matched the short growing season and harvest index was already high enough that enlarging it could be detrimental for yield. There should also be selection for higher rate of accumulation of yield per day to maturity to compensate for the tendency for higher biomass arising from longer duration of crop growth.

Panicle length and panicle girth could be considered as the sub-components of one of the two basic yield components i.e. seed number, other being seed weight. The importance of these two sub-components have been revealed by their high correlations with grain yield and biomass and AGR, CGR, LAI and LAD, whereas the trait 10 ml seed weight has not shown any correlation during both the years with yield and most of the important growth parameters. However, its correlation with AGR was significant during 2003 and its correlation with panicle length was also significant during both the years and during grain filling period i.e. S₄ the two important growth parameters AGR and CGR showed significant correlation with 10 ml seed weight. Therefore, the importance of 10 ml seed weight which represents seed weight (other important basic yield

component) cannot be ruled out. Agong and Ayiecho (1992), Joshi and Rana (1995) and Sarma *et al.* (2001) have also reported the importance of panicle length for higher yield and Bressani *et al.* (1987) reported no correlation between seed weight and yield, whereas, Joshi and Rana (1995) reported high direct effect of seed weight on yield.

Mc Neal *et al.* (1978) have also reported that selection of these two important yield component proved more successful in wheat, however, as has been observed and argued by Watson (1952), Wallace *et al.* (1993), Yan and Wallace (1995) and Kelley *et al.* (1998) that yield components/attributes are not independent expression as some of them are negatively correlated and selection for one lead to counter selection for the other. However, in our material no negative correlation has been found between yield system and yield component traits, but path coefficient analysis has shown negative direct effects of days to flowering, days to seed fill and biomass/day to plant growth either at phenotypic or genotypic level during the two years. Among the important growth parameters AGR and LAI have shown high negative direct effects, in general, both at phenotypic and genotypic level during the two years.

Therefore, it can be concluded that indirect selections made on the basis of all the yield system traits, basic yield sub-components i.e. panicle length, panicle girth and 10ml seed weight and four important growth parameters i.e. AGR, CGR, LAI and LAD *per se* or by formulating a selection index based on them could be effective in improving yield by making selection on the natural variability present in the present material.

However, if selection is to be made on those traits which are negatively inter-related one has to be cautious and as per Yan and Wallace (1995) selection for intermediate values of negatively correlated traits is required to be done rather than the extreme values of two traits. This is apparently a simple statement but how to achieve this at statistical level has not been discussed by these authors.

Piepho (1995) has given an aggregate measure, C_i value, based on logarithmic transformation of yield components. This value is an intensive contribution of yield components to the variability and assesses both the variability of yield components as well as its inter-dependence with other component. The yield component with largest C_i value explains the maximum variation in complex trait. Any compensating relation with other component due to negative association will be reflected in lower C_i value, thereby, perhaps detecting effective yield components. The C_i value of any yield contributing traits could be calculated and relative contribution of each trait could be detected for making selection on the basis of individual traits or by entering them into a selection index.

Comparison of a group of high yielding genotypes with a group of low yielding genotypes during the two years (Table 26) revealed, in general, that high yielding genotypes were having higher days to maturity (late maturing) and low yielding genotypes, the lower days (early maturing). The harvest index of high yielding genotypes was also much higher than that of low yielding genotypes (Table 26). The four important growth parameters i.e. AGR, CGR,

LAI and LAD which have been shown to be important for selection have been found to show, in general, much higher magnitudes in the former (high yielding) than in the latter. Similarly, harvest index, which indicates partitioning of photosynthates to economic yield, aerial biomass/plant which indicate total photosynthetic capacity of genotype and yield/day to maturity, yield/day to seed fill and biomass/day to plant growth which are the rates of accumulation of yield and biomass are much higher in the high yielding but late genotypes than in the low yielding and, in general, early genotypes.

In the present material, as has been argued by Wallace *et al.* (1993), that if, some of the early genotypes show higher biomass there is possibility of those genotypes showing higher harvest index than the late genotype, because rate of yield and biomass accumulation is expected to be higher in such early genotypes. Therefore, under such situation high yielding genotypes in early maturity group could be expected to be selected on the basis of making selection for harvest index and rate of yield and biomass accumulation by making use of the most suitable growth parameters i.e. AGR, CGR, LAI and LAD. In our material the data is such that no such possibility exists. High yielding and late genotypes and low yielding and early genotypes, in general, made two fixed groups. If varieties are to be evolved for early maturity which may be enforced upon by the environmental condition, in some areas, selection of genotypes could not be done by avoiding the loss of – high yielding ability inherent in late maturing genotypes. PRA9101 and Annapurna were the two standard genotypes having higher yield but comparatively more number of days to

maturity, whereas, IC35407 another standard genotype, was early maturing but comparatively low in yielding ability.

Grouping of different early maturing and late maturing genotypes separately during 2002 and 2003 (Table 27) has again revealed that, in general, early genotypes were having lower yields than late genotypes and apart from this, all the growth parameters and important yield and biomass accumulating traits alongwith harvest index and aerial biomass have been found to be having lower values in the early maturing genotypes than in the late maturing ones. This also again indicated that late maturing genotypes will always be higher yielding, but for the condition specifically in hills where temperature may fall suddenly during September or October, because of sudden change in weather and snowfall, late maturing genotypes may not be suitable in these area. Early maturing genotypes will be the requirement, but the loss of yield because of their lower yield and biomass accumulating potentiality and lower harvest index will be sure to be born by the cultivators. The high significant phenotypic and high genotypic correlations of days to maturity with yield and biomass found in the present material have the bearing on the expression of yielding ability thereby leading to definite groups of early but low yielding and late and high yielding groups of genotypes. For the evolution of early and high yielding genotypes specifically for hilly areas like that of Himachal Pradesh, a hunt for suitable genotypes from other parts of the country or outside the country is, therefore, imperative, and germplasm collection, in this regard, is suggested for the future amaranth breeders of Himachal Pradesh. The study has also revealed that in

the late maturity group the two genotypes Sangla A10 and JRS503 have highest yielding capacity, having better combination of most of the yielding traits found in this study, than the so far identified standard genotypes PRA9101 and Annapurna and could be tested on several locations in Himachal Pradesh for their suitability of release for commercial cultivation.

SUMMARY

SUMMARY

The studies were intended to understand the nature and magnitude of variations, correlations and path coefficients of growth parameters, yield system, protein content, some other traits including yield and identification of potential yielding genotypes in grain amaranth. Twenty-two genotypes of grain amaranth were evaluated at the farm of the Department of Plant Breeding and Genetics, CSK HPKV, Palampur, during *Kharif*, 2002 and 2003.

Eleven growth parameters viz., Absolute Growth Rate (AGR), Relative Growth Rate (RGR), Net Assimilation Rate (NAR), Leaf Area Ratio (LAR), Relative Leaf Growth Rate (RLGR), Specific Leaf Area (SLA), Specific Leaf Weight (SLW), Leaf Weight Ratio (LWR), Crop Growth Rate (CGR), Leaf Area Index (LAI) and Leaf Area Duration (LAD) were calculated by taking data on leaf area and dry weight per plant, periodically at twelve days interval. These growth parameters were calculated on the basis of the average of the data recorded at three stages (73 days - harvesting) during 2002 and six stages (35 days - harvesting) during 2003. Data were recorded on nine yield system traits (days to flowering, days to maturity, days to seed fill, yield/day to maturity, yield/day to seed fill, aerial biomass/plant, seed yield/plant, biomass/day to plant growth and harvest index) and stem girth, plant height, panicle length, panicle girth, 10 ml seed weight, protein content and leaf area at maximum leaf weight stage.

Analysis of variances for the growth parameters (taken at all stages) and yield system and other traits were found to be significant indicating considerable genetic variability. Heritabilities in broad sense were high (>60%) for all eleven growth parameters and sixteen other plant traits except stem girth, plant height, protein content and leaf area at maximum leaf weight stage which showed low heritabilities during both the years.

The growth parameters, AGR, CGR, LAI and LAD showed correlations with grain yield during both the years. AGR and CGR showed correlations with yield sub-components, panicle length and panicle girth, during both the years, whereas LAI and LAD with panicle girth for two years but with panicle length for one year only. RGR and LAR showed negative correlations with protein content; and SLW and LWR with panicle girth during one year only.

Positive correlations of days to flowering, days to maturity, aerial biomass/plant, yield/day to maturity, yield/day to seed fill, biomass/day to plant growth and harvest index (all yield system traits), panicle length and panicle girth (sub-components of yield) and plant height were present with seed yield/plant.

Positive correlations were also observed among the different pairs of trait combinations viz., days to flowering with days to maturity, yield/day to seed fill, panicle length and panicle girth; days to maturity with days to seed fill, aerial biomass/plant, yield/day to maturity, harvest index and panicle girth; aerial biomass/plant with yield/day to maturity, yield/day to seed fill, biomass/day to plant growth, harvest index, plant height, panicle length and panicle girth; yield/day to maturity with yield/day to seed fill, biomass/day to plant growth,

harvest index, plant height, panicle length and panicle girth; yield/day to seed fill with biomass/day to plant growth, harvest index, plant height, panicle length and panicle girth; biomass/day to plant growth with harvest index, plant height, panicle length and panicle girth; harvest index with plant height, panicle length and panicle girth; stem girth with plant height; plant height with panicle length and panicle girth; and panicle length with panicle girth and 10 ml seed weight.

Collation of significant correlations of growth parameters and plant trait combinations at four growth durations/stages i.e. initial active vegetative stage (S_1), initial active vegetative stage to pre-flowering stage (S_2), initial post-flowering stage (S_3) and initial post-flowering to grain filling period (S_4) have revealed that S_2 stage (35-73 days) is the most important stage followed by S_4 stage (74 days - harvesting) for the estimation of growth parameters.

Path coefficient analysis revealed the significance of RGR, days to seed fill and 10 ml seed weight. The correlations of these with yield were not observed but these traits were found to be directly or indirectly contributing towards yield or yield sub-components. LAI and ~~AGR~~ showing correlations with yield were revealed to be having high negative direct contributions by the path coefficient analysis.

On the basis of these studies, it was concluded that AGR, CGR, LAI and LAD are the most effective growth parameters for indirect selection along with yield system traits i.e. aerial biomass/plant, harvest index, yield/day to maturity, yield/day to seed fill and biomass/day to plant growth and sub-components (panicle length and panicle girth) of the basic components of yield.

The grain amaranthus genotypes Sangla A10 and JRS 503 have been found to be high yielding having optimum combinations of the important traits studied along with long maturity duration. However, looking for high yielding genotypes with early maturity is the demand in hilly areas like Himachal Pradesh, where early winter rains/ snowfall enforces the cultivators to go for early genotypes with high yield. Hence, identifications of such genotypes in amaranthus should be the future thrust of the plant breeders.

LITERATURE CITED

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- Agong, S.G. and Ayiecho, P.O. 1992. Regression and correlation analysis in grain amaranth (*Amaranthus hypochondriacus* and *A. cruentus*). Indian Journal of Agricultural Sciences 62(12):822-826.
- Al-Jibouri, H.A., Miller, P.A. and Robinson, H.P. 1958. Genotypic and environmental variance and covariance in upland cotton cross of interspecific origin. Agronomy Journal 50:633-636.
- Allard, R.W. 1960. Principles of Plant Breeding. John Wiley and Sons., Inc., New York.
- *Ayiecho, P.O. and Jain, S.K. 1990. A regression and path analysis of yield related traits in two populations of grain amaranths. East African Agricultural and Forestry Journal (Kenya) 55(3):147-158.
- Bansal, G.L., Rana, M.C. and Upadhyay, R.G. 1995. Evaluation of some grain amaranth cultivars under mid-hill conditions. Indian Journal of Plant Physiology 38(2):180-181.
- *Blackman, V.N. 1919. The compound interest law and plant growth. Annals of Botany 33:353-360.
- Borojevic, S. 1990. Principles and methods of Plant Breeding. Elsevier Science Publishers, Amsterdam, The Netherlands. pp. 70-213.

- Bressani, R., Gonzales, J.M., Zuniga, J., Breuner, M. and Elias, L.G. 1987. Yield, selected chemical composition and nutritive value of fourteen selections of amaranth grain representing four species. *Journal of the Science of Food and Agriculture* 38(4):347-356.
- Burton, G.W. and Devane, E.H. 1953. Estimating heritability in tall fescue (*Festuca arundinacea* L.) from replicated clonal material. *Agronomy Journal* 45:478-481.
- *Calderon, E., Gonzalez, J.M. and Bressani, R. 1991. Agronomic, physical, chemical and nutritional characteristics of fifteen amaranth varieties. *Turrialba* 41(4):458-464.
- *Chatterjee, B.N., Bhattacharya, K.K., Miah, A.A., Wallis, E.S. and Mlyth, D.F. 1987. Growth analysis of ricebean. Food legume improvement for Asian Farming Systems 249, Proceedings No. 18, ACIAR, Australian Centre for International Agriculture Research (Queensland), Australia.
- Chauhan, J.S., Singh, C.V. and Singh, R.K. 1994. Phenotypic and genotypic variability for physiological attributes in upland rice (*Oryza sativa* L.). *Indian Journal of Plant Physiology* 37(3):203-205.
- Das, Y., Thakur, S.R., Singh, K.P. and Sharma, S.K. 2004. Association among growth and yield parameters in ricebean (*Vigna umbellata*) genotypes. *Indian Journal of Plant Physiology* 9(1):94-97.
- Dewey, D.R. and Lu, K.H. 1959. A correlation and path coefficient analysis of components of crested wheat grass seed production. *Agronomy Journal* 51:515-518.

- *De Wit, C.T., Van Laar, H.H., Vankeulen, H., Goudrian, J., Van, H.D.J. and Vos, N.M. 1979. Physiological potentials of crop production. Sneeep and A.J.T. Hendriksen, Plant Breeding Perspectives, Centre for Agricultural Publishing and Documentation, Wageningen, Holland. pp. 47-82.
- *Donald, C.M. 1961. Competition for light in crops and pastures. Symposia of the Society for Experimental Biology 15:282-313.
- Engledow, F.L. and Wadham, S.M. 1923. In : Wallace, D.H., Ozbun, J.L and Munger, H.M. 1972. Physiological genetics of crop yield. Advances of Agronomy 24:97-147.
- Falconer, D.S. 1981. Introduction to quantitative genetics. Oliver and Boyad, London. pp. 281-284.
- Fisher, R.A. 1918. The correlation between the relatives on the supposition of Mendelism inheritance. Transactions of Royal Society, Edinburgh 52:399-433.
- Fisher, R.A. 1954. Statistical methods for Research Workers. 12th Edition, Hafner Publishing Company, Inc., New York.
- Fisher, R.A. and Yates, Y. 1963. Statistical tables for Biological, Agricultural and Medical Research. Oliver and Boyad, Edinburgh, London.
- Frey, K.F. 1988. Increasing grain yield of oats. Plant Physiology and Biochemistry 26:539-542.

- Gadekar, P., Dhumale, D.B. and Raut, R.S. 1990. Interrelationships between yield and its components in ricebean (*Vigna umbellata*). Indian Journal of Agricultural Sciences 60 (8):547-549.
- *Galtan, F. 1889. Natural Inheritance. Macmillan, London.
- Geetha, K., Vaidehi, M.P. and Gouramma, T. 1994. Certain physico-chemical and functional qualities of selected amaranthus grains for consumer's benefit. Mysore Journal of Agricultural Sciences 28:169-172.
- Ghosh, N., Mondal, S.K. and Ghoshal, K.K. 1999. Inheritance of seed yield and associated characters of grain amaranth (*Amaranthus cruentus* L.). Journal of Interacademica 3(2):124-127.
- Gill, D.S., Verma, M.M. and Brar, G.S. 1992. Physiological parameters determining yield in mungbean. Crop Improvement 19(1):29-33.
- *Girenko, M.M. and Chikova, V.A. 1988. Amaranth. *Nauchno tekhnicheskii Byulleten Vsesoyuznogo Ordena Lenina i Ordena Druzhby Narodov Nauchno Issledovatel skogo Instituta Rasteniievodstva Imeni N.I. Vavilova* No. 181. pp. 63-64.
- Gregory, F.G. 1926. The effect of climatic conditions on the growth of barley. Annals of Botany 40:1-26.
- *Hirano, M., Honjyo, K., Kuroda, E., Hareyama, S. And Miura, T. 1990. Growth characteristics and yield ability of grain amaranth. Report of the Tohoku Branch, the Crop Science Society of Japan 33:49-54.

- *Imeri, A., Gonzalez, J.M., Flores, R., Elias, L.G. and Bressani, R. 1987. Genetic variability, and correlations between yield, grain size, chemical composition and protein quality of twenty five cultivars of amaranth (*Amaranthus caudatus*). *Archivos Latinoamericanos de Nutricion* 37(1):132-146.
- Jackson, M.L. 1967. Soil Chemical Analysis. Prentice Hall of India, Limited, New Delhi. pp. 219-221.
- *Jain, S.K. and Hauptil, H. 1980. Grain amaranth. A new crop for California Agronomy Progress Report 107. Agricultural Experiment Station University of California, Davis.
- Jha, P.K., Sah, J.P. and Chettri, M.K. 1992. Assessment of grain amaranth productivity in Nepal. Bangladesh Botanical Society, Dhaka (Bangladesh). Proceedings of the international botanical conference on plant science and man; problems and prospects, Dhaka (Bangladesh). pp. 99-106.
- *Johnson, B.L. and Henderson, T.L. 2002. Water use patterns of grain amaranth in the northern Great Plains. *Agron-j.* Madison: American Society of Agronomy 94(6):1437-1443.
- Johnson, H.W., Robinson, H.F. and Comstock, R.E. 1955. Estimates of genetic and environmental variability of soybean. *Agronomy Journal* 47:314-318.
- Joshi, B.D. 1986. Genetic variability in grain amaranth. *Indian Journal of Agricultural Sciences* 56(8):574-576.

- Joshi, B.D. and Rana, J.C. 1995a. Genetic analysis for yield and its components in grain amaranth. *Journal of Hill Research* 8(2):195-198.
- Joshi, B.D. and Rana, J.C. 1995b. Genetic divergence in grain amaranth (*Amaranthus hypochondriacus*). *Indian Journal of Agricultural Sciences* 65(8):605-607.
- *Kasanga, H. and Monsi, M. 1954. On the light transmission of leaves and its meaning for the production of dry matter in plant communities. *Japan Journal of Botany* 19:304-324.
- Kelly, J.D., Kolkman, J.M. and Schneider, K. 1998. Breeding for yield in dry bean (*Phaseolus vulgaris* L.). *Euphytica* 102:343-356.
- Kempthorne, O. 1957. *An Introduction to Genetic Statistics*. John Wiley and sons Inc., New York.
- *Li, C.C. 1956. *Population genetics*. The University of Chicago Press, Chicago, U.S.A. pp. 28-41.
- Lohithaswa, H.C., Nagaraj, T.E., Savithramma, D.L. and Hemareddy, H.B. 1996. Genetic variability studies in grain amaranth. *Mysore Journal of Agricultural Sciences* 30(2):117-120.
- *Lush, J.L. 1940. Inter-sire correlation and segregation of offsprings on damasa of method estimating heritability of characters. *Proceedings of American Society Animal Production* 33:293-301.
- Mc Neal, F.M., Qualset, C.D., Boldridge, D.E. and Stewart, V.R. 1978 Selection for yield and yield components in wheat. *Crop Science* 98:795-799.

- Mohideen, M.K., Muthukrishnan, C.R., Shanmugavelu, K.G., Rengaswamy, P. and Vadivel, E. 1983. Evaluation of grain amaranth types at Coimbatore. *South Indian Horticulture* 31(1):11-14.
- Nelson, R.L. and Schweitzer, L.E. 1988. Evaluating soybean germplasm for specific leaf area. *Crop Science* 28(4):647-649.
- Niles, H.E. 1922. Correlation causation Wright's theory of path coefficient. *Genetics* 8:256-260.
- Pandey, R.P., Nair, P.K.R. and Tiwari, J.P. 1981. Correlation of morpho-physiological and sink parameters in cowpea. *Indian Journal of Agricultural Sciences* 51(4):221-224.
- Panse, V.G. 1957. Genetics of quantitative characters in relation to Plant Breeding. *Indian Journal of Genetics and Plant Breeding* 17(2):318-328.
- Panse, V.G. and Sukhatme, P.V. 1984. *Statistical Methods for Agriculture Workers*. ICAR, New Delhi.
- Piepho, H.P. 1995. A simple procedure for yield component analysis. *Euphytica* 84:43-48.
- Radford, P.J. 1967. Growth analysis formulae-their uses and abuses. *Crop Science* 7:171-175.
- Robertson, L.D. and Frey, K.J. 1987. Honey comb design for selection among homozygous oat lines. *Crop Science* 27:1105-1108.

- Sarma, B.K., Das, A. and Bujarbaruah, K.M. 2003. Underutilized life support crop species: production and research in north eastern hill region of India. Director, ICAR Research complex for NEH Region, Umiam, Meghalaya. pp.5-14.
- Shukla, S. and Singh, S.P. 2002. Genetic divergence in amaranth (*Amaranthus hypochondriacus* L.). Indian Journal of Genetics and Plant Breeding 62(4):336-337.
- Shukla, S. and Singh, S.P. 2003. Correlation and path analysis in grain amaranth (*Amaranthus spp.*). Indian Journal of Genetics and Plant Breeding 63(2): 163-164.
- Singh, B.G. and Singh, J.N. 1982. Effect of seasonal changes on growth parameters of greengram (*Vigna radiata* L.). Indian Journal of Plant Physiology 25:382-389.
- Singh, R., Rao, V. and Singh, D. 2000. Relationship of yield and yield attributes with physiological traits in brassicas. Indian Journal of Agricultural Sciences 70(9):581-583.
- Singh, S.P. and Singh, G.S. 1996. Genetic variability, heritability, genetic advance and correlation studies on physiological parameters in mungbean (*Vigna radiata* L. Wilczek). Indian Journal of Plant Physiology. New Series 1(1):68-69.

- Singh, S.P., Lal, K.B. and Shri Krishna. 1995. Physiological parameters for selection in Lentil (*Lens esculenta* L.). Legume Research 18(2):129-132.
- Smith, H.F. 1936. A discriminant function for plant selection. Annals of Eugenics, (London) 7:240-250.
- Takeda, K. and Frey, K.J. 1987. Improving grain yield in back cross populations from *Avena sativa* x *Avena sterilis* matings by using independent culling for harvest index and vegetative growth index or unit straw weight. Theoretical and Applied Genetics 74 : 659-665.
- Teutonico, R.A. and Knorr, D. 1985. Amaranth : composition, properties and applications of a rediscovered food crop. Food Technology 39(4):49-61.
- Thakur, S.R., Das, Y. and Singh, K.P. 2003. Stage specificity in growth parameter analysis for indirect selection in ricebean. Journal of Nature Conservation 15(2):501-509.
- Thakur, S.R., Saini, J.P. and Chaudhary, H.K. 1994. Association of early seedling and mature plant characters with yield in common beans under aerial moisture stress. Crop Improvement 21(1):24-29.
- Turk, K.J. and Hall, A.E. 1980. Drought adaptation of cowpea. III. Influence of drought on plant growth and relation with seed yield. Agronomy Journal 72:428-433.
- *Turkey, J.W. 1954. Causation, regression and path analysis, statistics and mathematics in biology. Iowa State College Press of America. Iowa.

- Turner, M.E. and M.E. Stewans, S. 1959. The regression analysis of causal path. *Biometrics* 15:623-658.
- *Wallace, D.H. 1991. System analysis of yield trials can raise efficiency of breeding for yield. *In* : J. Prakash and R.L.M. Peirik (eds.) *Proceedings of International Seminar on New Frontiers in Horticulture*. Kluwer Academic Publishers, Dordrecht, The Netherlands. pp. 1-10.
- Wallace, D.H. and Masaya, P.N. 1988. Using yield trial data to analyze the physiological genetics of yield accumulation and the genotype x environmental interaction effect on yield. *Annual Report on Bean Improvement Co-operation* 31:7-24.
- Wallace, D.H., Boudoin, J.P., Beaver, J., Coyne, D.P., Halseth, D.E., Masaya, P.N., Munger, H.M., Myers, J.R., Silbernagel, M., Yourstone, K.S. and Zobel, R.W. 1993. Improving efficiency of breeding for higher crop yield. *Theoretical and Applied Genetics* 86:27-40.
- Watson, D.H. 1952. The Physiological basis of variation in yield. *Advances in Agronomy* 4:101-145.
- Welbank, P.J., French, S.A.W. and Witts, K.J. 1966. Dependence of yield of wheat varieties on their leaf area duration. *Annals of Botany* 30:291-299.
- Wright, S. 1921. Correlation and causation. *Journal of Agricultural Research* 20:557-587.

- Wright, S. 1923. The theory of path coefficient in reply to Nile's criticism. *Genetics* 8:235-255.
- Wright, S. 1934. The method of path coefficient. *Annals of Mathematics and Statistics* 5:161-215.
- Wright, S. 1960. Path coefficient and complimentary concepts. *Biometrics* 16:189-200.
- Yan, W.K. and Wallace, D.H. 1995. Breeding for negatively associated traits. *Plant Breeding Reviews* 13:141-177.

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