QUANTITATIVE STUDIES IN GRAIN AMARANTH POPULATIONS.

by

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DEDICATION

TO MY HUSBAND, JOSEPH,

DAUGHTER, CAROL,

SON, CORNELIUS

This thesis is my original work and has not been presented for a degree in any other University.

JANE IVARA — DATE 9/8/1988

This thesis has been submitted for examination with our approval as University supervisors.

DR. P.O. AYIECHO — DATE 9/8/88

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ABSTRACT

Twenty-two grain amaranth populations were subjected to comparative evaluation for the number of days to flowering, the number of leaves on the main stem, the number of leaves on the main branches, leaf length, leaf width, the number of days to maturity, plant height, plant weight, seed yield and harvest index in a randomised block design during the short rains of 1986 and long rains of 1987 at Kabete. The populations were Jumla, 125A, 1024, 718, UNK47, UNK44, 723, 674, 1023, 1008, 51, 84, 862, and 812 (all *Amaranthus hypochondriacus*); 1011, 434, UC87, and UC100 (*A. cruentus*), 1113A and 982 (*A. caudatus*); 1004 and 386 (*A. hybridus*). The results indicated that *A. cruentus* gave the highest means for the number of leaves on the main stem, leaf length, leaf width, plant height, plant weight and seed yield. *A. hybridus* gave the highest means for harvest index and the lowest means for the number of days to flowering, and the number of days to maturity, while *A. caudatus* gave the highest mean for the number of leaves on the main branches.

Six of the above populations, namely, Jumla, 1023, 434, 1011, 982 and 1113A were investigated for within population variation for the above traits by planting eight S1 families from each population in a

three-replicate compact family block design at Kabete in 1987. The amount of variability inherent within each of the six populations varied for the various traits. Population 1011 was the most heterogenous population as it showed significant variation among the families for all the traits except the number of days to flowering. Population 434 was the least variable population as it showed significant variation among its families for leaf length only. Population Jumla had significant variation for all the other traits except plant weight, the number of days to maturity and the number of leaves on the main stem. Population 1023 showed significant variability for the number of days to flowering, the number of days to maturity, leaf width, plant height and plant weight. Population 982 showed significant variation for the number of leaves on the main stem, the number of leaves on the main branches, leaf length, leaf width and plant height. Population 1113A showed significant variation for only four traits, namely, the number of days to flowering, the number of leaves on the main stem, plant height and seed yield.

The variability within the populations was reflected in the values of broad sense heritability and selection response estimates which were estimated for each population separately. Traits like the number of leaves on the main stem, leaf length, leaf width, and plant height had high heritability estimates in population 1011. Likewise high expected selection response estimates were obtained for seed yield in populations Jumla, and 1113A, and the number of days to flowering in populations 1023 and 1113A.

The data from the six populations were subjected to phenotypic correlation and path-coefficient analyses to help identify the best metric traits that can be used as seed yield predictors. The data indicated that the highly heritable traits such as leaf length, plant height and plant weight in population 1011; leaf width in Jumla and plant height in population 1023 had high positive correlations with seed yield. All the traits except the number of days to maturity and the number of days to flowering in all populations and plant height in population 434 correlated positively with seed yield in the S1 populations. The results also showed that bigger plants with higher total dry matter productivity had higher seed yields as is indicated by the high positive correlations of seed yield with the number of leaves, leaf length, leaf width and plant weight.

Based on the correlations and path-coefficients, plant weight and harvest index were found to be the best positive indicators of plant yield.

CHAPTER ONE

INTRODUCTION

Amaranths belong to the genus *Amaranthus* which has about 60 species (Willis, 1973). The commonly cultivated grain types are *Amaranthus hypochondriacus*, *A. caudatus*, *A. hybridus* and *A. cruentus*. These species evolved as crop plants in central and south America where they were domesticated in about 3,000 to 5,000 B.C.

The status of the crop in its centres of origin in the Andean South America, Central Mexico and Guatemala declined soon after the Spanish conquest (Sauer, 1950). Currently it persists only as a minor grain crop in South America. In Asian and African countries the crop is both a vegetable and a grain crop (Grubben, 1976).

Although it has declined in importance, amaranth stands out as a crop of great superiority. For example grain amaranths are known to be of high nutritional value, a valuable health food and a cash crop for marginal lands (Early, 1967; Sauer, 1967; Downton, 1973; Theisen *et al*., 1978; Feine, 1979; Sanchez-Marroquin *et al*., 1979). As a source of carbohydrates, proteins, minerals and vitamins, grain amaranths compare well with crops like sorghum, maize, millets, wheat, beans, groundnuts, soybeans and potatoes. The average protein content of 16 percent in the amaranth seed is higher than that of most common grains such as rye (13 percent); barley, wheat and maize (10 percent) and rice (7 percent) (Nat. Res. Council, 1984). Lysine, an essential amino acid, which is limiting in maize and wheat is adequately present in grain amaranths. Another advantage of grain amaranths is their adaptability. Amaranths utilise the C_4 photosynthetic pathway and are therefore efficient in photosynthesis in the hot tropical conditions. They can also do well in the environments that are quite harsh for crops like sorghums and millets (Kauffman and Hass, 1984; Gupta, 1985). They are also relatively resistant to pests and diseases.

Grain amaranths have high yield potentials. Various studies have indicated that average yields range from 3.0 tons to 5.0 tons per hectare (Schimidit, 1977; Vietmeyer, 1981; Joshi, 1981; Gupta, 1985).

The grain amaranth seeds can be milled into flour for making pap or the African ugali when blended with maize meal. When blended with wheat flour, it can be used to make bread, chapatis, biscuits and cakes. Due to its tenderness and nutritive value, the amaranth leaves can serve as a substitute for the commonly expensive vegetables.

Because of their superiority over the common grain crops amaranths are presently receiving intensive research attention focused on the improvements of their yields and adaptability. For example the grain amaranth project in Kenya is focused on improving the yield and adaptability of the grain amaranths in the marginal areas. In California, U.S.A., well designed breeding experiments have been made to improve grain yields by reducing lodging and seed shattering while increasing harvest index. An attempt is also being made to improve early seedling growth, resistance to the root rot fungi and drought resistance. The current trends of research on grain amaranths also involve studies on certain areas of genetic research like germplasm assembly and evaluation, biosystematics, species relationships and breeding system.

The present study was undertaken with objectives of the Kenyan grain amaranth project in mind, that is, improved seed yield. The study was conducted to evaluate the possibility of improving the various amaranth populations by selection. Studies were conducted to:

- evaluate genetic variability for grain yields and related traits in a number of grain amaranth populations.

- study the nature of association among the traits studied.
- use the genetic variability data obtained to predict the selection gain for grain yield in the various populations studied.

CHAPTER TWO

LITERATURE REVIEW

2.1 QUANTITATIVE VARIATION STUDIES

2.1.1 Quantitative Variation in Crop Plants

Quantitative genetic studies are of utmost importance in plant breeding programmes because of the useful information they provide about the genetic variation and the inheritance of quantitative traits. The improvement of quantitative traits, especially yield and yield related traits, always form one of the most important objectives in the plant breeding programmes. The information on quantitative variability is important in determining the heritabilities of characters, the role of heterosis and predicting selection gains for the various traits (Dudley and Moll, 1969). According to Dudley and Moll (1969) the plant breeder is interested in varieties which show a high mean performance and genetic variability. If, however, the varieties have a similar ancestry the genetic variances are likely to be similar, making the mean population performance the most important factor in choosing among them.

Genetic variance, which can be partitioned into the components attributable to additive, dominance and epistatic effects is obtained by appropriately designed experiments (Cockerham, 1963; Falconer, 1981). A lot of attention has been directed towards assessing the extent of genetic variation and the particular types of gene action affecting several quantitative traits in various crops. A large number of such experiments have been reported that cover essentially all the major crop species. Significant genetic variation has been partitioned into its various components through the data collected by several workers. The additive genetic variation has been noted to be predominant for most of the important traits in most of the studies reported. The non-additive genetic variance, though present, has been shown to be smaller than the additive genetic variance. For example, in tobacco the studies on the number of days to flowering, plant height, leaf length, leaf width, the number of harvestable leaves and yield have shown additive genetic variance to be predominant (Matzinger _et al_., 1960, 1966; Matzinger, 1968). In soybeans the data collected on the maturity date, height, seed weight, and yield have also shown significant additive genetic variance to be predominant (Brim and Cockerham, 1961; Hanson _et al_., 1967; Weber _et al_., 1970). Maksudov (1964), Singh _et al_. (1968) and Verhalen *et al*. (1971) have also reported significant genetic variation for the vegetative period, boll weight, the number of branches, the height of fruiting bodies and the number of bolls in cotton. Other studies on cotton by Gupta and Singh (1970) and Baker and Verhalen (1973) have revealed the presence of significant dominance genetic variation for earliness, lint percentage and fibre length. Vishnu and Chaugale (1962), Handley *et al*. (1965), Graham and Lessman (1966) and Eckebil *et al*. (1977) also reported substantial genetic variation for the number of days to bloom, plant height, threshing percentage, head weight, seed weight and panicle characteristics in sorghum populations. And a more recent study by Patil *et al*. (1987) in mungbean also support the above findings for quantitative traits.

Though the newly released varieties show success in performance, it appears that the most significant improvement has been for traits that are simply inherited, that is, qualitative traits. The progress in the improvement of the quantitative characters is often slow due to their nature of inheritance. The inheritance of these traits is known to be of complex nature as a result of the interaction of the polygenes and the environmental factors affecting their phenotypic manifestation.

However, several studies conducted on these characters have shown potentials for crop improvement if there is adequate genetic variability and high heritability. Many of such experiments suggest that there will be selection response in the characters that show genetic variability. Foster and Rutger (1980), while working on wild rice, Zizania acquatica, found high heritability estimates for heading date, plant height and seed length. They concluded that simple mass selection could be effective for these traits. This has also been noted for earliness in tomato (Tayel et al., 1959); maturity range in mungbean (Empig et al (1970); yield, number of days to flowering and maturity in female hops (Roberts et al., 1980); yield and the number of pods per plant in beans (Agwanda, 1988); yield, yield:height ratio and harvest index in grain amaranths (Ayiecho, 1985).

2.1.2 Genetic Variation Studies in Grain Amaranths:

Amaranth falls in the class of self-pollinated crops which often have substantial amounts of outcrossing like cotton and sorghum (Allard, 1960; Simmonds, 1979; Harwood, 1980; Jain et al., 1982). Such crops often have a lot of inherent variability within the populations. For example some studies which have been conducted on the simply inherited characters in the grain amaranth populations have revealed some evidences of heterozygosity. Hauptli and Jain (1980),found that a population of grain amaranth from Tanzania was largely polymorphic for red or green inflorescence colour and translucent or opaque seed coat colour. Vaidya and Jain (unpublished) noted that certain amaranth populations were polymorphic for monogenic seedling colour and di-genic leaf marker traits such as leaf margin colour, leaf margin hairness and leaf texture. On the other hand, allozyme studies by Jain et al (1980) revealed that the levels of allozyme variation in the grain amaranths from India were quite low as compared to their relatively large amounts of variability for morphological traits. They suggested that enzyme monomorphism has been re-tained in spite of human and natural selection for mor-phological diversity. Another study by Hauptli and Jain (1984) reported that four simply inherited traits in the grain amaranths from Latin America were largely monomorphic. These traits included the overall plant pigmentation which was scored as red, orange or green; presence or absence of V-leaf markings; seed coat colour which was either white black or yellow; and seed coat appearance which was either opaque or translucent.

Amaranth populations have not been extensively studied for variation in quantitative traits (Zeven and

Harten, 1979; Frankel and Soule, 1981; Ayiecho, 1985). However, the few studies that have been conducted have shown ample variation for quantitative traits. A study conducted by Hauptli and Jain (1980) on a population of Amaranthus cruentus originally from Tanzania revealed large variation for flowering time plant height, seed yield, harvest index and seed size. In another study Hauptli and Jain (1984) found significant morphological variation among families in the grain amaranth populations from Latin America. Vaidya and Jain (unpublished) reported that the grain amaranth populations from India were more variable for leaf length, leaf width, petiole length, the number of leaves per plant, the number of branches per plant, plant height, the number of days to flowering, inflorescence length and biomass productivity than those sampled from the new world. In another study on grain amaranths by Ayiecho (1985) substantial additive genetic variation was reported for yield related traits in a population of Amaranthus hypochondriacus and a population of Amaranthus cruentus. In this study harvest index showed high additive x additive effects in the Amaranthus cruentus population. Threshing percentage and 500 seed weight showed high genetic variance in the two populations while seed:heihgt ratio, the number of days to flowering, and seed yield showed variation in the *Amaranthus hypochondriacus* population.

2.2 YIELD AND YIELD COMPONENTS

Plant yield, a polygenically inherited trait, is known to be directly or indirectly influenced by a number of component traits (Engledow and Wadham, 1923). Studies on these component traits often referred to as yield components, give more reliable information for plant yield predictions than studies on yield *per se* (Moll *et al*., 1962).

Several studies in various crops have been conducted to establish the relationships of the component quantitative traits with plant yield with promising results. Dewey and Lu (1959), while working on yield of crested wheat grass, found that seeds per spike and plant size were important yield components. Grafius (1960), suggested that ear number per plant, kernels per row, rows per ear and kernel weight were the most important maize yield components. McNeal (1960) and McNeal *et al*. (1978) studied heads per plant, kernels per head, grams per kernel, kernel weight, spikelets per head, kernels per plant and plant yield in wheat. They found that heads per plant, kernels per head, kernel weight and kernel number had significant relationships with plant yield. Grafius (1964), studied the yield components of barley including the number of heads per unit area, average number of kernels per head and average kernel weight and suggested that when the components are correlated and their heritabilities are not near zero, one should select for:-

1. one component if the relationships are positive,
2. both components if the relationships are negative,
3. if the expected gains for all components are high we might select for the complex trait, in this case yield itself.

In a study on tobacco, Paul _et al_ (1965) found that yield of tobacco plant was negatively correlated with the level of alkaloids, a character that needs to be improved in tobacco cultivation. Paul _et al_. (1965) suggested that in order to improve both yield and the level of alkaloids one would have to:-

1. select for the characters independently in different cycles of selection.
2. make selections on basis of an index, for example, an index that maximises the improvement for yield while holding alkaloids constant. This was found to lead to increased yield.

In field bean, Adams (1967) noted that yield is a product of three components; the number of seeds per pod, the number of pods per plant and the average seed size. He concluded that components of yield in beans are genetically independent and that negative correlations are believed to be developmental rather than genetic. Negative correlations were believed to be caused by genetically independent components developing in sequential patterns that are free to vary in response to either a limited constant input of metabolites or an oscillatory input of these substances such that the input is limiting at critical stages in the developmental sequence. In safflower, Abel and Driscoll (1976), used multiple regression method for yield component analysis and concluded that the number of heads per plant was the factor contributing most to safflower yield, followed by the number of seeds per head and seed weight. Ehdaie and Ghaderi (1978), indicated that whether one should select for the components of yield or yield itself in safflower will depend on the heritabilities, correlations among the yield components and their correlations to yield. And in wheat, McNeal *et al*. (1978), reported that the use of yield components to improve the yield of wheat was a better approach than the direct selection of yield *per se*. They showed that kernels per spike gave a significant regression coefficient for grain yield while other traits did not. McNeal _et al_ (1978) concluded that a single character can be used to improve yield. McNeal _et al_ (1978) also noted that a long term yield improvement results from improving all the yield components.

Yield prediction studies in grain amaranths have also produced promising results. For example, Hauptli and Jain (1980, 1984), found that taller plants were more yielding than shorter ones in _Amaranthus cruentus_. Based on stepwise regression plant height, the number of days to flowering and leaf length had high correlations with plant yield. Ayiecho (1985), while working on yield related traits in two grain amaranth populations found that bigger plants had higher seed yields. In his experiment harvest index was positively correlated to seed yield in a population of _Amaranthus hydrochondriacus_. Based on correlations, path-coefficient analysis and stepwise multiple regression the best yield predictors in the two populations were plant height, seed yield: height ratio, harvest index, head weight and plant weight.

CHAPTER THREE

MATERIALS AND METHODS:

3.1 MATERIALS:

Quantitative variation studies in grain amaranths were conducted using the following twenty-two grain-amaranth populations.

Table 1. The populations used in the study.

Species	Population	Seed colour
Amaranthus hypochondriacus	Jumla	white
	125A	white
	1024	gold
	718	brown
	UNK47	white-brown
	UNK44	white-brown
	723	brown
	674	black
	1023	white
	1008	white
	51	white
	84	white
	862	gold
	812	white
Amaranthus cruentus	1011	white
	434	white
	UC87	white-grey
	UC100	white
Amaranthus caudatus	1113A	white
	982	white
Amaranthus hybridus	1004	black
	386	black

The populations were obtained from the Grain Amaranth project of the Department of Crop Science, University of Nairobi.

2. METHODS

2.1 Field experiments

The experiments were conducted at the Field Station of the University of Nairobi, Kabete campus,during the short rains of 1986 and the long rains of 1987 to study the variation among the above populations. The experiments were also conducted to study the variation within six of the above populations.

2.1.1 Variation among the populations

The above twenty-two grain amaranth populations were planted in a four replicate randomised block design during the short rains of 1986 and the long rains of 1987. In each replicate each population was planted in a plot of 2 rows by 3m. The inter-row spacing was 50 cm while the within row spacing was 20 cm. Di-ammonium fertilizer was applied at a rate of 100 kg/ha at planting time and the plots were weeded twice. Within each population in each replicate individual plant data was taken on a random sample of 5 plants for the following traits.

1. The number of days to flowering measured as the day the first anther was observed.

2. The number of leaves on the main stem immediately after flowering.

3. The number of leaves on the main branches. All leaves on the primary branches that were greater than 1 cm broad were counted after flowering.

4. The length of the leaf blade for the three largest leaves.

5. Leaf width, measured on the widest part of the leaf blade for the same leaves measured for length.

6. The number of days to maturity. This was taken on the day the seeds were firm enough to appear flourly when crushed.

7. The plant height at maturity.

8. The total plant dry weight for oven dried plants.

9. The seed yield per plant

10. The harvest index, estimated as

$$\frac{\text{seed yield per plant}}{\text{Total plant dry weight}}$$

2.1.2 Variation within the populations

Eight S1 families derived from each of the following six populations; Jumla, 1023, 434, 1011, 982 and 1113A, were used. The eight S1 families in each population were derived by selfing eight randomly selection plants. The S1 families from each of the six populations were planted in a compact family block design with three replicates during the long rains of 1987. Each family was planted in a row of 4 m long. The inter-row and intra-row spacings were 50 cm and 20 cm respectively. Data was taken on five randomly selected plants in each replicate for each family for the same traits as above.

2.2 Statistical analysis

The variation among the twenty-two populations were analysed using a mixed effects model as given by Steel and Torrie (1960) as follows:

Table 2. Analysis of variance among the populations.

Source	d.f.	M.S.	E.M.S.
Replications in seasons	s(r-1)		
Seasons	s-1	M4	$\sigma_e^2+rg\sigma_s^2$
Populations	g-1	M3	$\sigma_e^2+r\sigma_{gs}^2+rs\ \Sigma\tau i^2/g-1$
Seasons x Populations	(s-1)(g-1)	M2	$\sigma_e^2+r\sigma_{gs}^2$
Error	By subtraction	M1	σ_e^2

where

σ_e^2 = error variance.

σ_{gs}^2 = variance of the seasons-population. interaction factor.

τ_i = Effect of i^{th} population.

r = Number of replicates.

s = Number of seasons.

g = Number of populations.

The variation within each of the six populations from which the S1 families were obtained was obtained by subjecting the S1 data in each population to a random model analysis as follows.

Table 3. Analysis of variance among the S1 families.

Source	d.f.	M.S.	E.M.S.
Replicates	r-1		
Families	f-1	Mf	$\sigma_e^2 + r\sigma f^2$
Error	By subtraction	Me	σ_e^2

The variance estimates from this analysis were used to estimate the broad sense heritability and the expected selection response values as follows.

σ_f^2 = between family variance, obtained as:-

$$\sigma_f^2 = \frac{Mf-Me}{r}$$

This gives an estimate of genotypic variance, σ_G^2

$\sigma_p^2 = \sigma_G^2 + \sigma_e^2$ = phenotypic variance estimate.

f = number of families.

r = number of replicates,

The broad sense heritability estimate, h^2_{BS} is given by

$$\frac{\sigma^2_G}{\sigma^2_p}$$

The expected response to mass selection was estimated assuming a selection pressure of 10 percent as follows.

$$R = ih^2_{BS}\sigma_p$$

where R = response after one generation of selection.

σ_p is the phenotypic standard deviation obtained from the above analysis as follows:

$$\sigma_p = (\sigma^2_G + \sigma^2_e)^{\frac{1}{2}}$$

i = selection intensity.

Simple linear correlations were calculated for the six populations from which the S1 families were derived using the individual plant data for the original populations and that of the S1 populations. The effects of the various quantitative traits on yield was analysed using the path-coefficient analysis as given by Dewey and Lu (1959).

CHAPTER FOUR

RESULTS

4.1 VARIATION AMONG THE POPULATIONS

The analysis of variance (Table 4) indicates that there was significant variation among the populations for all the traits studied. The population means and coefficients of variation for the number of days to flowering, the number of leaves on the main stem, the number of leaves on the main branches, leaf length, leaf width, the number of days to maturity, plant height, plant weight, seed yield and harvest index are presented in Table 5. The data presented in Table 5 also suggest substantial variation among the populations within the various species and among the species means.

The data presented in Table 5 show that *A. cruentus* had the highest mean number of days to flowering. However the lattest flowering populations, UNK47 and UNK44 were *A. hypochondriacus* populations. The lowest number of days to flowering were recorded in Jumla (34.18 days) which is also an *A. hypochondriacus* population. While there was substantial variation among the populations of *A. hypochondriacus* the means for *A. caudatus* and *A. hybridus* populations were fairly uniform. This could be a function of the number of

Table 4. Mean squares for the analysis of variance for the 22 original populations (1986 and 1987).

Source of variation	d.f.	No. of days to flowering	No. of leaves on main stem	No. of leaves on main branches	Leaf length (cm)	Leaf width (cm)	No. of days to maturity	Plant height (cm)	Plant weight (g)	Seed yield (g)	Harvest index
Replications	3	46.38	613.87**	5376.7**	14.36	11.96*	524.2**	1437**	31420**	421.93	0.039**
Populations	21	5351.3**	3384.1**	1507.8**	417.67**	188.33**	6809.1**	88307**	8024.9**	1656.6**	0.1807**
Seasons	1	634.2**	158.1*	21286**	2741**	1098.9**	3274.5	1.1×10^{5}**	1.09×10^{5}**	105.99	0.6314**
Populations x Seasons	21	268.21**	151.44**	6414.2**	63.53**	32.23**	570.65**	3732.1**	10467**	3521.46*	0.028**
Error	830	13.609	33.93	461.96	8.78	3.35	40.718	466.14	4442.5	141.19	0.0064

* P = 0.05

** P = 0.01

Table 5. Population means for quantitative characters for the original populations over two years (1986 and 1987).

Population	No. of days to flowering	No. of leaves on the main stem	No. of leaves on the main branches	Leaf length (cm)	Leaf width (cm)	No. of days to maturity	Plant height (cm)	Plant weight (g)	Seed yield (g)	Harvest index
A. hypochondriacus										
1. JUMLA	34.18	11.20	32.40	12.72	6.35	65.70	73.90	52.83	14.41	0.29
2. 125A	36.18	12.25	42.03	12.74	7.19	72.30	84.97	87.63	16.47	0.20
3. 1024	46.65	22.80	52.97	18.53	9.96	77.42	126.55	126.64	29.47	0.24
4. 718	63.98	24.50	38.60	20.77	11.28	98;65	178.95	121.55	12.70	0.13
5. UNK47	69.13	34.88	65.93	18.97	9.51	108.13	187.40	167.39	16.82	0.11
6. UNK44	69.90	33.37	56.18	19.47	9.69	108.30	195.57	164.52	17.66	0.11
7. 723	62.15	37.63	73.10	17.22	9.59	93.28	203.20	184.66	15.52	0.09
8. 674	35.82	11.20	32.78	10.98	5.25	65.15	69.95	42.09	12.48	0.32
9. 1023	47.85	25.15	56.87	15.64	8.02	81.45	119.65	107.83	22.00	0.22
10. 1008	33.80	9.48	26.18	11.33	7.24	69.50	66.75	59.96	10.60	0.21
11. 51	51.33	31.23	83.13	18.76	10.02	87.43	160.53	155.69	29.52	0.21
12. 84	43.48	21.00	49.78	16.14	8.48	77.55	114.70	101.75	25.25	0.26
13. 862	46.48	20.00	53.58	17.38	8.74	79.85	118.20	111.97	26.73	0.25
14. 812	51.48	30.98	84.50	16.53	8.62	83.47	146.85	131.97	31.96	0.26
MEAN	49.81	23.26	53.43	16.23	8.56	83.44	131.94	115.46	20.12	0.21
A. cruentus										
15. 1011	55.35	29.78	73.08	21.13	13.66	88.20	176.75	175.09	26.52	0.15
16. 434	55.80	28.30	44.65	19.97	11.65	86.12	179.63	136.60	25.91	0.21
17. UC87	62.27	31.70	66.78	19.19	10.19	93.63	178.38	143.67	21.81	0.16
18. UC100	57.69	34.85	58.18	20.98	13.29	90.43	193.95	191.25	22.80	0.16
MEAN	57.69	31.16	60.67	20.32	12.19	89.59	182.18	161.65	24.26	0.17
A. caudatus										
19. 1113A	56.70	29.35	90.33	15.24	8.61	95.30	164.80	142.61	15.59	0.12
20. 982	56.07	29.83	82.70	16.65	9.30	92.65	165.10	149.71	17.38	0.11
MEAN	56.38	29.59	86.52	15.94	8.95	93.97	164.95	146.16	16.48	0.11
A. hybridus										
21. 1004	35.52	11.68	33.98	12.36	6.27	67.28	76.95	60.01	15.53	0.28
22. 386	36.95	12.03	33.18	13.35	6.65	66.53	83.87	68.76	17.07	0.26
MEAN	36.23	11.85	33.58	12.85	6.46	66.90	80.41	64.38	16.30	0.27
C.V.	7.3	24.0	38.4	17.8	20.2	7.6	15.5	54.6	58.2	39.3

populations studied in each species. In *A. hypochondriacus* a total of 14 populations were used in the study. On the other hand in *A. caudatus* and *A. hydridus* only two populations were studied in each case.

The highest mean number of leaves on the main stem were recorded in the species *A. cruentus*. The lowest number of leaves on the main stem (9.48) were noted in population 1008 (*A. hypochondriacus*). Population 723 (*A. hypochondriacus*) had the highest number of leaves on the main stem (37.63). The highest mean number of leaves on the main branches were recorded in *A. caudatus*. Population 1113A had the highest number of leaves on the main branches (90.33), while population 1008 had the lowest number of leaves on main branches (26.18). Similar patterns of variation among the population means were noticed for the number of leaves on the main stem and number of leaves on the main branches as for days to flowering, that is, wide variations among the *A. hypochondriacus* populations and less variation within *A. caudatus* and within *A. hybridus* (Table 5).

The species means for leaf length and leaf width show that *A. cruentus* had the largest leaves (20.32 cm and 12.19 cm for length and width respectively).

The species that had the smallest leaves was _A. hybridus_. However the population with the smallest leaves, 674, was an _A. hypochondriacus_ population. The largest leaves were found in population 1011 which is an _A. cruentus_. The populations of _A. hypochondriacus_ were highly variable for leaf length and leaf width measurements. In this species, the leaf size of population 718 is almost twice that of population 674. Such wide variations were not noticed in the other three species.

The means for number of days to maturity show that the species that was the earliest to mature was _A. hybridus_ while _A. caudatus_ was averagely a late maturing species. However, the earliest and the lattest maturing populations, 674 and UNK44 respectively, were _A. hypochondriacus_ populations. They matured in 65.15 and 108.30 days respectively. The number of days to maturity were consistent with the number of days to flowering as the earlier flowering populations matured earlier.

Though the shortest and the tallest populations (1008 and 723 respectively) were _A. hypochondriacus_ populations, _A. cruentus_ had the highest mean plant height and _A. hybridus_ the lowest mean height. As already indicated for the other traits _A. hypochondriacus_ had the greatest variation among its populations for this trait.

Plant weight is closely associated with plant height as the tallest populations were also the heaviest. Therefore the species that had the highest mean plant dry weight was A. cruentus while the species that had the lowest mean plant dry weight was A. hybridus. Among the populations of A. cruentus UC100 and 434 had the highest and the lowest mean plant dry weights respectively. However among the populations studied, the one which had the lowest dry matter yield was an A. hypochondriacus population, 674 (42.09 gm).

A. cruentus was the highest yielding species (24.26 g) while A. hybridus gave the lowest mean seed yield (16.30 g). The lowest yielding population was an A. hypochondriacus population, 1008. Similarly the highest yielding population, 812 was also A. hypochondriacus.

A. hybridus had the highest mean harvest index while A. caudatus gave the lowest mean harvest index (0.27 and 0.11 respectively). On the other hand the populations which showed the highest and lowest harvest indices, 674 and 723 respectively were A, hypochondriacus populations. Generally the populations which were tall and had high plant weights showed the lowest harvest indices. For example the populations 723, UNK47, and UNK44 which had the largest plants gave the lowest harvest indices. On the other hand population 674 which was the shortest and also had the lowest total plant. dry weight had the highest harvest index.

Table 4 also shows that all traits showed significant population x season effect. All traits except the number of days to maturity and seed yield had significant season effects. The coefficients of variation ranged from 7.3 to 58.2 percent.

Table 6 shows the branching scores for all the original populations in 1987. The populations of *A. cruentus* were the least branched. For example population UC87 had no branches. On the other hand the populations of *A. hybridus* were the most branched. The two populations of *A. hybridus* had secondary branches. *A. caudatus* and *A. hypochondriacus* showed variability in the amount of branching scored in their populations. In these two species half of the populations had only primary branches and the other half had secondary branches on the primary branches.

4.2 VARIATION WITHIN THE POPULATIONS

The analysis of variance Table 7 shows that the six populations namely Jumla, 1023, 434, 1011, 982 and 1113A had significant differences among themselves for all the traits studied. This was confirmed by Duncan's

Table 6. Branching scores for the original populations (1987)

Population	Branching score*
A. hypochondriacus	
1. JUMLA	2
2. 125A	2
3. 1024	2
4. 718	2
5. UNK44	1
6. UNK47	1
7. 723	1
8. 674	2
9. 1023	2
10. 1008	2
11. 51	1
12. 84	1
13. 862	1
14. 812	1
A. cruentus	
1. 1011	1
2. 434	1
3. UC87	0
4. UC100	1
A. cruentus	
1. 113A	2
2. 982	1
A. hybridus	
1. 1004	2
2. 386	2

*The branching was scored as follows:-
0 = No branches; 1 = only primary branches on the main stem
2 = Secondary branches on the primary branches.

Table 7. Analysis of variance among the six populations selected for S1 family analysis.

Trait		Mean squares		
		Replications	Populations	Error
	d.f.	2	5	712
Number of days to flowering		14.204	10539**	15.275
Number of leaves on the main stem		537.39	7486.9**	26.02
Number of leaves on the main branches		5444.2	11200	954.68
Leaf length		37.34	1029.4**	5.75
Leaf width		24.81	970.76**	4.02
Number of days to maturity		49.13	5831.4**	7.85
Plant height		12955	302000**	804.64
Plant weight		2850.3	338000**	6295.6
Seed yield		410.18	955.62**	96.07
Harvest index		0.012	0.523**	0.009

* P = 0.05
** P = 0.01

multiple range test, (Table 8), which indicated that populations differed significantly for the various traits. For example Jumla, 1023, 1113A and 434 differed significantly with respect to number of days to flowering and Jumla, 1023, 1011, and 982 for number of leaves on the main stem. Population 982 and 1113A showed equality of means with respect to leaf length, leaf width, plant weight and harvest index. The analysis of variation within each of these populations for the quantitative traits shows that each population was quite variable (Table 9). For example the three populations, namely Jumla, 1023 and 1113A had substantial variation for days to flowering. The families within 1011 and 982 were also significantly different among themselves for the number of leaves on the main stem and the number of leaves on the main branches. Jumla and 1113A also showed significant variation for the number of leaves on the main branches and the number of leaves on the main stem respectively.

In case of leaf length, the analysis of variance revealed significant variation in Jumla, 434, 1011 and 982. Leaf width showed significant variation within populations 1023, 1011 and 982. The number of days to maturity and plant weight were variable for two populations only, namely 1023 and 1011. All the

Table 8. Duncan multiple range test for the six populations selected for S1 family analysis.

Number of days to flowering;

Jumla	1023	1113A	434	952	1011
31.80	41.14	50.43	53.71	54.50	55.02

Number of leaves on the main stem;

Jumla	1023	434	1113A	1011	982
12.23	17.12	25.82	26.14	29.37	33.46

Number of leaves on the main branches;

Jumla	434	1011	1023	1113A	982
37.33	42.95	69.68	70.40	91.34	119.42

Leaf length;

Jumla	1023	982	1113A	1011	434
15.01	16.26	20.07	20.10	21.55	22.39

Leaf width;

Jumla	1023	982	1113A	434	1011
7.36	9.05	12.36	12.63	13.90	14.22

Number of days to maturity;

Jumla	1023	434	1011	1113A	982
65.51	71.36	79.53	79.76	81.73	83.54

Table 8. (Contd...)

Plant height;

Jumla	1023	1011	434	982	1113A
90.02	118.16	180	196.15	198.6	214.61

Plant weight;

Jumla	1023	434	1011	982	1113A
82.17	91.62	133.87	170.73	192.70	209.56

Seed yield;

Jumla	982	1113A	1011	1023	434
18.39	18.41	21.14	22.10	22.12	25.96

Harvest index;

1113A	982	1011	434	Jumla	1023
0.10	0.11	0.13	0.20	0.23	0.26

Table 9. Mean squares for analysis of variance among the S1 families for six populations

Trait	Source	d.f.	Mean squares					
			Jumla	1023	434	1011	982	1113A
Number of days to flowering	Replications	2	17.17	18.53	26.80	20.40	96.83	4.35
	Families	7	6.85*	15.47*	8.39	6.01	61.29	21.98*
	Error	110	2.08	4.85	4.60	7.15	62.79	5.98
Number of leaves on the main stem	Replications	2	40.41	450.48	184.51	369.53	17.55	26.01
	Families	7	4.28	40.58	11.86	154.11*	159.59**	32.94*
	Error	110	3.33	18.15	12.74	33.62	56.77	8.12
Number of leaves on the main branches	Replications	2	5.43	2877.8	1404.5	268.51	2664.00	6061.7
	Families	7	182.62*	48.88	199.69	3352.5*	6194.1*	1745.5
	Error	110	49.37	235.39	496.84	930.5	2520.5	1058.2
Leaf length	Replications	2	55.18	4.13	13.93	3.74	38.98	3.65
	Families	7	22.61*	5.93	10.86*	47.47*	25.02*	6.26
	Error	110	3.84	4.45	3.87	3.08	9.10	3.87
Leaf width	Replications	2	6.37	18.54	16.04	12.95	30.68	1.72
	Families	7	7.74	14.38*	13.12	12.49*	10.54*	3.46
	Error	110	0.84	2.82	8.23	2.04	4.11	2.94
Number of days to maturity	Replications	2	0.158	12.70	25.60	5.43	51.11	56.57
	Families	7	0.360	4.46*	3.02	10.42*	69.86	13.87
	Error	110	0.392	2.44	2.83	5.03	23.37	8.39
Plant height	Replications	2	1922.3	1006.1	2962	9004.3	9347.7	1262.4
	Families	7	383.4*	1111.00*	1411	1565.5*	2998.6*	352.74*
	Error	110	77.54	164.02	3089.9	112.86	796.2	348.53
Plant weight	Replications	2	8929.3	1387.2	6520	4047.1	18014	14238
	Families	7	1665.1	304.66*	5264.1	2362.4*	10895	15916
	Error	110	1022	1387.2	2439.4	4377.6	16037	10928
Seed yield	Replications	2	117.3	24.68	203.21	66.90	549.77	236.32
	Families	7	218.86*	87.39	194.82	298.94*	186.93	219.91*
	Error	110	63.07	67.48	95.65	64.19	150.77	69.511
Harvest index	Replications	2	0.0271*	0.038	0.0094	0.0018	0.016	0.0014
	Families	7	0.0192*	0.0429	0.0013	0.0019*	0.0088	0.0020
	Error	110	0.0041	0.038	0.0015	0.0008	0.0056	0.0014

* P = 0.05
** P = 0.01

populations except 434 had significant variation for plant height. Only three populations, Jumla, 1011 and 1113A had significant variation for seed yield. Variability for harvest index was also noted to be significant within only two populations, Jumla and 1011.

Table 10 shows that in all the populations the S1 family means were lower than the original population means for the number of days to flowering and the number of days to maturity. This was also true for the number of leaves on the main stem and the number of leaves on the main branches with the exception of Jumla and 982 in which S1 families had more leaves than the original population and 1023 and 1113A in which the S1 families had more leaves on the main branches. On the other hand the S1 populations had taller plants and larger leaves than their original populations. An exception was 1023 in which the S1 families gave a lower mean plant height than the original population. Similarly, apart from 1023, 434 and 1011 the S1 families had heavier plants than the respective original populations. Furthermore all the S1 populations, except 1011 were higher yielding than the respective original populations. And apart from 1023 the S1 populations had higher harvest indices than the original populations.

Table 10. S1 Population and the original population means

	Trait									
	No. of days to flowering	No. of leaves on the main stem	No. of leaves on the main branches	Leaf length (cm)	Leaf width (cm)	No.of days to maturity	Plant height (cm)	Plant weight (g)	Seed yield (g)	Harvest index
JUMLA-Original population	34.18	11.20	32.40	12.72	6.35	65.70	73.90	52.83	14.41	0.29
S1 population	31.80	12.23	37.33	15.01	7.36	65.51	90.02	82.17	18.39	0.23
1023 -Original population	47.85	25.15	56.64	15.64	8.02	81.45	119.65	107.83	22.00	0.22
S1 population	41.14	17.12	70.40	16.26	9.05	71.36	113.16	91.62	22.12	0.26
434-Original population	55.80	28.30	44.65	19.97	11.65	86.12	179.63	136.60	25.91	0.21
S1 population	53.71	25.82	42.95	22.39	13.90	79.53	196.15	133.87	25.96	0.20
1011-Original population	55.35	29.78	73.08	21.13	13.66	88.20	176.75	175.09	26.52	0.15
S1 population	55.02	29.37	69.68	21.55	14.22	79.76	180.00	170.73	22.10	0.13
982-Original population	56.70	29.83	82.70	16.65	9.30	92.65	165.80	149.71	17.38	0.11
S1 population	54.50	33.46	119.42	20.07	12.36	83.54	198.60	193.70	18.41	0.11
1113A-Original population	56.70	29.35	90.33	15.24	8.61	95.30	164.80	142.61	15.59	0.12
S1 population	50.43	26.14	91.34	20.10	12.63	81.73	214.61	209.56	21.14	0.10

The results show that all the traits, apart from the number of days to flowering, showed significant differences between families in population 1011. This population can therefore be ranked as the most heterogenous population. On the other hand population 434 showed no variation for all traits except leaf length. Hence population 434 can be ranked as the most homogenous population.

4.3 BROAD SENSE HERITABILITIES AND SELECTION RESPONSE ESTIMATES

The estimates for broad sense heritability and predicted response obtained from S1 data are presented in Tables 11 and 12 respectively for Jumla, 1023, 434, 1011, 982 and 1113A. While heritability estimates are given for all traits predicted response were obtained for days to flowering, days to maturity, seed yield and harvest index only. The highest heritability estimate (0.82) was obtained for leaf length in population 1011. The heritability estimates were high for all traits in population 1011 except the number of days to flowering. Generally the traits that show high heritability estimates are expected to have a high expected selection response estimates. For example the heritability for seed yield in population 1011 is 0.54 and the expected response is 11.31. Similarly harvest index

Table 11. Components of variation and broad sense heritabilities based on S1 family analysis for the quantitative traits of six populations:

TRAIT		POPULATION JUMLA	1023	434	1011	962	1113A
Number of days to flowering	σ^2_G	1.59	3.45	1.26	-0.076	-1.5	5.33
	σ^2_P	3.67	8.38	5.86	0.401	2.68	11.32
	h^2_{BS}	0.43	0.41	0.21	0	0	0.47
Number of leaves on the main stem	σ^2_G	0.31	7.47	-0.05	40.16	34.27	8.27
	σ^2_P	3.64	25.61	0.78	73.78	91.04	16.40
	h^2_{BS}	0.08	0.29	0	0.54	0.37	0.50
Number of leaves in the main branches	σ^2_G	44.41	-12.43	-19.81	807.33	1224.5	229.1
	σ^2_P	93.78	3.25	13.31	1737.8	3745.0	1267.3
	h^2_{BS}	0.47	0	0	0.46	0.33	0.0007
Leaf length	σ^2_G	6.27	0.49	2.33	14.79	5.31	0.79
	σ^2_P	10.11	4.93	6.20	17.87	14.40	4.66
	h^2_{BS}	0.62	0.09	0.37	0.82	0.36	0.16
Leaf width	σ^2_G	2.3	3.85	1.63	3.48	2.14	0.17
	σ^2_P	3.14	6.66	9.86	5.52	6.24	3.11
	h^2_{BS}	0.73	0.57	0.16	0.63	0.35	0.05
Number of days to maturity	σ^2_G	-0.0021	0.67	0.06	1.79	15.49	1.82
	σ^2_P	0.0240	3.11	2.89	6.82	36.85	10.21
	h^2_{BS}	0	0.32	0.02	0.26	0.39	0.17
Plant height	σ^2_G	101.93	315.66	-111.9	484.2	734.13	1.40
	σ^2_P	179.49	479.68	94.06	597.07	1530.34	349.93
	h^2_{BS}	0.56	0.65	0	0.81	0.47	0.004
Plant weight	σ^2_G	214.36	-72.16	941.56	6415.6	-342.8	1662.66
	σ^2_P	1236.36	20.31	3380.96	10793.2	726.33	12590.66
	h^2_{BS}	0.17	0	0.27	0.59	0	0.13
Seed yield	σ^2_G	51.93	6.63	33.06	78.25	12.05	55.60
	σ^2_P	115	74.11	128.7	142.43	162.82	125.11
	h^2_{BS}	0.45	0.06	0.26	0.54	0.07	0.44
Harvest [illegible]	σ^2_G	0.005	0.001	-0.00001	0.0011	0.001	0.0006
	σ^2_P	0.009	0.039	0.00008	0.0018	0.006	0.0019
	h^2_{BS}	0.52	0.03	0	0.58	0.16	0.33

Table 12. Expected selection gains after one generation of selection for the number of days to flowering, number of days to maturity, seed yield and harvest index of six populations.

TRAIT	POPULATION					
	JUMLA	1023	434	1011	923	1113A
Number of days to flowering	-1.44	-2.08	-0.89	0	0	-2.77
Number of days to maturity	0	-0.99	-0.01	-1.19	-4.26	-0.95
Seed yield	8.46	1.20	5.17	11.31	1.56	8.63
Harvest index	0.08	0.002	0	0.04	0.02	0.02

showed a high heritability of 0.52 and 0.58 in populations Jumla and 1011 respectively. The gains due to selection for this trait are also highest in Jumla and 1011.

4.4 CORRELATIONS AND PATH EFFECTS

The phyenotypic correlation estimates among the traits studied are presented in Tables 13 to 18 and the path effect coefficients of the various traits on seed yield in Tables 19 to 24 for populations Jumla, 1023, 434, 1011, 982 and 1113A. While the correlations were based on original population and S1 data, path-coefficients were estimated using S1 data only.

The correlations in the population Jumla (Table 13) show that the highest correlation coefficient of 0.954 was obtained between plant weight and seed yield. Other high correlations noted in this population included those between number of leaves on the main stem and number of leaves on the main branches (0.864), leaf length and leaf width (0.876), plant height and leaf length (0.7112), plant weight and leaf length (0.8380), plant weight and leaf width (0.736) and plant height and plant weight (0.638). Harvest index showed low correlations with all traits apart from seed yield. Apart from the number of days to maturity and the

Table 13. Phenotypic correlations for Jumla

Top = Original population (1986); n = 20
Bottom = S1 family data, n = 120

	No. of days to flowering	No. of leaves on main stem	No. of leaves on main branches	Leaf length	Leaf width	No. of days to maturity	Plant height	Plant weight	Seed yield
Number of days to flowering									
Number of leaves on main stem	0.02940^{NS} 0.3210								
Number of leaves on main branches	0.3460^{NS} 0.2360	0.8640 0.2940							
Leaf length	0.397 0.502	0.746 0.4802	0.6553 0.4275						
Leaf width	0.163^{NS} 0.4390	0.581 0.399	0.449 0.4033	0.6930 0.8760					
Days to maturity	−0.317^{NS} 0.0435^{NS}	−0.209^{NS} −0.0016^{NS}	0.363^{NS} −0.005^{NS}	0.143^{NS} −0.0692^{NS}	0.073^{NS} −0.1416^{NS}				
Plant height	−0.134^{NS} 0.3369	0.603 0.5287	0.513 0.4122	0.606 0.7112	0.663 0.652	0.297^{NS} −0.1130^{NS}			
Plant weight	0.307^{NS} 0.4514	0.688 0.4409	0.5890 0.5078	0.8380 0.7190	0.736 0.7240	0.0228^{NS} −0.0743	0.6112 0.638		
Seed yield	0.245^{NS} 0.4293	0.6200 0.4287	0.525 0.3498	0.837 0.6277	0.7285 0.5957	0.0600^{NS} 0.0107^{NS}	0.557 0.5144	0.954 0.7989	
Harvest index	0.008^{NS} −0.0013^{NS}	0.049^{NS} 0.1180^{NS}	0.046^{NS} −0.1082^{NS}	0.1995^{NS} 0.0244^{NS}	0.1615^{NS} 0.0076^{NS}	0.065^{NS} −0.0714^{NS}	−0.065^{NS} 0.0093^{NS}	0.1513^{NS} −0.1056^{NS}	0.397 0.445

number of days to flowering in the original population all the traits showed significant positive correlations with seed yield. There was no general trend of differences between correlation coefficients obtained for original population and the S1 family data. The notable large differences were noted between S1 and original population data for the correlations between number of leaves on the main stem and number of leaves on the main branches, leaf length and number of leaves on the main stem, leaf width and days to flowering, number of days to maturity and number of leaves on the main branches, plant weight and number of days to maturity and harvest index and number of days to maturity.

In Table 14, the phenotypic correlations in population 1023 show that the highest correlation was obtained between number of leaves on the main stem and the number of leaves on the main branches (0.9585). In this population high positive correlations were obtained between the number of days to flowering and the number of leaves on the main stem and on the main branches, number of days to flowering and leaf length, leaf length and the number of leaves on the main branches (0.6110), leaf width and leaf length (0.8556). Plant height and plant weight in population 1023 gave significant positive correlations with all traits except the number of days

Table 14. Phenotypic correlations for 1023

Top= original population (1986) n = 20
Bottom = S1 family data n =120

	No. of days to flowering	No. of leaves on main stem	No. of leaves on main branches	Leaf length	Leaf width	No. of days to maturity	Plant height	Plant weight	Seed yield
Nmber of days to flowering									
Number of leaves on main stem	0.5156								
	0.6361								
Number of leaves on main branches	0.5349	0.9585							
	0.5015	0:6133							
Leaf length	0.5705	0.0261^{NS}	0.5133						
	0.6282	0.4775	0.6110						
Leaf width	0.4502	-0.1250^{NS}	0.4331	0.8556					
	0.4443	0.4281	0.4366	0.4960					
Days to maturity	0.4846	0.2532	-0.0605^{NS}	0.1481^{NS}	0.2574^{NS}				
	0.2416	0.0380^{NS}	-0.0317^{NS}	0.1516^{NS}	0.0631^{NS}				
Plant height	0.3932	0.6578	0.5979	0.8565	0.7440	0.2993^{NS}			
	0.5612	0.6308	0.6173	0.6689	0.3842	0.1402^{NS}			
Plant weight	0.4163	0.4109	0.5485	0.8376	0.0578	0.3761	0.3968		
	0.4321	0.2947	0.5499	0.6348	0.2019	0.2256	0.5004		
Seed yield	0.3423^{NS}	0.9657^{NS}	0.2982^{NS}	0.7161	0.7342	-0.0236^{NS}	0.5348	0.8291	
	0.5128	0.3700	0.6217	0.6962	0.4673	0.0900	0.4856	0.7677	
Harvest index	-0.4331	0.1740^{NS}	-0.4162	-0.2512^{NS}	-0.1164^{NS}	-0.3833	-0.5524	0.4167	0.5805
	0.1692	0.1882	0.1797	0.1436^{NS}	0.5087	-0.0406^{NS}	0.1080^{NS}	-0.2575	0.3208

to maturity and harvest index. Among all the traits in this population plant weight gave the highest correlation with seed yield. Harvest index showed a significant positive correlation with leaf width and a negative correlation with plant height and plant weight. As the case with Jumla there was no general trends in differences between correlations from original population data and S1 data. Some notable differences between the correlations from the S1 data and those from original population data were observed for those correlations of number of leaves on the main stem and some traits like number of leaves on the main branches, leaf length, leaf width, plant weight and seed yield; leaf width and all other traits except number of days to flowering, number of leaves on the main branches and harvest index.

The phenotypic correlations for population 434 are given in Table 15. The correlations of all traits with harvest index were nonsignificant except those between harvest index and the number of days to maturity in the S1 populations and seed yield. The highest correlation in this population was 0.976 between the number of leaves on the main stem and the number of leaves on the main branches. Leaf length showed a high correlation with leaf width (0.9172) and with the number of leaves on the main branches (0.8190). The number of days to maturity had no strong association with any

Table 15. Phenotypic correlations for 434

Top = Original population (1986), n = 20
Bottom S1 family data, n = 120

	No. of days to flowering	No. of leaves on main stem	No. of leaves on main branches	Leaf length	Leaf width	No. of days to maturity	Plant height	Plant weight	Seed yield
Number of days to flowering									
Number of leaves on main stem	0.1780^{NS}								
	-0.2151								
Number of leaves on main branches	-0.4652	0.976							
	-0.3655	0.6665							
Leaf length	-0.1316^{NS}	0.4713	0.8190						
	-0.4108	0.5851	0.7165						
Leaf width	-0.0741^{NS}	0.1908^{NS}	0.2284^{NS}	0.9172					
	-0.2735	0.2782	0.3615	0.5435					
Days to maturity	0.4810	-0.1552^{NS}	-0.1293^{NS}	-0.2064^{NS}	-0.1134^{NS}				
	0.4938	-0.1461^{NS}	-0.1634	-0.1400^{NS}	-0.0719^{NS}				
Plant height	0.3894	0.3807	0.2138^{NS}	0.3073^{NS}	0.4152	0.3342^{NS}			
	-0.1130^{NS}	0.1239^{NS}	0.0864^{NS}	0.0483^{NS}	0.0414^{NS}	-0.0199^{NS}			
Plant weight	0.0659^{NS}	0.4796	0.7071	0.8046	0.4456	-0.0116^{NS}	0.5780		
	-0.3111	0.5930	0.7932	0.8178	0.4036	-0.0903^{NS}	0.0687^{NS}		
Seed yield	-0.1639^{NS}	0.4063	0.6516	0.5757	0.6379	-0.0624^{NS}	0.2949^{NS}	0.7153	
	-0.3665	0.5304	0.7301	0.7729	0.3718	-0.2500	0.0247^{NS}	0.8563	
Harvest index	-0.0593^{NS}	-0.0486^{NS}	0.0096^{NS}	-0.2172^{NS}	-0.1672^{NS}	0.0561^{NS}	-0.2297^{NS}	-0.2485^{NS}	0.4512
	-0.1599^{NS}	-0.0556^{NS}	0.0003^{NS}	-0.0309^{NS}	-0.0302^{NS}	-0.3278	-0.0909^{NS}	-0.1538^{NS}	0.3508

of the traits except the number of days to flowering. Plant height showed a significant positive correlation of 0.5780 with plant weight. With the exception of the number of days to flowering, number of days to maturity and harvest index, all the other traits had significant positive correlations with plant weight. Seed yield also had significant positive correlations with number of leaves on the main stem, number of leaves on the main branches, leaf length, leaf width, plant weight and harvest index.

Table 16 shows that in population 1011, high correlations were obtained between plant weight and seed yield (0.8317), leaf length and number of leaves on the main branches (0.7242) and leaf length and leaf width (0.6571). Plant height showed significant positive correlations for the S1 populations with all traits except the number of days to flowering, and the number of days to maturity. All the correlations with plant weight were strong and positive except its correlation with the number of days to flowering, the number of days to maturity and plant height. Seed yield also had significant positive correlations with all traits except the number of days to flowering and the number of days to maturity. Significant negative correlations were obtained between harvest index and plant weight, plant height, number of days to maturity and number of days to flowering. All the correlation between

Table 16. Phenotypic correlations for 1011

Top = original population (1986) n = 20
Bottom S1 family data, n = 120

	No. of days to flowering	No. of leaves on the main stem	No. of leaves on main branches	Leaf length	Leaf width	No. of days to maturity	Plant height	Plant weight	Seed yield
Number of days to flowering									
Number of leaves on	-0.0337^{NS}								
main stem	0.0627^{NS}								
Number of leaves	-0.0062^{NS}	0.3702^{NS}							
on main branches	-0.1179^{NS}	0.3403							
Leaf	-0.3517^{NS}	0.1345^{NS}	0.4345						
length	-0.0647^{NS}	0.4126	0.7242						
Leaf	-0.1224^{NS}	0.6069	0.5185	0.6342					
width	-0.0233^{NS}	0.3791	0.5752	0.6571					
Days to	0.2731^{NS}	0.1736^{NS}	0.0545^{NS}	0.1781^{NS}	0.0293^{NS}				
maturity	0.5142	0.0960^{NS}	-0.0712^{NS}	-0.0177^{NS}	0.1731^{NS}				
Plant	0.1519^{NS}	0.3764^{NS}	0.2877^{NS}	-0.0087^{NS}	0.1506^{NS}	0.5524			
height	0.0302^{NS}	0.4845	0.3408	0.5681	0.5817	0.0988^{NS}			
Plant	-0.0633^{NS}	0.4582	0.5518	0.4201	0.4212	0.5483	0.2727^{NS}		
weight	0.0188^{NS}	0.4649	0.8316	0.7738	0.6368	0.0950^{NS}	0.4752		
Seed	-0.3657^{NS}	0.4893	0.5368	0.4836	0.3791	-0.3713^{NS}	0.3167^{NS}	0.8317	
yield	-0.1495^{NS}	0.4929	0.7778	0.7112	0.5596	0.1072^{NS}	0.4189	0.8219	
Harvest	-0.0841^{NS}	-0.379^{NS}	-0.2748^{NS}	0.0482^{NS}	-0.1608^{NS}	0.4870	0.0859^{NS}	-0.5876	0.4350
index	-0.3758	-0.0093^{NS}	-0.0548^{NS}	-0.0718^{NS}	-0.1819	-0.3639	-0.1995	-0.2544	0.2875

the number of days to flowering and all the other traits in this population were low except those with the number of days to maturity and harvest index.

The phenotypic correlations for population 982 in Table 17 show that the highest correlation of 0.9748 was obtained between the number of leaves on the main branches and the number of leaves on the main stem. A high correlation of 0.9002 was also noted between leaf width and leaf length. Other high correlations were noted between leaf length and number of leaves (both on the main stem and on the main branches) for the S1 populations and between leaf width and number of leaves on the main branches. Plant height and plant weight gave significant positive correlations with all traits apart from the number of days to flowering, the number of days to maturing and harvest index for both original and S1 populations. Seed yield also showed positive correlations with all traits except number of days to flowering and number of days to maturity for both original and S1 populations. In this population harvest index was the trait that gave the highest correlation with seed yield. Harvest index had weak correlations with the rest of the traits except number of days to flowering. Apart from the number of days to maturity all the traits had negative correlation to the number of

Table 17. Phenotypic correlations for 982

Top = original population (1986), n = 20
Bottom S1 family data, n = 120

	No. of days to flowering	No. of leaves on main stem	No. of leaves on main branch	Leaf length	Leaf width	No. of days to maturity	Plant height	Plant weight	Seed yield
Number of days to flowering									
Number of leaves on main stem	0.0037^{NS}								
	0.0935^{NS}								
Number of leaves on main branches	0.0531^{NS}	0.9748							
	-0.2345	0.5778							
Leaf length	-0.4636	0.3180^{NS}	0.3236^{NS}						
	-0.1828	0.5066	0.6374						
Leaf width	-0.5917	0.2495^{NS}	0.2462^{NS}	0.9002					
	-0.0483^{NS}	0.4721	0.4721	0.7604					
Days to maturity	0.5234	0.1324^{NS}	0.1090^{NS}	0.1571^{NS}	-0.0428^{NS}				
	0.4362	0.1059^{NS}	-0.1103^{NS}	-0.0833^{NS}	-0.0380^{NS}				
Plant height	-0.4332	0.2614^{NS}	0.2627^{NS}	0.5907	0.7355	-0.0300^{NS}			
	-0.3667	0.4623	0.5685	0.6811	0.4824	-0.3080			
Plant weight	-0.1922^{NS}	0.2024^{NS}	0.1657^{NS}	0.6131	0.5097	0.3673^{NS}	0.04655		
	-0.0751^{NS}	0.4464	0.5524	0.6016	0.5180	0.0678^{NS}	0.4987		
Seed yield	-0.3554^{NS}	0.2243^{NS}	0.2155^{NS}	0.6357	0.6100	-0.2737^{NS}	0.2543^{NS}	0.5072	
	-0.1039^{NS}	0.3240	0.4517	0.4327	0.4354	-0.0838^{NS}	0.4070	0.6443	
Harvest index	-0.4235	0.1220^{NS}	-0.1131^{NS}	0.2768^{NS}	0.3494^{NS}	-0.6428	0.0300^{NS}	0.0075^{NS}	0.7816
	0.0010^{NS}	-0.0284^{NS}	0.0349^{NS}	0.0041^{NS}	-0.0801^{NS}	-0.0357^{NS}	-0.0478^{NS}	-0.1628^{NS}	0.5402

days to flowering.

In population 1113A high correlations were obtained between leaf length and number of leaves on the main branches (0.8416), leaf length and leaf width (0.8263) and between number of leaves on the main stem and number of leaves on the main branches (Table 18). Plant height had strong associations with all traits except number of days to flowering, number of days to maturity and harvest index. Plant weight also showed positive correlations with all traits except harvest index and number of leaves on the main stem for the original population. The number of days to flowering correlated weakely to all traits except the number of days to maturity. Harvest index showed significant negative correlations in both original and S1 populations with all traits except the number of days to flowering, number of leaves on the main stem, plant height and seed yield. In this population a high correlation of 0.7056 was obtained between plant weight and the number of days to maturity. The number of days to maturity also showed a significant positive correlation of 0.4850 with the number of days to flowering and a significant negative corrrelation with harvest index. Plant weight gave the highest correlation of 0.7519 with seed yield in this population. All the other traits gave positive correlations with seed yield except the number of days to

Table 18. Phenotypic correlations for 1113A:

Top = original population (1986) n = 20
Bottom = S1 family data, n = 120

	No. of days to flowering	No. of leaves on main stem	No. of leaves on main branch	Leaf length	Leaf width	No. of days to maturity	Plant height	Plant weight	Seed yield
Number of days to flowering									
Number of leaves	0.3501^{NS}								
on main stem	0.2315								
Number of leaves	-0.1520^{NS}	0.7749							
on main branches	-0.0741^{NS}	0.4596							
Leaf length	-0.0146^{NS}	0.1209^{NS}	0.8416						
	0.0503^{NS}	0.3077	0.6309						
Leaf	0.1281^{NS}	0.2755^{NS}	0.4457	0.8263					
width	0.0430^{NS}	0.3078	0.4673	0.7714					
Days to	0.4850	0.0829^{NS}	-0.1992^{NS}	-0.1072^{NS}	0.0820^{NS}				
maturity	0.4637	0.0776^{NS}	-0.0418^{NS}	0.1494^{NS}	0.0886^{NS}				
Plant	0.0260^{NS}	0.4234	0.4374	0.5235	0.5996	-0.0267^{NS}			
height	-0.0023^{NS}	-0.3852	0.5429	0.5233	0.4727	0.0095^{NS}			
Plant	0.2991^{NS}	-0.0756^{NS}	0.3840	0.2727^{NS}	0.2357^{NS}	0.7056	0.1229		
weight	0.0962^{NS}	0.3002	0.5872	0.7251	0.5452	0.0808^{NS}	0.4718		
Seed	0.1692^{NS}	0.0670^{NS}	0.3497^{NS}	0.4366	0.2225^{NS}	-0.4856	0.2687^{NS}	0.4086	
yield	0.0082^{NS}	0.1987	0.4999	0.6634	0.4783	-0.1131^{NS}	0.3869	0.7519	
Harvest	-0.2673^{NS}	-0.1812^{NS}	-0.1881^{NS}	0.0660^{NS}	-0.0437^{NS}	-0.4508	0.0026^{NS}	-0.3762	0.4482
index	-0.1059^{NS}	-0.1739^{NS}	-0.2221	-0.2624	-0.2112	-0.2925	-0.1427^{NS}	-0.4497	0.1595^{NS}

maturity.

The path-effects coefficients in Table 19 to 24 indicate that high direct effects of plant weight and harvest index on seed yield were common to all the populations. Plant weight gave the highest positive direct effect on seed yield in population Jumla followed by harvest index (Table 19). The number of days to flowering, the number of leaves on the main branches, the number of leaves on the main stem, leaf length, leaf width and plant height gave a substantial positive indirect effect on seed yield through plant weight. Most of the other path-effects in this population were low.

In Table 20 plant weight is indicated as having the highest direct effect on seed yield followed by harvest index in population 1023. Plant height, leaf length, number of leaves on the main branches, and number of days to flowering had substantial positive indirect effects on seed yield through plant weight. Most of the other path-coefficients in this population are small.

Plant weight also has the highest positive direct effect on seed yield, followed by harvest index in population 434 (Table 21). The number of leaves on the main stem, the number of leaves on the main branches, leaf length, and leaf width gave a high positive indirect

Table 19. Direct and indirect path-effects of predictor variables on seed yield using Jumla S1 populations

CAUSE AND EFFECT	DIRECT	INDIRECT VIA									
		No. of days to flowering	No. of leaves on the main stem	No. of leaves on the main branch	Leaf length	Leaf width	No.of days to maturity	Plant height	Plant weight	Harvest index	Total
Number of days to flowering	0.0047	-	-0.0054	-0.0083	0.0404	-0.0380	0.0045	-0.0166	0.4087	-0.0007	0.4287
Number of the leaves on main stem	-0.0168	0.0144	-	-0.0104	0.0387	-0.0346	-0.0002	-0.0261	0.3992	0.0643	0.4286
Number of leaves on the main branches	-0.0353	0.0106	-0.0049	-	0.0344	-0.0350	-0.0005	-0.0203	0.4597	-0.059	0.3497
Leaf length	0.0805	0.0225	-0.008	-0.0151	-	-0.0754	-0.0071	-0.035	0.6510	0.0133	0.6267
Leaf width	-0.0866	0.0196	-0.0067	-0.0142	0.0705	-	-0.0145	-0.032	0.6555	0.0041	0.5956
No. of days to maturity	0.1025	0.0019	0.00003	0.0002	-0.0056	0.0122	-	0.0055	-0.0627	-0.0389	0.0151
Plant height	-0.0492	0.0151	-0.0089	-0.0146	0.0573	-0.0565	-0.0116	-	0.5777	0.0051	0.5144
Plant weight	0.9054	0.0202	-0.0074	-0.0179	0.0579	-0.0627	-0.0076	-0.0313	-	-0.0576	0.7990
Harvest index	0.5453	-0.0001	-0.0020	0.0038	0.0020	-0.0007	-0.0073	-0.0005	-0.0956	-	0.445

Table 20. Direct and indirect path-effects of predictor variables on seed yield using 1023 S1 populations:

CAUSE AND EFFECT	DIRECT	INDIRECT VIA									
		No. of days to flowe-ring	No. of lea-ves in the main stem	No. of lea-ves on the main bran-ches	Leaf length	Leaf width	No. of days to maturity	Plant height	Plant weight	Harvest index	TOTAL
Number of days to flowering	0.0699	–	0.0188	0.02880	-0.0789	-0.0103	-0.0233	-0.0548	0.3625	0.0886	0.5127
Number of leaves on the main stem	-0.0296	0.0445	–	0.0244	0.060	-0.0099	-0.0037	-0.0616	0.2472	0.0985	0.3698
Number of leaves on the main branches	0.0398	0.0351	-0.0181	–	0.0768	-0.0101	0.0031	-0.0602	0.4613	0.0941	0.6218
Leaf length	0.1256	0.0439	-0.0141	0.0243	–	-0.0115	-0.0146	-0.0653	0.5326	0.0752	0.6961
Leaf width	-0.0232	0.0311	-0.0127	0.0174	0.0623	–	-0.0060	-0.0375	0.1693	0.2664	0.4671
Number of days to maturity	-0.0964	0.0169	-0.0011	-0.0013	0.019	-0.0015	–	-0.0137	0.1893	-0.0213	0.0900
Plant height	-0.0976	0.0392	-0.0187	0.0246	0.0841	-0.0089	-0.0135	–	0.4198	0.0566	0.4856
Plant weight	0.8389	0.0302	-0.0087	0.0219	0.0798	-0.0047	-0.0218	-0.0488	–	-0.1192	0.767
Harvest index	0.5238	0.0118	-0.0056	0.0072	0.0180	-0.0118	0.0039	-0.0105	-0.2160	–	0.320

Table 21. Direct and indirect path-effects of predictors variables on seed yield using 434 S1 populations.

CAUSE AND EFFECT	DIRECT	INDIRECT VIA									
		No. of days to flowe-ring	No. of leaves on the main stem	No. of leaves on the main branches	Leaf length	Leaf width	No. of days to maturity	Plant height	Plant weight	Harvest index	TOTAL
Number of days to flowering	0.0398	-	0.0006	0.0137	-0.0423	0.0018	-0.0264	-0.0011	-0.2759	-0.0767	-0.3665
Number of leaves on the main stem	-0.0027	-0.0086	-	-0.0249	0.0602	-0.0018	0.0078	0.0012	0.5258	-0.0267	0.5304
Number of leaves on the main branches	-0.0374	-0.0146	-0.0018	-	-0.0737	-0.0024	0.0087	0.0009	0.7033	0.0001	0.7305
Leaf length	0.1029	-0.0164	-0.0016	-0.0268	-	-0.0036	-0.0075	0.0005	0.7252	-0.0148	0.7579
Leaf width	-0.0062	-0.0109	-0.0007	-0.0135	0.0559	-	0.0038	0.0004	0.3579	-0.0145	0.3722
Number of days to maturity	-0.0535	0.0197	0.0004	0.0061	0.0144	0.0005	-	-0.0002	-0.0801	-0.1573	-0.245
Plant height	0.0097	-0.0045	-0.0003	-0.0032	0.0050	-0.0027	0.0011	-	0.0609	-0.0436	0.022
Plant weight	0.8867	-0.0124	-0.0016	-0.0297	0.0841	-0.0027	0.0048	0.0007	-	0.0738	0.850
Harvest index	0.4797	-0.0064	0.0001	-0.0001	-0.0032	0.0002	0.0175	-0.0009	-0.1364	-	0.350

Table 22. Direct and indirect path-effects of predictor variables on seed yield using 1011 S1 population

CAUSE AND EFFECT	DIRECT	INDIRECT VIA									
		Number of days to flowering	No. of leaves on the main stem	No. of leaves on the main branches	Leaf length	Leaf width	No. of days to maturity	Plant height	Plant weight	Harvest index	TOTAL
Number of days to flowering	0.0584	-	0.0025	-0.007	0.0038	-0.001	-0.0211	0.0023	0.0162	-0.202	0.1479
Number of leaves on the main stem	0.0405	0.0036	-	0.021	-0.0246	0.0227	-0.0039	0.0373	0.4007	-0.005	0.4923
Number of leaves on the main branches	0.0631	-0.0068	0.0137	-	-0.043	0.0345	0.0029	0.0262	0.7168	-0.029	0.7784
Leaf length	-0.0597	-0.0037	0.0167	0.0456	-	0.0394	0.0007	0.0438	0.6670	-0.038	0.1118
Leaf width	0.0601	-0.0013	0.0153	0.0362	-0.039	-	-0.0071	0.0448	0.5489	-0.098	0.5599
Number of days to maturity	-0.0412	0.0300	0.0038	-0.004	0.0010	0.0104	-	0.0076	0.0818	-0.196	-0.1066
Plant height	0.0771	0.0017	0.0196	0.0215	-0.0339	0.0349	-0.004	-	0.409	-0.107	0.4189
Plant weight	0.8620	0.001	0.0188	0.052	0.046	0.0382	0.003	0.0366	-	-0.137	0.822
Harvest index	0.5396	-0.021	-0.003	-0.0034	0.0042	-0.0109	0.0149	-0.015	-0.2192	-	0.2880

Table 23. Direct and indirect path-effects of predictor variables on seed yield using 982 S1 populations.

CAUSE AND EFFECT	DIRECT	INDIRECT VIA								
		No. of days to flowering	No. of leaveas on the main stem	No. of leaves on the main branches	Leaf length	Leaf width	No. of days to maturity	Plant height	Plant weight	Harvest index	TOTAL
Number of days to flowering	0.0107	-	-0.0022	0.0010	0.0255	-0.0014	0.0434	-0.0368	-0.0579	0.0007	-0.1038
Number of the leaves on main stem	0.0235	-0.001	-	-0.0022	-0.0707	0.0133	-0.0105	0.0464	0.3443	-0.0189	0.324
Number of leaves on the main branches	-0.0042	-0.0025	0.0136	-	-0.0889	0.0163	0.001	0.0571	0.4261	0.0232	0.4517
Leaf length	-0.1395	-0.0019	0.0120	-0.0027	-	0.0214	0.0083	0.0683	0.4641	0.0027	0.4327
Leaf width	0.0282	-0.0005	0.0111	-0.0034	-0.1061	-	0.0038	0.0484	0.3996	0.0533	0.6354
Number of days to maturity	-0.0996	0.0047	0.0025	0.0005	0.0116	-0.0011	-	-0.0309	0.0523	-0.0238	-0.0838
Plant height	0.1003	-0.0039	0.0109	-0.0024	-0.095	0.0136	0.0307	-	0.3847	-0.0318	0.4071
Plant weight	0.7714	-0.0008	0.0105	-0.0023	-0.0839	0.0146	-0.0068	0.0500	-	-0.1084	0.6443
Harvest index	0.6661	0.00001	-0.0007	-0.0001	-0.0006	0.0023	0.0036	-0.0048	-0.1256	-	0.5402

Table 24. Direct and indirect path-effects of predictor variables on seed yield using 1113A S1 populations

CAUSE AND EFFECT	DIRECT	INDIRECT VIA									
		No. of days to flowering	No. of leaves on the main stem	No. of leaves on the main branches	Leaf length	Leaf width	No. of days to maturity	Plant height	Plant weight	Harvest index	TOTAL
Number of days to flowering	-0.007	-	-0.0007	-0.0006	0.0111	-0.0015	-0.017	0.0001	0.0872	-0.0635	0.0081
Number of leaves on the main stem	-0.0033	-0.0016	-	0.0039	0.0684	-0.010	-0.002	-0.023	0.274	-0.104	0.2024
Number of leaves on the main branches	0.0085	0.0005	-0.0051	-	0.1403	-0.016	0.0015	-0.032	0.5328	-0.1332	0.4973
Leaf length	0.2225	-0.003	-0.001	0.0053	-	-0.027	-0.005	-0.031	0.6585	-0.1573	0.6620
Leaf width	-0.0354	-0.003	-0.001	0.0039	0.1716	-	-0.003	-0.028	0.4947	-0.1266	0.4732
Number of days to maturity	-0.0367	-0.003	-0.0002	-0.0003	0.0332	-0.0031	-	-0.005	0.0733	-0.1754	0.1121
Plant height	-0.0602	0.00001	-0.0012	0.0046	0.1164	-0.0167	-0.0003	-	0.428	-0.0855	0.385
Plant weight	0.9074	0.0006	-0.0009	0.0049	0.1614	-0.0193	-0.0029	-0.0284	-	-0.2697	0.753
Harvest index	0.5998	0.0007	0.0005	-0.001	-0.058	0.0074	0.0107	-0.0085	-0.408	-	0.1436

effect on seed yield through plant weight. Leaf length had the highest positive indirect effect on seed yield through plant weight. All the other path effects in this population are small.

Path-coefficients in population 1011 (Table 22) show that plant weight gave the highest positive direct path-effect on seed yield followed by harvest index. Plant height, leaf width, number of leaves on the main stem, and number of leaves on the main branches gave high positive indirect effects on seed yield through plant weight.

Path-coefficients for population 982 given in Table 23 also indicate that plant weight had the highest positive direct effect on seed yield. This was followed by harvest index. Leaf length also showed the highest positive indirect effect on plant yield through plant weight. The number of leaves on the main stem, the number of leaves on the main branches, leaf width and plant height also gave substantial positive indirect effects on seed yield through plant weight. Most of the other path-coefficients in this population are low.

In population 1113A, (Table 24), plant weight and harvest index had the highest positive direct effects on seed yield. Leaf length had a high positive indirect effect on seed yield through plant weight. Plant height, the number of leaves on the main branches and leaf width showed a relatively high positive indirect effect on seed yield through plant weight. Harvest index also had a substantial negative indirect effect on seed yield through plant weight. Most of the other path-effects in this population are low.

CHAPTER FIVE

DISCUSSION

5.1 QUANTITATIVE GENETIC VARIATION

It is evident from the variation analysis that the grain amaranth populations studied here are quite variable for the morphological traits. The variations among the populations suggest genetic diversity among the populations. Such genetic variation in plant morphological traits has been described as a powerful physiological tool in breeding programmes as it is associated with heterosis (Moll et al., 1962; Wilson, 1981). The six populations Jumla, 1023, 434, 1011, 982 and 1113A were quite distinct as indicated by the analysis in Tables 7 and 8. The variation analysis within these six populations indicates that these populations vary in the level of heterogeneity. Vaidya and Jain (unpublished) explained that in grain amaranths the variation among families was largely heritable and that it was the family differences that lead to differences among landrace populations. Vaidya and Jain (unpublished) also suggested that high genetic variability in grain amaranths could be accounted for by several selective forces which include edaphic, climatic and man-made factors and also high outcrossing rates. These conclusions were based on variation analysis of Indian amaranths. Hauptli and Jain (1984) also noted that populations of grain amaranths were distinct and varied in their levels of polymorphism for morphological traits. Ayiecho (1985) concluded that the variation in landrace populations of grain amaranths was caused by high levels of additive and additive x additive variation components for most yield related traits. The differences in grain amaranths observed in this study could be due to populations having come from different areas and variability within populations may be due to natural outcrossing and lack of previous selection. Amaranth populations are known to have substantial amounts of outcrossing (Simmonds, 1979 and Jain *et al.*, 1982).

The presence of genetic variability in the six populations was confirmed by the fairly large genotypic variance and heritability estimates. Seed yield had a heritability estimate of 0.54 in population 1011 and also a high selection response estimate. Similarly plant height had high heritability estimates in all populations except 434 and 1113A. In addition to this, the number of leaves on the main branches and leaf length showed high heritabilities in population Jumla, 1011 and 982. These traits which were also positively correlated to seed yield are likely to be of positive value as an aid to selection. The plant breeder is interested in such traits that are highly correlated with seed yield and have high heritability values. Simple mass selection technique is known to be inefficient for traits with low heritability (Hallauer and Sears, 1969; Falconer, 1981). On the other hand if the traits under selection have high heritability values, mass selection leads to substantial progress (Falconer, 1981). This has been demonstrated for oats by Lonquist (1967) and Chandhanamutta and Frey (1973) and in wheatgrass by Knowles (1977). Response to mass selection for traits with substantial levels of heritability has also been demonstrated in grain amaranths by Ayiecho (1985) for yield related traits. Alternatively where the trait of importance has low heritability as in case of seed yield in populations 1023, 434 and 982, indirect selection may be applied by selecting for traits that have high heritability and are strongly associated with the trait of interest. In this study plant height in population 1023 and population 982 had high heritability estimates and also a strong association with seed yield and could therefore be used as a selection criteria for seed yield.

Although the experiments for analysing the variation within the six populations were conducted in one environment and in one season only, the family means could be used as estimates of genotypic means. Selection can also therefore be based on family means for the traits with low heritability such as plant weight in Jumla and 1113A, seed yield in 1023, 434 and 982, and harvest index in 1023, 434 and 982. Falconer (1981) has indicated the usefulness of family selection for traits with low heritability estimates. However, Moll and Robinson (1967) suggested that in terms of gain per generation of mass selection, the response may be greater than response to family selection even for traits with low heritability. The differences in the means of the original population and that of the S1 families are likely to be due to drift as a result of small sample size.

5.2 CORRELATIONS AND PATH COEFFICIENTS

Correlated response depends on the degree of genetic correlation between the trait of interest and the one used as the selection criterion (Falconer, 1981). Therefore, one widely utilised advantage of correlations among traits is the enhancement of the rate of selection in the primary traits (Moll and Stuber, 1974). In this study grain yield had a low heritability in population 1023 and 982 but had significant correlations to plant height according to S1 analysis. Plant height had high heritability estimates in these populations. Seed yield is therefore likely to be improved indirectly by selecting for taller plants. Such relationships can also be established among other quantitative traits included in this study such as plant weight and seed yield in 1113A; plant weight and leaf width in Jumla; number of leaves on the main stem and plant weight in 434. The plant size traits, namely, plant height and plant weight were negatively or weakely correlated with harvest index, indicating that in large plants more metabolites were used in vegetative growth than seed formation and seed filling. This relationship was also found in grain amaranths by Hauptli and Jain (1980) and Ayiecho (1985). In the present study the bigger plants also had more and larger leaves as indicated by the positive correlations between the number of leaves and plant size traits and between leaf length and plant size traits. The increase in the vegetative parts on the plants resulted in higher seed yields because of an increased sink: source ratio. Such sink-source relationships have also been reported by Yap and Harvey (1972) in barley, Thurling (1974) in rapeseed and by Dornhoff and Shibbles (1970) in soybeans. The patterns of relationships in this study suggest that selection for larger plants with increased leaf size and leaf number may lead to higher grain yields in grain amaranths. However weak or negative correlations between harvest index and plant size traits, leaf length and leaf width suggests the large plants are less efficient in seed production than the smaller plants. Path-effect coefficients also indicate that plant height has a high positive indirect effects on plant yield through plant weight in all populations except population 434. Plant height was also noted by Hauptli and Jain (1984) and by Ayiecho (1985) as one of the best predictors of yield in grain amaranths.. In a heterogenous population tall plants have an advantage over shorter ones and micro-environmental differences may favour fast growing genotypes (Graham and Lessman, 1966; Hamblin and Donald, 1974; Wilcox and Schapaguh, 1980). A positive genetic relationship has also been found between height and grain yields in oats (Rosielle and Frey, 1975) and in Sorghum bicolor (Campbell et al., 1975).

Leaf number and leaf size scored at flowering may act as an indicator of growth during the early stages. Many small leaves have been found to be more favourable to plant growth than few large leaves. Tsunoda (1959) found that better adapted soybean varieties had small leaves. Donald (1968) found that in wheat small leaves tend to be erect and large leaves tend to be droopy. And Hayashi and Ito (1962), and Gardener (1966) found that a steep leaf angle is associated with a faster growth rate. However in the present study leaf size and leaf number are positively related and also relate positively to seed yield. A breeding programme leading to a proportionally larger increase in leaf number in relation to leaf size is therefore more likely to lead to higher seed yields. The path-coefficients indicate that though leaf length and leaf width both show a high positive indirect effect on seed yield through plant weight, leaf length has a proportionally higher positive effect than leaf width in all populations except Jumla. Larger leaves also seem to favour dry matter productivity. The large positive correlations between leaf length and leaf width on seed yield are therefore attributed to their effect through plant weight. However breeding for wider leaves may not be favourable as this may cause leaf drooping which in turn causes a horizontal leaf position. As mentioned above erect leaves are associated with higher growth rates. Cooper et al (1971), explained that more erect leaf arrangement allows the incoming light to be distributed over a large leaf area leading to a more efficient light conversion and higher crop photosynthetic rate. This may explain why breeding for longer leaves may be preferred to breeding for wider leaves. Gardener (1966) found that in barley high yielders had narrow and upright leaves while low yielding barleys had wide and drooping leaves. Tanner _et al_ (1966) used leaf width and leaf angle to select for high yielding wheat, barley and oat varieties. And Rhodes (1972, 1973, and 1975) obtained upto 30 percent yield increase after 4 generations of selection for long leaves in ryegrass. In this study leaf length had high heritability estimates in all populations except 1023 and 1113A. This may make leaf length a favourable trait for improving seed yield.

Harvest index is another trait which can be used as a selection criterion. It correlated positively to seed yield in all populations except the S1 populations of 1113A. Harvest index also had a high direct effect on seed yield. The plants which had higher dry matter yields had higher seed yields and had a lower harvest index. According to Donald and Hamblin (1976) and Mohamed _et al_ (1976) an increase in harvest index is accompanied by a higher relative increase in seed yields than in dry matter. Therefore selection for increased harvest index is likely to lead to increased seed production efficiency at the expense of dry matter yields. By using partial regression coefficients Thurling (1974) found that increase in seed yield per unit area in rapeseed was almost entirely accounted for by total dry matter yields and harvest index. Harvest index has also been suggested as a valuable selection criteria for the improvement of cereal yields (Donald, 1962; Syme, 1972; Nass, 1973). Much of the yield increase made in cereals to date can be attributed to increased harvest index (Van Dobben, 1962; Vogel et al., 1963; Cannel, 1968). Ayiecho (1985) found that in grain amaranths harvest index was an important yield predictor and that selection for harvest index led to substantial response in grain yields. The negative association between harvest index and plant size traits also indicates that harvest index can be improved by reducing plant size.

Plants that take longer time to flower had a longer vegetative phase and higher seed yields. However they are less efficient in seed production than the earlier flowering plants as suggested by the correlations between harvest index and days to flowering and days to maturity. Notable differences in correlation coefficients in the S1 and original population were also common in the six populations. This could be attributed to differences in sample size (n = 20 in the original population; n = 120 in the S1 population) and the seasonal differences.

5.3 CONCLUSIONS AND SUGGESTIONS

In this study, the results show that there was significant variation among the amaranth populations studied. It also suggests that significant variability exists in the six populations for the various traits studied.

Grain yield was positively correlated to all the traits except number of days to maturity and the number of days to flowering in populations 434, 1011, 982 and 1113A. The broad sense heritability estimates show that the traits that were positively related to seed yield were also highly heritable and can be used as an aid to selection. The relationships of plant size traits, namely, plant height and plant weight, with seed yield and harvest index indicate that yield can be increased by breeding for plants that have a higher seed production efficiency.

Leaf number and leaf size traits (leaf length and leaf width) were also positively correlated to seed yield and had substantial indirect influence on seed yield. These traits could therefore act as selection criteria in a breeding programme.

The path-coefficients also indicate that plant weight and harvest index have a high direct effect on seed yield. The results of this study therefore agree with the findings of Hauptli and Jain (1984) where leaf length was shown to have an effect on seed yield and Ayiecho (1985) who showed that plant weight, plant height and harvest index were good yield predictors in grain amaranths.

The total plant dry matter productivity as measured by the total plant dry weight depends on growth at various stages of development. An understanding of morphology and physiology of amaranth plant growth would be very useful in planning selection strategies. Since plant weight had significant variability within and among the populations it may be useful to find out the stages at which it influences the amaranth seed yields most. For example Thurling (1974) found that in rapeseed growth before anthesis had a greater influence on yield than post anthesis growth. The number of days to flowering and the number of days to maturity may act as indicators of growth. Hauptli and Jain (1984) found that the number of days to flowering had an influence on plant weight and seed yield. Therefore growth analysis studies may be suggested here. Such studies may help in giving an insight into the influence of various growth parameters on seed yield. This study may help in designing proper breeding programmes.

The present study suggests the influence of sample size and environmental factors on the results obtained. This calls for larger sample sizes in further studies. Therefore larger number of families per population and more plants per family be used if similar studies have to be undertaken. The studies also need to be replicated over years and in locations where grain amaranths have potential as a crop. For more detailed information on the genetics of the yield related traits, more elaborate mating designs than the one used in this study also need to be considered.

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