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SHORT COMMUNICATION

SELECTION CRITERIA FOR YIELD OF LEAFY AMARANTHUS

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ABSTRACT

Populations of amaranthus (*Amaranthus* sp.) obtained from a physical-genetic admixture were studied to identify the best performing cultivars and determine the most important yield components. Most of the characters showed significant differences. Entries 15 and 29 performed best with entry 29 having the highest total green leaf yield. Significant correlations (P<0.01) were found between days to germination, to first harvest, days to second and third harvest, number of harvests, second and third harvest yield, with total yield. Path analysis revealed that second harvest yield makes the largest direct effect and had the highest significant (P<0.01) correlation with total yield. Number of harvests made the largest indirect effect on yield. It is clear that improvement of yield of leafy amaranthus can be achieved through increasing the frequency of harvests and yield in each harvest. Principal component analysis came to a similar conclusion.

Key Words: **Amaranth, path analysis, principal component analysis, yield components**

RÉSUMÉ

Les populations d'amaranthes (*Amaranthus* sp) obtenues d'un mélange génético-physique étaient étudiées en vue d'identifier les cultivars les plus performants et de déterminer les composants de rendement les plus importants. La plus part de caractères, à l'exception du nombre de jours à la germination, ont montré des différences significatives. Les entrées 15 et 29 ont eu une meilleure performance tandis que l'entrée 29 a manifesté un rendement total plus élevé en feuilles vertes. Des corrélations significatives (P<0.01) étaient trouvées entre le nombre de jours à la germination, le nombre de jours à la première récolte, à la deuxième et troisième récoltes, le nombre de récoltes, le rendement à la deuxième et troisième récoltes avec le rendement total. L'analyse de rendements a montré que le rendement à la deuxième récolte avait des effets directs plus grands et une plus grande corrélation significative (P<0.01) avec le rendement total; ce qui montre son importance dans la détermination du rendement. Le nombre de récoltes, par contre, avait des effets indirects plus larges sur le rendement. Les résultats ont indiqué que l'amélioration de rendement de l'amaranthe à feuilles peut être obtenue en augmentant la fréquence de récoltes et de rendement à chaque récolte. L'analyse des composants principaux a abouti à une conclusion similaire.

Mots Clés: **Amaranthe, analyse de rendements, analyse de principaux composants de rendement, composants de rendement**

INTRODUCTION

Uganda has many species of Amaranthus and may be a centre of origin of some of the amaranthus species, if the wild *Amaranthus spinous* is used as an indicator. Majority of these species, however, appear to be introductions made a long time ago, without existing evidence of when, where and by whom they were introduced. More recently, grain amaranthus cultivars (*A. hypochondriacus, A. cruentus* and *A. caudatus*) were introduced in the country (C. Ayo, pers. comm.). The grain and leafy amaranthus cultivars were genetically mixed up prior to the commencement of the current breeding programme since they intercross freely (Rubaihayo, 1994).

Amaranthus physical-genetic mixture base population was used to select 52 distinct populations which were evaluated for growth and yield in the second season of 1992. Results from these populations showed that early germination resulted in early first harvest and tended to reduce number of harvests and total yield as well as yield at each harvest. It was also observed that as the number of days to germination increased, days to flowering, days to first and second harvest and the difference in the number of days from first to second harvest tended to increase (Rubaihayo, 1994). Based on the above results, a second trial, using the same populations, was conducted at Kawanda during the first season of 1993 to (i) identify the best performing cultivars which could then be tested at other locations in Uganda for future recommendation for release to farmers; and (ii) study the associations among different characters and determine the characters that account for majority of the variation which could be used in selection.

MATERIALS AND METHODS

Fifty two distinct populations of amaranthus cultivars developed between October, 1990 and July, 1992 from a physical-genetic admixture in the Amaranthus breeding programme based at Kawanda Agricultural Research Institute, Uganda (N 0.25' lat., E 32^0 32' long., 1196 m asl), plus four locally collected amaranthus landraces, i.e. *A. dubius, A. graecizans, A. lividus* and *A. hybridus* sub sp. *incurvatus*, were planted in the first season (March - June) 1993 trial.

A randomised complete block design with three replications were used. One teaspoon-ful of seeds was mixed with ten teaspoon-fuls of dry sand to avoid crowding of seedlings. The seed-sand mixture was broadcast in shallow grooves along the rows. The plants were later thinned to a spacing of 10 cm between plants within the two central rows.

Data were collected from two central rows, except for the 50% flowering, which was collected from the two guard rows. Parameters measured included days to germination; 50% flowering; first, second and third harvests; and difference in number of days from first to second harvest. Fresh yield was recorded for each cutting and the number of cuttings per plot recorded. The first harvest was done by cutting the main stem at plant height of 30 cm. A plant stump, 15 cm high, was left to produce new branches. Cutting was, in all cases, done half way up the internode so that new branches could develop from the nodes below the cut. Harvesting continued in all the plots, whenever the new branches were 15 cm above the previous cut. Harvesting stopped in individual plots, whenever new branches flowered before attaining 15 cm length. Total leaf yield per plot was computed.

Analysis of variance was carried out and the means separated by the least significant difference method. Correlation analysis was also done. Path coefficient analysis measures the direct influence of one variable upon another and permits the separation of the correlation coefficient into components of direct and indirect effects (Dewey and Lu, 1959). Path coefficient analysis was carried out using the method suggested by McGiffen *et al.* (1994), whereby multiple regression is carried out and the standardised partial regression coefficients from the analysis used as the path coefficients. The following characters were used for path coefficient analysis: days to 50% flowering, days to first cutting, days to second cutting, days to third cutting, number of harvests, first cutting yield, second cutting yield, third cutting yield and total yield. Principal component analysis was carried out basing on the correlation matrix. These computations were carried out using MSTATC statistical package (Anonymous, 1990).

RESULTS AND DISCUSSION

Mean separation of growth and yield indicated that many cultivars were significantly different ($P \leq 0.05$) in the characters studied except for number of days to germination. As for overall yield, entry 29 yielded highest (4.3 kg), closely followed by 15 (4.2 kg) (Table 1). Rubaihayo (1994) had reported that entries 15, 2 and 10 had poor performance during the previous season but performed very well in this season.

Significant correlations ($P \leq 0.01$) were found between days to germination, days to first, second and third harvest, number of harvests, second and third harvest yield, with total yield (Table 2). Days to 50% flowering was strongly correlated with days to first harvest and second harvest, but negatively correlated with third harvest, number of harvests and third harvested yield probably due to shortage of moisture in the later part of the growing season. Days to first harvest were correlated negatively with number of harvests, second, third and total yield, thus collaborating with the evidence of the influence of moisture stress experienced in the later part of the growing season to yield.

Data of path coefficient analysis are presented in Table 3. Days to first harvest had a direct negative effect on total yield and it also registered large indirect negative effects through number of harvests, second and third harvest yield, resulting in a negative correlation with yield. Days to second harvest had a slightly direct positive effect but this was offset by the large negative indirect effect via number of harvests, second and third harvest yields, resulting in a negative correlation with yield. Days to third harvest had a direct negative effect on yield but due to the high and positive indirect effect of number of harvests and third harvest yield, the total correlation with yield was positive. The direct positive effect of number of harvests coupled with the indirect effect through third harvest resulted in a highly significant ($P \leq 0.01$) correlation. This was also true for the direct effect of yield of the second harvest. This analysis suggests that production improvement programmes could be directed towards more harvests, increasing yield of each harvest from the second harvest, and reduction in number of days between harvests.

Since these variables were highly correlated positively or negatively (Manly, 1986), the data were subjected to principal component (PC) analysis. The results of the principal component analysis showing the relative contribution of the individual growth and yield variables to variability among the entries are presented in Table 4 for the first season of 1993. The first 4 of the 10 PCs had values greater than 1.0 and were, therefore, retained. Together, they accounted for about 80.92% of the variance. PC1 had high loadings for the number of harvests, days to third harvesting, third harvest yield and days to second harvest, and accounted for 40.58% of the total variation. This PC had time and yield characters influencing total green leaf yield at various stages. Similarly, PC2 had high loadings for the second harvest and in number of days from first and second harvesting and accounted for 18% of the variation. The third PC was highly loaded on days to 50% flowering and accounted for 11.91%. The fourth PC, which accounted for 10.15%, had a high loading for first harvest yield.

The data of the second season of 1992 were also subjected to this analysis for purposes of comparison (Table 5). Four PCs which accounted for 87.56% of the total variation were retained. The first PC was highly loaded for days to first harvest, days to germination and second harvest, and accounted for 42.31% suggesting the importance of growth period to total yield of the green leaf. PC2, which accounted for 19.8%, had high loading for days to 50% flowering and difference in number of days between first and second harvesting, again indicating the importance of length of growth period to green leaf yield. The third and fourth PCs had high loading only on one variable each, number of harvests and first harvest yield, accounting for 16.32 and 9.13%, respectively. This indicated the influence of yield at each harvesting stage to total yield. Comparing second season of 1992 and first season of 1993, PCs 1 and 3 for the 1992 season had high loadings

TABLE 1. Performance of amaranthus cultivars at Kawanda, Uganda

	Number of days to						Yield at harvest			
Entry number	Germi nation	50% FL	1st HV	2nd HV	3rd HV	No. of HVs	1 (kg)	2 (kg)	3 (kg)	Total yield (kg)
1	2	33.7	30.3	48.3	42.7	2.7	0.5	1.3	0.5	2.3
2	2	33.7	27.3	43.7	66.3	3.0	1.0	1.3	1.3	3.5
3	2	45.3	33.0	48.7	65.3	3.0	0.9	1.3	0.8	3.1
4	2	43.0	32.7	46.7	64.0	3.0	0.9	1.4	0.9	3.2
5	2	45.3	33.7	51.7	22.7	2.3	0.7	1.3	0.2	2.2
6	2	33.0	28.3	46.3	42.3	2.7	0.8	1.5	0.7	3.1
7	2	33.7	31.0	46.7	44.3	2.7	0.8	1.4	0.8	3.0
8	2	36.3	29.7	46.3	66.0	3.0	0.7	1.2	1.1	2.9
9	2	45.3	33.3	47.0	42.3	2.7	1.1	1.7	0.5	3.3
10	2	43.0	34.7	54.3	-	2.3	1.4	2.1	0.2	4.1
11	2	44.0	38.7	54.3	20.7	2.3	1.7	0.8	0.5	3.1
12	2	48.7	42.0	64.0	21.7	2.3	0.7	0.9	0.3	2.1
13	3	33.0	27.3	46.3	43.3	2.7	0.8	1.7	0.7	3.2
14	2	34.3	27.3	46.3	67.0	3.0	0.8	1.6	1.0	3.3
15	2	43.0	28.3	51.3	65.3	3.0	0.9	2.4	0.9	4.2
16	2	36.3	28.0	42.3	62.3	3.0	0.7	1.3	1.7	3.6
17	2	33.0	29.3	43.7	41.7	2.7	0.9	1.3	0.8	2.6
18	2	33.0	29.3	44.0	63.3	3.0	0.7	1.4	1.3	3.4
19	2	34.3	28.3	42.7	64.3	3.0	1.0	1.5	1.4	3.9
20	2	43.0	29.0	44.3	41.7	2.7	0.8	2.1	0.9	.9
21	2	37.7	28.7	44.0	63.3	3.0	0.6	1.5	1.2	3.4
22	2	33.0	27.7	46.3	44.3	2.7	0.9	1.7	0.6	3.3
23	2	33.7	27.7	52.3	44.3	2.7	0.6	1.6	0.5	2.7
24	2	40.3	30.0	46.3	64.0	3.0	0.7	1.1	1.1	2.9
25	2	37.0	28.3	45.0	61.3	3.0	0.8	1.7	1.3	3.8
26	2	39.0	29.3	48.7	66.0	3.0	1.0	2.1	0.9	3.9
27	2	34.3	28.7	46.3	64.0	3.0	0.7	1.6	0.9	3.2
28	2	47.7	42.0	49.7	68.0	3.0	1.0	0.9	0.9	2.9
29	2	33.7	28.3	46.3	66.0	3.0	0.8	2.4	1.1	4.3
30	2	33.0	27.7	46.7	44.3	2.7	0.8	1.8	0.7	3.3
31	2	41.7	31.7	48.7	67.0	3.0	1.2	1.3	1.1	3.7

TABLE 1. continued

32	3	55.0	38.7	54.3	45.3	2.7	0.8	0.9	0.3	1.9
33	2	33.0	34.7	48.3	21.7	2.3	0.9	0.9	0.3	2.2
34	2	33.0	31.0	46.3	22.7	2.3	0.9	1.3	0.4	2.7
35	2	33.0	30.7	46.3	44.3	2.7	0.7	1.3	0.7	2.6
36	2	33.0	27.7	43.7	41.7	2.7	1.1	1.2	0.9	3.2
37	2	33.0	28.3	44.0	63.3	3.0	0.5	1.3	1.1	2.9
38	2	35.0	30.0	45.3	43.7	2.7	0.8	1.2	0.7	2.7
39	2	43.0	30.0	48.3	64.3	3.0	0.9	2.2	0.9	4.1
40	2	40.3	4.3	48.3	63.3	3.0	1.0	1.1	1.0	3.1
41	3	64.7	39.7	58.0	22.7	2.3	0.7	1.1	0.7	2.1
42	2	39.0	29.0	45.3	67.3	3.0	0.8	1.2	1.3	3.3
43	2	36.3	29.7	48.0	68.0	3.0	0.6	1.2	0.9	2.6
44	2	44.3	31.7	49.7	42.3	2.7	1.0	1.3	0.7	3.0
45	3	37.0	29.0	46.3	64.0	3.0	0.7	1.8	1.0	3.4
46	2	45.3	35.3	54.3	42.3	2.7	0.9	1.2	0.8	2.8
47	2	33.0	27.3	46.7	64.0	3.0	0.9	1.6	1.1	3.6
48	3	88.0	40.0	61.3	-	2.0	1.7	0.9	-	2.6
49	2	38.3	29.3	48.0	-	2.0	0.6	1.3	-	1.9
50	2	45.7	32.0	51.0	46.3	2.7	0.6	1.3	0.6	2.5
51	3	37.7	37.7	52.7	66.0	3.0	0.9	1.1	0.7	2.8
52	2	33.0	28.7	46.3	67.0	3.0	0.7	1.4	1.2	3.3
53	3	35.0	38.0	48.7	43.3	2.7	0.9	0.8	0.6	2.3
54	4	46.3	43.0	52.3	22.7	2.3	0.5	0.8	0.3	1.4
55	3	42.3	36.0	54.3	42.3	2.7	1.0	1.2	0.8	3.0
56	2	47.7	33.7	51.7	45.3	2.7	0.9	1.7	0.5	3.1
LSD (P=0.05)	NS	9.6	6.2	7.8	41.3	0.6	0.6	0.8	0.8	1.6
C.V (%)	29.9	14.9	12.0	9.9	52.7	14.4	41.3	34.1	61.0	32.6

NS - not significant at $P \leq 0.05$; FL = Flowering; HV = harvest

TABLE 2. Correlation coefficients among different characters of amaranthus

	1	2	3	4	5	6	7	8	9	10	11
1	-										
2	.491**	-									
3	.556**	.658**	-								
4	.418**	.731**	.776**	-							
5	-.319*	-.420**	-.457**	-.551**	-						
6	-.203ns	.144ns	-.286*	.379**	-.174ns	-					
7	-.347**	-.442**	-.478**	-.567**	.985**	-.168ns	-				
8	.029ns	.404**	.317*	.324*	-.290*	.041ns	-.246ns	-			
9	-.351**	-.243ns	-.583**	-.280*	.245ns	.424**	.306*	-.005ns	-		
10	-.333*	-.434**	-.534**	-.646**	.840**	-.201ns	.860**	-.211ns	.218ns	-	
11	-.431**	-.257ns	-.559**	-.418**	.512**	.185ns	.590**	.308*	.778**	.612**	-

*,**, ns = significant at 0.05, 0.01 and not significant, respectively.
1 - days to germination; 2 - days to 50% flowering; 3 - days to first harvest; 4 - days to second harvest; 5 - days to third harvest; 6 - difference in number of days from 1st to 2nd harvest; 7 - number of harvests; 8 - first harvest yield; 9 - second harvest yield; 10 - third harvest yield; 11 - total yield

TABLE 3. Break-down of correlations with total yield into direct and indirect components (direct effect bolded)

	Effect through								
Character	1	2	3	4	5	6	7	8	Correlation with total yield
1	**-.019**	-.029	.013	.143	-.182	.174	-.148	-.209	-.257
2	-.013	**-.044**	.014	.156	-.197	.137	-.354	-.258	-.559
3	-.014	-.034	**.018**	.188	-.235	.140	-.170	-.311	-.418
4	.008	.020	-.010	**-.341**	.406	-.125	.149	.405	.512
5	.008	.021	-.010	-.336	**.412**	-.106	.186	.415	.590
6	-.008	-.014	.006	.099	-.101	**.431**	-.003	-.102	.308
7	.005	.026	-.005	-.084	.126	-.002	**.607**	.105	.778
8	.008	.023	-.012	-.286	.354	-.090	.133	**.482**	.612
Residual									.100

1 - days to 50% flowering; 2 - days to first cutting; 3 - days to second cutting; 4 - days to third cutting; 5 - number of harvests; 6 - first harvest yield; 7 - second harvest yield; 8 - third harvest yield

TABLE 4. Latent vectors of principal component analysis based on correlation matrix (1993 season)

Variable	PC1	PC2	PC3	PC4
No. of harvests	**.433**	.160	.270	.193
No. of days to third harvesting	**.424**	.170	.257	.211
Third harvest yield	**.418**	.200	.191	.009
Second harvest yield	.182	**-.429**	.294	.120
First harvest yield	-.089	.113	.602	**-.622**
Days to germination	-.118	.388	-.050	.555
Difference in number of days between 1st and 2nd harvesting	-.125	**-.590**	.260	.312
Days to 50% flowering	-.281	.205	**.473**	.260
Days to first harvest	-.370	.398	.089	-.028
Days to second harvest	**-.414**	-.098	.274	.209
Eigen value	4.0	1.8	1.1	1.0
Percent variance	40.58	18.28	11.91	10.15
Cumulative variance	40.58	58.86	70.77	80.92

Bolded: Significant contributors to the total variations

TABLE 5. Latent vectors of principal component (PC) analysis based on correlation matrix (1992 Season)

Variable	PC1	PC2	PC3	PC4
Days to 1st harvest	**.546**	-.028	-.034	.204
Days to germination	**.502**	.137	.079	-.258
Days to 50% flowering	.323	**.548**	.242	.317
Difference in number of days between 1st and 2nd harvesting	-.046	**.676**	-.427	.142
Number of harvests	-.156	.307	**.774**	-.368
Second harvest yield	**-.377**	.355	-.294	-.408
First harvest yield	-.421	.042	.258	**.685**
Eigen value	2.96	1.38	1.14	.64
Percent variance	42.31	19.80	16.32	9.13
Cumulative variance	42.31	62.11	78.43	87.56

Bolded: Significant contributors to the total variations

on variables which were different from those of 1993 season.

All the PCs had traits related to number of days and/or weight and were, therefore, time and fresh weight components. An interrelationship was implied among traits with high loadings on the same axis (Brown, 1991). Clearly, time to first harvesting and the length of the harvesting period as well as yield of green leaf per harvest, were shown by the PC analysis to be important components of total green leaf yield, collaborating the results of the correlation matrix (Table 2) and path coefficient analysis.

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