Interrelationship, direct and indirect Effect of Different Component Characters on Grain Yield in Amaranth Genotypes (Amaranthus hypochondriacus) under Varied Plant Densities

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Abstract In grain amaranth (Amaranthus hypochondriacus L.) ten genotypes were evaluated for twelve characters under four plant density levels viz., very high (D1), high (D2), normal (D3) and low plant density (D4) levels to study the relationship of different characters on yield and their direct and indirect effects. The study was conducted at College Orchard, Department of Horticulture, Pandit Jawaharlal Nehru College of Agriculture and Research Institute, TNAU, Karaikal during kharif 2007. The results revealed that the correlation and direct effect of component traits on grain yield were, in general, highly influenced by the plant densities both in direction and magnitude. The fresh weight of the inflorescence, length of the primary inflorescence and number of secondary branches per inflorescence recorded strong positive correlation with grain yield as well as strong intercorrelations among themselves, indicating that improvement of grain yield in amaranthus could be achieved by exercising selection for these component traits. The path analysis indicated that fresh weight of the inflorescence, leaf area at 50 per cent flowering, length of the primary inflorescence and number of secondary branches per inflorescence had direct positive effects on grain yield. Therefore, these parameters should be kept in mind for better planning of any improvement programme in amaranth.

Keywords Amaranth; Grain yield; Correlation and path analysis

1 Introduction

Amaranthus species are being cultivated since centuries as a leafy vegetable, as well as an important subsidiary food grain crop in many parts of the world (Tucker, 1986). Grain amaranth serves as an alternative source of nutrition for people in developing countries since it is a rich and inexpensive source of protein, vitamins and dietary fibre (Prakash and Pal, 1991; Shukla et al., 2003). Unlike other vegetables, grain amaranth is cultivated during hot summer months when no green vegetables are available (Singh and Whitehead, 1996). Besides immense nutritional importance, it can also be successfully grown under varied soil and agro climatic conditions (Katiyar et al., 2000; Shukla and Singh, 2000). Recently, current interest in grain amaranth resides in the fact that it has a great amount of genetic diversity and phenotypic plasticity. Grain amaranth is extremely adaptable to adverse growing conditions, resist heat and drought, has no major disease problem and is among the easiest of plants to grow. Improvement of grain yield is the main target of breeding program to develop amaranthus varieties for diverse ecosystems. Population density is a major environmental factor influencing the genetic parameters like variability and association among the characters. Study of the extent of such influence of different plant density levels in these genetic parameters is required to formulate appropriate breeding strategies. However, grain yield is a complex trait, controlled by many genes and highly affected by
In addition, grain yield is also related with other characters such as plant type, growth duration and yield components. The low heritability of grain yield characters made selection for high yielding varieties usually use secondary traits associated with yield. Thus, information on contribution of each plant character to grain yield is important to make selection process more efficient. Causal relationship between predictor variables and response variable can be defined by path analysis. Using path analysis, correlation coefficient is partitioned into two components, which are direct effect of a predictor variable on its response variable and indirect effect of that predictor variable on the response variable through other related variables. Path analysis has been intensively used to estimate contribution of yield related traits to grain yield of rice and assisted breeders to determine selection criteria to improve yield. However, information on relationship of agronomic traits and grain yield in the breeding program for specific environment particularly for different plant density levels is very limited.

2 Materials and methods

Grain amaranthus genotypes were obtained from the germplasm collection of NBPGR maintained at the University of Agricultural Sciences, Bangalore and Forestry College and Research Institute, Mettupalayam, India. Plants were grown from November-February, 2007, in a Randomized Complete Block Design with three replications. The soil was a well-drained sandy loam, pH above 6. The soil was prepared by cultivation three times to obtain a loose, friable, soil. Cow manure was applied along with urea, diammonium phosphate and muriate of potash as per TNAU crop production guide (2005). Irrigations were at a 7 day interval during the growing season. The insecticides chlorpyriphos or dimethoate were applied at 1.5 mL/L. Genotypes were grown in bed of 2 m×1.5 m. Seed were sown in a single line in the middle of the bed. Plants were thinned 15 days after sowing to maintain very high (30 cm×20 cm), high (30 cm×30 cm), normal (45 cm×20 cm) and low (45 cm×30 cm) densities. Observations were recorded from five randomly selected plants of each genotype in each replication and population density for plant height, leaf area at 50% flowering, weight of the inflorescence, number of rachis per inflorescence, rachis length per inflorescence, number of secondary branches per inflorescence, grain yield per plant, grain yield per plot, and total carbohydrate and protein contents. For quality traits, composite samples drawn from five random plants of genotypes under population densities were used for analysis. The association between yield and component traits and intercorrelation among component traits was computed based on per se performance of the genotypes as genotypic correlation coefficient (Goulden, 1952). The variance and covariance components were utilized to calculate genotypic correlation coefficient as outlined by Al - Jibour et al. (1958). Path analysis was adopted to partition the genotypic correlation coefficient into direct and indirect effects as suggested by Dewey and Lu (1959). The path coefficients were ranked on the scales given below (Lenka and Misra, 1973).

3 Results and discussion

Information on the strength and direction of component characters with seed yield and also intercorrelation among themselves would be very useful in formulating an effective selection criteria for improvement of yield. A simple measure of correlation of characters with yield is inadequate, as it will not reflect the direct influence of component characters on the yield. Thus, it is necessary to split the correlation coefficients into direct and indirect effects (Dewey and Lu, 1959). This would help to identify with certainty the component traits to be relied upon during selection to improve seed yield. Such an attempt was made in the present study. Genotypic correlation coefficients were calculated through variance and
covariance analysis for all possible combinations of thirteen characters. The results are tabulated and presented for individual density level (Tables 1~4). The correlation established with grain yield by the all characters showed high fluctuation among the four plant density levels. The genotypic correlation coefficients worked out among the characters revealed (Figure 1) that grain yield per plant established strong positive significant correlation with fresh weight of the inflorescence in all the plant density levels, except high plant density. Length of the primary inflorescence and plant height also showed very high positive correlation with grain yield under very high and normal plant density levels, respectively. Similar results were also obtained by Shukla and Singh (2003) for length of the inflorescence. These results indicate that among the various component traits fresh weight of the inflorescence contributed more towards grain yield in all the density levels, except high plant density. However, fresh weight of the inflorescence showed higher positive correlation towards grain yield in high plant density level. Length of the inflorescence and plant height had strong positive correlation with grain yield under very high and normal plant density levels, respectively. Fresh weight of the inflorescence, length of the inflorescence and number of secondary branches per inflorescence had strong positive significant intercorrelation among themselves in all the density levels, except low plant density level. This result is in corroboration with the findings of Shukla and Singh (2003). Plant height had positive correlation with diameter of the inflorescence, fresh weight of the inflorescence and length of the primary inflorescence under very high, high and normal plant density levels. These results reveal that the selection exercised for any one of these four component traits viz., fresh weight of the inflorescence, length of the primary inflorescence, number of secondary branches per inflorescence and plant height may lead not only to improvement of the character concerned, but also to the simultaneous improvement of other traits. Days to 50 percent flowering showed negative correlation with grain yield in all the four plant density levels. No significant negative and inter correlations were observed for any trait with grain yield in all the four plant density levels.

Table 1 Genotypic correlation for different characters in very high plant density (D1: 30 cm × 20 cm)

| Characters | DFF | LAF | LI | DI | FWI | NR | LR | NSB | TCC | PC | Grain yield per plant |
|------------|-----|-----|----|----|-----|----|----|-----|-----|----|-----------------------|
| PH         | -0.299 | -0.273 | 0.122 | 0.757** | 0.316 | -0.002 | -0.149 | -0.014 | -0.093 | -0.105 | 0.181 |
| DFF        | 0.293 | -0.254 | -0.411 | -0.277 | -0.023 | -0.399 | -0.414 | -0.314 | -0.531 | -0.281 |
| LAF        | 0.273 | -0.312 | 0.219 | 0.411 | 0.086 | 0.135 | 0.402 | -0.149 | 0.332 |
| LI         | 0.388 | 0.820** | 0.411 | -0.132 | 0.589 | 0.216 | 0.159 | 0.694* |
| DI         | 0.614 | 0.044 | 0.033 | 0.534 | 0.147 | 0.015 | 0.346 |
| FWI        | 0.427 | -0.074 | 0.636* | 0.142 | 0.034 | 0.817** |
| NR         | -0.174 | 0.159 | 0.226 | -0.131 | 0.466 |
| LR         | 0.330 | 0.688* | 0.152 | 0.085 |
| NSB        | -0.143 | 0.557 | 0.515 |
| TCC        | -0.137 | 0.347 |
| PC         | -0.064 |
Table 2 Genotypic correlation for different characters in high plant density (D2: 30 cm × 20 cm)

| Characters | DFF | LAF | LI | DI | FWI | NR | LR | NSB | TCC | PC | Grain yield per plant |
|------------|-----|-----|----|----|-----|----|----|-----|-----|----|-----------------------|
| PH         | -0.016 | 0.251 | 0.496 | 0.380 | 0.596 | -0.139 | -0.354 | 0.354 | 0.119 | -0.090 | 0.499 |
| DFF        | 0.248 | -0.137 | -0.411 | -0.287 | -0.022 | -0.353 | -0.430  | -0.375 | -0.510 | -0.583 |
| LAF        | 0.193 | 0.241 | 0.310 | 0.466 | -0.319 | -0.162 | 0.434  | -0.113 | 0.177 |
| LI         | 0.318 | 0.666* | 0.060 | -0.015 | 0.558 | 0.145  | -0.042 | 0.375 |
| DI         | 0.552 | -0.397 | 0.101 | 0.557 | -0.127 | 0.014  | 0.364 |
| FWI        | 0.101 | -0.158 | 0.648* | 0.217 | 0.041  | 0.624 |
| NR         | 0.198 | 0.046 | 0.279 | 0.225 | 0.301 |
| LR         | 0.276 | -0.093 | 0.430  | 0.235 |
| NSB        | -0.184 | 0.549  | 0.415 |
| TCC        | -0.094 | 0.311 |
| PC         | 0.131 |

Note: *Significance at 5 per cent level; **Significance at 1 per cent level; PH: Plant height, DFF: Days to 50 per cent flowering, LAF: Leaf area at 50 per cent flowering, LI: Length of the primary inflorescence, DI: Diameter of the inflorescence, FWI: Fresh weight of the inflorescence, NR: Number of rachis per inflorescence, LR: Length of the rachis per inflorescence, NSB: Number of secondary branches per inflorescence, TCC: Total carbohydrates content, PC: Protein content

Table 3 Genotypic correlation for different characters in normal plant density (D2: 45 cm × 20 cm)

| Characters | DFF | LAF | LI | DI | FWI | NR | LR | NSB | TCC | PC | Grain yield per plant |
|------------|-----|-----|----|----|-----|----|----|-----|-----|----|-----------------------|
| PH         | -0.108 | 0.188 | 0.728* | 0.528 | 0.830** | -0.075 | -0.075 | 0.716* | 0.061 | 0.052 | 0.687* |
| DFF        | 0.264 | -0.130 | -0.143 | -0.226 | -0.245 | 0.653 | -0.207 | -0.343 | -0.575 | -0.383 |
| LAF        | 0.075 | -0.106 | 0.268 | 0.063 | -0.197 | 0.072 | 0.373 | -0.152 | 0.206 |
| LI         | 0.577 | 0.638* | -0.141 | 0.258 | 0.525 | 0.003 | 0.152 | 0.326 |
| DI         | 0.421 | 0.051 | 0.240 | 0.285 | -0.029 | -0.182 | 0.198 |
| FWI        | -0.005 | 0.097 | 0.808** | 0.109 | 0.175 | 0.783** |
| NR         | 0.163 | -0.194 | 0.222 | -0.294 | 0.375 |
| LR         | 0.180 | -0.056 | 0.485 | 0.009 |
| NSB        | -0.229 | 0.380 | 0.623 |
| TCC        | -0.113 | 0.289 |
| PC         | 0.056 |

Note: *Significance at 5 per cent level; **Significance at 1 per cent level; PH: Plant height, DFF: Days to 50 per cent flowering, LAF: Leaf area at 50 per cent flowering, LI: Length of the primary inflorescence, DI: Diameter of the inflorescence, FWI: Fresh weight of the inflorescence, NR: Number of rachis per inflorescence, LR: Length of the rachis per inflorescence, NSB: Number of secondary branches per inflorescence, TCC: Total carbohydrates content, PC: Protein content

Table 4 Genotypic correlation for different characters in low plant density (D2: 45 cm × 30 cm)

| Characters | DFF | LAF | LI | DI | FWI | NR | LR | NSB | TCC | PC | Grain yield per plant |
|------------|-----|-----|----|----|-----|----|----|-----|-----|----|-----------------------|
| PH         | -0.260 | 0.234 | 0.284 | 0.363 | 0.384 | 0.017 | 0.083 | 0.286 | 0.337 | 0.095 | 0.526 |
| DFF        | 0.284 | -0.215 | -0.329 | -0.066 | 0.084 | -0.558 | -0.220 | -0.330 | -0.491 | -0.358 |
| LAF        | 0.130 | -0.076 | 0.526 | 0.143 | -0.241 | 0.010 | 0.440 | -0.186 | 0.351 |
| LI         | 0.499 | 0.574 | -0.173 | 0.224 | 0.437 | 0.020 | 0.055 | 0.466 |
| DI         | 0.513 | 0.069 | 0.370 | 0.528 | 0.005 | -0.257 | 0.547 |
| FWI        | -0.192 | 0.001 | 0.701* | 0.188 | -0.060 | 0.652** |
| NR         | -0.012 | -0.273 | 0.260 | -0.316 | 0.088 |
| LR         | 0.386 | -0.323 | 0.422 | 0.056 |
| NSB        | -0.240 | 0.237 | 0.519 |
| TCC        | -0.109 | 0.348 |
| PC         | -0.111 |

Note: *Significance at 5 per cent level; **Significance at 1 per cent level; PH: Plant height, DFF: Days to 50 per cent flowering, LAF: Leaf area at 50 per cent flowering, LI: Length of the primary inflorescence, DI: Diameter of the inflorescence, FWI: Fresh weight of the inflorescence, NR: Number of rachis per inflorescence, LR: Length of the rachis per inflorescence, NSB: Number of secondary branches per inflorescence, TCC: Total carbohydrates content, PC: Protein content
The genotypic correlation coefficients of component traits with grain yield per plot were partitioned into direct and indirect effects through path coefficient analysis (Tables 5–8). In the present study the direct effects of all the component traits on grain yield showed high fluctuation in direction as well as in magnitude under four plant density levels. The traits viz., fresh weight of the inflorescence, length of the primary inflorescence and number of secondary branches per inflorescence which were identified as yield attributing traits based on correlation and intercorrelation studies, fresh weight of the inflorescence was found to be the most important contributing trait as it significantly improves the grain yield per plant in all the four plant density levels. In path analysis, as in case of correlation studies, these traits had very high positive direct effects on grain yield in all the plant density levels (Figure 2). In addition to that, leaf area at 50 per cent flowering, length of the primary inflorescence and number of secondary branches per inflorescence also identified as the most important yield contributing traits from the path analysis in all the four plant density levels. The length of the rachis per inflorescence had high positive direct effect on grain yield per plant in all the density levels except very high density. These results confirm that the fresh weight of the inflorescence should be given prime importance in selection programme for improvement of grain yield in grain amaranthus irrespective of plant density levels. The positive direct effect was exhibited by plant height in high and normal plant densities, whereas in very high and low plant density levels this trait showed high and very high negative direct effects. The other yield contributing trait diameter of the inflorescence had direct positive effect on grain yield in all density levels except high density level (D2). Total carbohydrates and protein content showed high positive direct effects on grain yield in very high density and also protein content recorded low positive direct effect under low plant density. In the present study, days to 50 per cent flowering and number of rachis per inflorescence recorded negative direct effects in all the density levels. Total carbohydrates recorded high and
negligible negative direct effects on grain yield in normal, high and low plant density levels respectively. Protein content showed high negative direct effects in normal density, whereas in high plant density this trait recorded negligible negative direct effects grain yield. The estimate of residual effect reflects the adequacy and appropriateness of the characters chosen for the path analysis. In the present study, the residual effect was low in all the four plant density levels indicating the adequacy of characters chosen for the study to reflect the grain yield.

4 Conclusion
Considering both correlation and path analysis together, it could be concluded that fresh weight of the inflorescence, length of the primary inflorescence, number of

Table 5 (diagonal) and indirect effects of component characters on grain yield in very high plant density (D2: 30 cm × 20 cm)

| Characters | PH  | DFF | LAF | LI  | DI  | FWI | NR  | LR  | NSB | TCC | PC  | $r_g$ with grain yield |
|------------|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----------------------|
| PH         | -0.822 | 0.552 | -0.283 | 0.021 | 0.253 | 0.031 | -0.006 | 0.120 | 0.004 | 0.095 | -0.127 | 0.181 |
| DFF        | 0.245 | -1.851 | 0.303 | -0.043 | -0.139 | -0.027 | 0.012 | 0.353 | 0.166 | 0.302 | 0.191 | -0.281 |
| LAF        | 0.226 | -0.545 | 1.031 | 0.499 | -0.101 | 0.021 | -0.199 | -0.073 | -0.054 | -0.387 | -0.223 | 0.332 |
| LI         | -0.110 | 0.512 | 0.323 | 1.158 | 0.167 | 0.098 | -0.254 | 0.103 | -0.290 | -0.228 | -0.542 | 0.694* |
| DI         | -0.703 | 0.867 | -0.352 | 0.089 | 0.297 | 0.063 | -0.005 | 0.002 | -0.163 | 0.145 | -0.244 | 0.346 |
| FWI        | -0.271 | 0.549 | 0.238 | 0.164 | 0.199 | 1.298 | -0.218 | 0.048 | -0.277 | -0.140 | -0.547 | 0.817* |
| NR         | -0.016 | 0.068 | 0.620 | 0.121 | 0.005 | 0.061 | -0.331 | 0.154 | -0.123 | -0.330 | -0.471 | 0.466 |
| LR         | 0.134 | 0.888 | 0.103 | -0.022 | 0.000 | -0.006 | 0.069 | -0.735 | -0.134 | -0.110 | -0.007 | 0.085 |
| NSB        | 0.011 | 0.861 | 0.157 | 0.128 | 0.135 | 0.073 | -0.114 | -0.276 | 1.357 | 0.152 | -0.372 | 0.515 |
| TCC        | 0.079 | 0.586 | 0.417 | 0.037 | -0.045 | 0.013 | -0.014 | -0.085 | 0.056 | 0.956 | -0.246 | 0.347 |
| PC         | 0.056 | 0.598 | 0.389 | 0.144 | 0.122 | 0.087 | -0.204 | -0.009 | -0.224 | -0.397 | 0.592 | -0.064 |

Note: *Significance at 5 per cent level; **Significance at 1 per cent level; Residual effect = 0.332; $r_g$ = Genotypic correlation; PH: Plant height; DFF: Days to 50 per cent flowering; LAF: Leaf area at 50 per cent flowering; LI: Length of the primary inflorescence; DI: Diameter of the inflorescence; FWI: Fresh weight of the inflorescence; NR: Number of rachis per inflorescence; LR: Length of the rachis per inflorescence; NSB: Number of secondary branches per inflorescence; TCC: Total carbohydrates content; PC: Protein content

Table 6 (diagonal) and indirect effects of component characters on grain yield in high plant density (D2: 30 cm × 30 cm)

| Characters | PH  | DFF | LAF | LI  | DI  | FWI | NR  | LR  | NSB | TCC | PC  | $r_g$ with grain yield |
|------------|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----------------------|
| PH         | 0.453 | -0.001 | 0.194 | -0.405 | -0.361 | -0.177 | 0.056 | -0.260 | 0.580 | -0.003 | -0.041 | 0.499 |
| DFF        | 0.000 | -0.641 | 0.143 | 0.112 | 0.259 | 0.063 | 0.007 | -0.250 | -0.564 | 0.006 | 0.049 | -0.583 |
| LAF        | 0.152 | -0.159 | 0.576 | -0.164 | 0.144 | -0.067 | -0.150 | -0.148 | -0.211 | -0.007 | -0.015 | 0.177 |
| LI         | 0.300 | 0.117 | 0.154 | 1.611 | -0.398 | -0.220 | -0.075 | -0.013 | 0.955 | -0.003 | -0.051 | 0.375 |
| DI         | 0.297 | 0.302 | -0.151 | -0.442 | -0.550 | -0.129 | 0.160 | 0.052 | 0.753 | 0.001 | -0.034 | 0.364 |
| FWI        | 0.383 | 0.194 | 0.187 | -0.644 | -0.341 | 2.209 | -0.029 | -0.069 | 0.888 | -0.003 | -0.552 | 0.624 |
| NR         | -0.105 | 0.018 | 0.358 | -0.190 | 0.363 | -0.025 | -0.242 | 0.148 | 0.100 | -0.005 | -0.023 | 0.301 |
| LR         | -0.262 | 0.358 | -0.090 | 0.018 | -0.064 | 0.332 | -0.080 | 0.449 | 0.362 | 0.001 | -0.002 | 0.235 |
| NSB        | 0.209 | 0.287 | -0.097 | -0.464 | -0.329 | -0.147 | -0.019 | 0.129 | 1.258 | 0.003 | -0.636 | 0.415 |
| TCC        | 0.087 | 0.251 | 0.262 | -0.145 | 0.059 | -0.051 | -0.089 | -0.048 | -0.237 | -0.006 | -0.300 | 0.311 |
| PC         | 0.241 | 0.411 | 0.114 | -0.403 | 0.248 | 0.049 | -0.072 | 0.128 | 0.600 | -0.015 | -0.077 | 0.131 |

Note: *Significance at 5 per cent level; **Significance at 1 per cent level; Residual effect = 0.266; $r_g$ = Genotypic correlation; PH: Plant height; DFF: Days to 50 per cent flowering; LAF: Leaf area at 50 per cent flowering; LI: Length of the primary inflorescence; DI: Diameter of the inflorescence; FWI: Fresh weight of the inflorescence; NR: Number of rachis per inflorescence; LR: Length of the rachis per inflorescence; NSB: Number of secondary branches per inflorescence; TCC: Total carbohydrates content; PC: Protein content
secondary branches per inflorescence and leaf area at 50 per cent flowering for all the plant density levels would be the appropriate selection parameters for improvement of grain yield in grain amaranthus. The length of rachis per inflorescence may also be taken as a selection parameter for improvement of yield as it had exerted positive direct effect in all density levels except very high density level.

**Authors' Contributions**

Dr. S. Ramesh Kumar conceived the overall study, performed the experiment designs and drafted the manuscript. Dr. G. Mohamed Yassin and Dr. R. Govindarasu took part in the experiment as chairman of the advisory committee. The above scientists read the manuscript and revised it. All authors had read and consent the final text.

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### Table 7 Direct (diagonal) and indirect effects of component characters on grain yield in normal plant density (D2: 45 cm × 20 cm)

| Characters | PH | DFF | LAF | LI | DI | FWI | NR | LR | NSB | TCC | PC | \( r_g \) with grain yield |
|------------|----|-----|-----|----|----|-----|----|----|-----|-----|----|----------------------------|
| PH         | 0.191 | 0.101 | 0.142 | -0.134 | 0.883 | -0.228 | 0.161 | -0.023 | -0.504 | -0.052 | 0.333 | 0.687                  |
| DFF        | 0.020 | -0.932 | 0.200 | 0.208 | -0.212 | 0.064 | 0.474 | -0.239 | 0.143 | 0.292 | -1.694 | -0.383              |
| LAF        | -0.363 | -0.249 | 0.748 | -0.140 | -0.179 | -0.073 | -0.132 | -0.072 | -0.051 | -0.306 | 0.002 | 0.006              |
| LI         | -0.174 | 0.131 | 0.071 | 1.473 | 1.186 | -0.205 | 0.234 | 0.081 | -0.460 | 0.048 | 0.040 | 0.326              |
| DI         | -0.144 | 0.169 | -0.114 | -1.498 | 1.167 | -0.176 | -0.291 | 0.131 | -0.307 | 0.055 | 0.008 | 0.198              |
| FWI        | -0.173 | 0.239 | 0.217 | -1.201 | 0.816 | 1.970 | -0.128 | 0.041 | -0.621 | -0.079 | -0.013 | 0.783*            |
| NR         | 0.017 | 0.251 | 0.056 | 0.195 | 0.193 | -0.018 | -1.761 | 0.083 | 0.177 | -0.247 | -0.007 | 0.375              |
| LR         | 0.012 | 0.640 | -0.155 | -0.345 | 0.440 | -0.029 | -0.421 | 0.348 | -0.134 | 0.055 | 0.038 | 0.009              |
| NSB        | -0.144 | 0.199 | 0.057 | -1.103 | 0.536 | -0.234 | 0.466 | 0.069 | 1.009 | -0.053 | -0.067 | 0.623              |
| TCC        | -0.120 | 0.341 | 0.288 | 0.090 | 0.090 | -0.025 | -0.549 | -0.232 | 0.144 | -0.793 | -0.054 | 0.289              |
| PC         | -0.143 | 0.393 | 0.168 | -0.748 | 0.012 | -0.220 | -0.836 | 0.029 | -0.446 | -0.267 | -0.852 | 0.056              |

Note: *Significance at 5 per cent level; **Significance at 1 per cent level; Residual effect = 0.415; \( r_g \) = Genotypic correlation; PH: Plant height; DFF: Days to 50 per cent flowering; LAF: Leaf area at 50 per cent flowering; LI: Length of the primary inflorescence; DI: Diameter of the inflorescence; FWI: Fresh weight of the inflorescence; NR: Number of rachis per inflorescence; LR: Length of the rachis per inflorescence; NSB: Number of secondary branches per inflorescence; TCC: Total carbohydrates content; PC: Protein content

### Table 8 Direct (diagonal) and indirect effects of component characters on grain yield in low plant density (D2: 45 cm × 30 cm)

| Characters | PH | DFF | LAF | LI | DI | FWI | NR | LR | NSB | TCC | PC | \( r_g \) with grain yield |
|------------|----|-----|-----|----|----|-----|----|----|-----|-----|----|----------------------------|
| PH         | -1.597 | 0.127 | -0.246 | 0.005 | -0.567 | -0.120 | 0.022 | -0.012 | 0.285 | -0.001 | -0.247 | 0.526                  |
| DFF        | 0.005 | -0.656 | 0.101 | 0.058 | -0.515 | 0.024 | -0.327 | 0.135 | -0.264 | 0.121 | -0.132 | -0.358              |
| LAF        | 0.124 | 0.092 | 0.428 | -0.059 | -0.001 | -0.097 | -0.029 | -0.042 | 0.084 | 0.007 | -0.368 | -1.015*            |
| LI         | -0.207 | 0.130 | 0.002 | 0.958 | -0.297 | -0.102 | -0.042 | 0.835 | -0.102 | 0.000 | -0.002 | 0.547              |
| DI         | -0.027 | 0.114 | -0.098 | -2.420 | 0.627 | -0.087 | -0.002 | 0.835 | -0.102 | 0.000 | -0.002 | 0.547              |
| FWI        | 0.175 | 0.256 | 0.026 | 0.017 | -0.247 | 0.986 | -0.004 | -0.062 | 0.588 | -0.002 | -0.004 | 0.652**            |
| NR         | -1.287 | 0.234 | 0.728 | 0.182 | 0.252 | -0.167 | -1.105 | 0.057 | 0.002 | -0.578 | -0.007 | 0.008              |
| LR         | 0.164 | 0.387 | 0.557 | 0.087 | 0.002 | 0.184 | -0.012 | 0.528 | 0.768 | -0.001 | -1.167 | 0.056              |
| NSB        | 0.228 | 0.183 | -0.084 | 0.128 | 0.009 | -0.524 | 0.027 | 0.085 | 0.964 | -0.285 | -0.014 | 0.519              |
| TCC        | 0.064 | 0.173 | 0.586 | -1.124 | 0.000 | -0.031 | -0.068 | -0.018 | -0.138 | -0.008 | -0.200 | 0.348              |
| PC         | 0.142 | 0.134 | 0.114 | -0.088 | 0.006 | 0.058 | -0.701 | 0.014 | -0.647 | -0.342 | 0.157 | -0.111              |

Note: *Significance at 5 per cent level; **Significance at 1 per cent level; Residual effect = 0.559; \( r_g \) = Genotypic correlation; PH: Plant height; DFF: Days to 50 per cent flowering; LAF: Leaf area at 50 per cent flowering; LI: Length of the primary inflorescence; DI: Diameter of the inflorescence; FWI: Fresh weight of the inflorescence; NR: Number of rachis per inflorescence; LR: Length of the rachis per inflorescence; NSB: Number of secondary branches per inflorescence; TCC: Total carbohydrates content; PC: Protein content
handing the grain amaranth germplasm and varieties to the corresponding author.

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