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Diversity for responses to some biotic and abiotic stresses and multivariate associations in Kabuli chickpea (*Cicer arietinum* L.)

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Summary

Kabuli chickpea (*Cicer arietinum* L.) is the common cultivated type of chickpea in arid and semi-arid environments in the Mediterranean region. Ascochyta blight, (*Ascochyta rabiei* (Pass.) Labr.), leaf miner (*Liriomyza cicerina*, Rond.) and cold, are the three most important stresses on chickpea grown under semi-arid conditions in this region. Phenotypic frequencies for responses to these stresses in the eight major chickpea-growing regions of the world were estimated from 5,672 kabuli chickpea accessions assembled from these regions. In addition, the accessions were evaluated for 12 morpho-physiological and three phenological characters under semi-arid Mediterranean conditions at the International Center for Agricultural Research in the Dry Areas (ICARDA), Aleppo, Syria. Considerable regional differences in frequency distributions for response to the three stresses were observed. Average phenotypic diversity for responses to the three stresses was lower ($H_o = 0.474$) than for morpho-physiological ($H_o = 0.754$) and phenological ($H_o = 0.812$) characters. The highest frequencies of accessions resistance to Ascochyta-blight and leaf-miner were found in South Asia and South Central Asia, respectively. A small number of chickpea breeding materials of ICARDA showed a moderate level of tolerance to cold. A group of four characters showing the strongest bivariate association with each of the three stresses was identified from the latter group. Then, a discrete multivariate log-linear analysis of the five-way frequency table was performed for each group. The simplest log-linear model for each group included both two- and three-factor association terms, but no independent factors. This suggested the potential for indirect selection for stress tolerance using one or more of these associated characters. The roles of these characters in ideotype breeding of kabuli chickpea for arid and semi-arid Mediterranean conditions deserves careful assessment.

Introduction

Of the two major types of chickpea (*Cicer arietinum* L.) cultivated at the present time – desi (characterised by small, angular and dark coloured seeds) and kabuli (characterised by large, ram head shaped and beige coloured seeds), the latter is the predominant type grown in West Asia and the African and European countries bordering the Mediterranean Sea. Worldwide, as well as in the Mediterranean-rim countries, Ascochyta blight and leaf miner are the most important disease and insect pest, respectively, of chickpea under traditional spring-sown conditions (Nene & Reddy, 1987; Reed et al., 1987).

Recently, winter sowing has shown considerable promise over spring sowing in increasing productivity of kabuli chickpea (Hawtin & Singh, 1984; Singh, 1988). The success of the winter-sown crop depends largely on Ascochyta blight resistance and cold tolerance (Singh et al., 1989b), which underscores the need for adequate genetic diversity for these traits in germplasm resources. The purposes of our studies were to (a) assess diversity for responses to Ascochyta blight, cold and leaf miner in representative samples of kabuli chickpea accessions from nine major chickpea-growing regions in the world, and (b) to identify plant attributes which might provide indirect selection criteria for increasing resistance or tolerance of kabuli chickpea to these stresses. Since ICARDA maintains the world's largest collection (over 6300 accessions) of kabuli chickpea germplasm in the world, this collection was well-suited for the purposes of our investigation.

Materials and methods

Germplasm material

We used 5672 accessions of kabuli chickpea from nine major chickpea-growing regions for the study (Table 1). The West Asian accessions consisted entirely of advanced breeding lines developed at ICARDA, Syria between 1980 and 1987. The remaining 4439 accessions from 17 countries represented kabuli chickpea germplasm from a wide range of agro-climate conditions around the world.

Table 1. Regional distribution of kabuli chickpea accessions used for the studies of diversity and multi character associations

Region and country[1]	Number of accessions
South Asia (India, Nepal and Pakistan)	504
South Central Asia (Afghanistan and Iran)	2107
West Asia (Advanced breeding materials ICARDA, Syria)	1233
Turkey	521
Nile Valley (Egypt, Ethiopia and Sudan)	87
North Africa (Algeria, Morocco and Tunisia)	379
South West Europe (Spain and Portugal)	318
Mediterranean type America (Chile and California, USA)	435
Central America (Mexico)	88
Total	5672

[1] ...untries are listed in parentheses.

Experimental nursery

The accessions were grown in an investigation field at the main research station of ICARDA near the village of Tel Hadya (36°35'E, 36°51'N, elevation 284 m A.S.L.) in northern Syria. Tel Hadya has a typical Mediterranean climate characterised by wet and cold winters, and dry and hot summers. The accessions were grown in a single two-row plot, with rows 2 m long and 45 cm apart. Two Syrian local cultivars, Ghab 1 and Ghab 2, were grown alternately after every 20th plot of accessions to serve as reference entries for nominal and ordinal characterisation of accessions for discrete variables. Sowing was done between 27 November and 4 December 1987. The total precipitation during the crop season in 1987–88 was 504 mm. Fertilizer was applied at 50 kg P_2O_5 per hectare prior to sowing. The crop was hand-weeded thrice and protected from Ascochyta blight by fortnightly spraying of chlorothalonil (tetrachloroisophthalonitrile) at the rate of 0.8 kg a.i. per hectare.

Data collection

Data were collected on plant responses to Ascochyta blight, cold and leaf miner, and for 15 other characters (Table 2). Responses to the three stresses were evaluated under artificially created stress conditions in groups of 500–1000 accessions in each season between 1979 and 1988. The screening techniques and rating scales have been described in detail for Ascochyta blight, cold and leaf miner by Singh et al. (1981), and Singh et al. (1989b), Weigand & Tahhan (1989), respectively and summarised in Singh et al. (1991). Accessions were scored on an ordinal scale of 1 to 9, where 1 = no visible damage or injury to 9 = severely damaged or mined. Accessions classified as desirable (i.e., scored 1–3) in one season were evaluated at least in two additional seasons to confirm their responses to the three stresses.

Data were collected from the experimental nursery and laboratory on each accession and check plots for all characters except responses to the three stresses. For the five discrete morphophysiological characters – growth habit, seed shape, seed colour, seed texture and pod dehiscence – each accession was evaluated on a nominal or ordinal scale. Growth habit was recorded on the basis of the majority of plants in a plot. Canopy width, plant height and flowering duration were measured on three randomly chosen plants from a plot, and their means recorded. Days to flowering and maturity were recorded, respectively, when 50% of the plants in a plot flowered and, 90% of the plants reached full maturity. At maturity, one of the two rows in a plot, covering about 0.09 m^2, was harvested, and the remaining row (also 0.09 m^2) was maintained for 45 days to score for pod dehiscence. Above-ground shoot yield (biological yield) and seed yield per metre square were measured from all plants harvested from one row of each plot. Seed size (100-seed weight), shape, colour, texture and seed protein content were determined from a random sample of seeds harvested from each row.

Data conversion

According to the standard classification system (Sokal & Rohlf, 1981), three of the 18 characters included in our studies were ordinal (or ranked) and five were nominal variables. The remaining 10 characters were continuous measurement variables. In order to (a) estimate comparable diversity parameters for all variables, and (b) perform nonparametric statistical analysis of frequency data, we converted the 10 continuous variables to discrete ordinal variables as follows: $1 = d_i > 1s$, $2 = d_i > -1s$ to $1s$, and $3 = d_i \leq -1s$, where d_i is the deviation of the i^{th} observation from the overall mean and s is the standard deviation of the trait. It should be noted that, whereas discrete ordinal conversion of the continuous variables is possible, reverse conversion of the ordinal or nominal variables to continuous varia-

Table 2. List of 18 characters used for the characterisation of kabuli chickpea accessions in 1987–88 winter-sown nursery at Tel Hadya, Syria

Type of Character	Name of character[†]	Desirable category[‡]
Stress response	Ascochyta-blight resistance (9)	Resistant
	Cold tolerance (9)	Tolerant
	Leaf-miner resistance (9)	Resistant
Morpho-physiological	Growth habit (5)	Erect
	Canopy width (20–96 cm)	Narrow
	Seeds meter^{-2} (3–2467)	Many
	Seed size (8.4–70.1 g)	Heavy
	Seed shape (2)	Kabuli
	Seed colour (8)	Beige
	Texture of seed surface (3)	Rough
	Plant height (25–85 cm)	Tall
	Pod dehiscence (9)	Absent
	Biological yield (25–1080 g)	High
	Seed yield (10–510 g)	High
	Seed protein content (13.5–28.2%)	High
Phenological	Days to flowering (115–156)	Early
	Flowering duration (12–83)	Long
	Days to maturity (174–206)	Early

[†] Figure(s) within parentheses indicates the number of classes used for rating accessions or the observed range of measurement. [‡] Desirable category for each character is based on farmers' preference and breeding experiences in the Mediterranean region.

bles is not. The discrete nominal conversion had several advantages: (a) It conformed to the descriptor system recommended by the International Board for Plant Genetic Resources (IBPGR), Rome, for the evaluation and characterisation of crop genetic resources, (b) allowed multivariate frequency analysis involving all three types of variables, and (c) unlike parametric statistical procedures, these analyses required no assumptions about the distribution of the variables. Furthermore, although the three class limits chosen for grouping the continuous variables into discrete catagories are somewhat arbitrary, this procedure is applicable for the exploratory data analysis using the discrete multivariate log-linear method (Tabachnick & Fidell, 1989). Similar data conversion procedure has proven useful for the analysis and interpretation of large-scale germplasm evaluation data (Clarke et al., 1991; Yang et al., 1991; Jana & Singh, 1993).

Association analyses

Bivariate associations between character-pairs were analyzed using the two-way log-likelihood ratio (G^2) test (Sokal and Rohlf, 1981). This test was extended to investigate multivariate associations of cross-classified categorical data as described by Fienberg (1980) and Tabachnick & Fidell (1989).

As the results of the discrete multivariate log-linear analysis become too complex for a meaningful interpretation with too many characters, we decided to limit the number of characters for this analysis to six. With this restriction, a careful screening and selection of characters was made. This step was followed by choosing and testing appropriate models, and finally selecting and interpreting the model (see Tabachnick & Fidell, 1989 for details). First, we carried out a series of bivariate log-likelihood ratio tests between each of the three stress-response traits and the remaining 15 characters. The relative magnitudes of the 15 log-likelihood statistics (G^2 values) and their respective probabilities were used to select five characters showing the strongest associations with response to Ascochyta blight, cold or leaf miner.

Diversity analysis

Phenotypic diversity for each character in a region was estimated using the Shannon-Weaver information index (h_s) as follows (Bowman et al., 1971):

$$h_s = -\sum p_i \ln p_i$$

where p_i is the relative frequency of the i^{th} state of the character under consideration. The mean diversity (H) for a region was estimated as the arithmetic average of the h_s values over the 18 characters.

Results

Phenotypic frequencies

Frequency distributions of each of the 18 characters varied considerably among regions. Only a small number of accessions showed moderate resistance (original response categories 3 and 4) to Ascochyta blight and leaf miner, and tolerance to cold (Table 3). There were no accessions in the desirable categories 1 and 2 for responses to Ascochyta blight and cold, and in the first three response categories for leaf miner. Germplasm resistant to Ascochyta blight was found in four regions, South Central Asia (0.4%), West Asia (3.3%), North Africa (0.5%) and South Central Europe (0.8%). Whereas most of the

Table 3. Regions with the highest frequency of kabuli chickpea accessions in the desirable category for responses to Ascochyta blight, cold and leaf miner

Type of stress[†]	Regions with the highest frequency in observed desirable category	Relative frequency (× 100) in desirable class[‡]
Ascochyta blight (category 3)	Europe	0.8 (3.3)
Cold (category 3)	South Asia	1.0 (0.3)
Leaf miner (category 4)	South Central Asia	0.2 (0.1)

[†] Most desirable category of response, observed on the original scale of 1–9, is given in parentheses. [‡] Number in parentheses are the respective relative frequencies (× 100) in West Asia.

Ascochyta blight-resistant accessions were found in the advanced breeding lines of ICARDA in West Asia, the best sources of cold tolerance and resistance to leaf miner were South Asia and South Central Asia, respectively.

Where applicable, the number of classes for a character was reduced to three, 1 = desirable, 2 = intermediate and 3 = undesirable, by merging appropriate adjoining classes. This reduction was necessary to avoid too many cells with frequencies 0–4. With the exception of seed shape, which had only two classes, frequencies in three classes were used for analysing joint frequencies for two or more characters. The joint frequency distributions for resistance to Ascochyta blight, cold tolerance and resistance to leaf miner, given in Table 4, were significantly ($P \leq 0.05$) different among regions. The highest frequency (0.7%) of desirable combinations (joint classes 121, 122 and 123) for responses to Ascochyta blight and cold, were found in the ICARDA breeding materials, whereas these combinations were absent in most other regions including Turkey, the putative centre of origin of chickpea. Joint frequency distributions, involving a series of two and three useful character combinations, were also significant among regions.

Table 4. Overall and regional joint frequencies of kabuli chickpea accessions for responses to Ascochyta, cold and leaf miner, expressed as percent relative frequency

Joint[1] class	Overall	South Asia	S.C. Asia	West Asia	Turkey	Nile Valley	North Africa	S.W. Europe	Central America	Mediterranean type America
111	0	0	0	0	0	0	0	0	0	0
112	0	0	0	0	0	0	0	0	0	0
113	0	0	0	0	0	0	0	0	0	0
121	0	0	0	0	0	0	0	0	0	0
122	0*	0	0	0.1	0	0	0	0	0	0
123	0.2	0	0.1	0.6	0	0	0	0	0	0
131	0	0	0	0	0	0	0	0	0	0
132	0.3	0	0.1	0.7	0	0	0	0.8	0	0
133	0.6	0	0.2	1.9	0	0	0.5	0	0	0
211	0	0	0	0	0	0	0	0	0	0
212	0*	0	0	0.1	0	0	0	0	0	0
213	0*	0	0	0.1	0	0	0	0	0	0
221	0	0	0	0	0	0	0	0	0	0
222	1.0	0.2	0*	4.0	0	0	0	0	0	0
223	2.6	0.2	0.4	9.2	0	0	0.5	1.6	0	0.7
231	0	0	0	0	0	0	0	0	0	0
232	2.0	0.4	0.2	5.0	1.2	0	0.5	8.4	0	0
233	7.7	1.0	1.4	27.0	1.7	0	0.3	2.7	0	2.9
311	0	0	0	0	0	0	0	0	0	0
312	0	0	0	0	0	0	0	0	0	0
313	0.2	1.0	0.3	0	0	0	0.5	0.3	0	0
321	0	0	0	0	0	0	0	0	0	0
322	2.1	16.0	1.5	0.8	0.2	0	0.5	0.8	1.4	0
323	18.1	20.0	26.7	4.9	10.5	0	14.6	24.7	28.8	37.6
331	0	0	0	0	0	8.0	0	0	0	0
332	7.6	23.2	2.5	6.4	16.7	0	4.9	10.8	2.7	11.3
333	56.7	38.0	66.6	39.0	69.7	92.0	77.6	49.9	67.1	47.5

[1] The first, second and third digits in each joint class represent responses to Ascochyta blight, cold and leaf miner, respectively, where 1 = desirable, 2 = intermediate and 3 = least desirable responses. * frequency > 0, but < 0.04%.

Diversity indices

Overall diversity index H_0 for each character was estimated by pooling the frequencies in respective categories in the nine regions (Table 5). Mean diversity index (H) for each character was calculated as the arithmetic average of the nine h_s values of the regions. The closeness between the overall and mean diversity indices indicates that phenotypic diversity for each character was largely attributable to the within-region component. With the exception of seed shape, which had only two categories (kabuli- and pea-shaped) and days to maturity, all characters had higher diversity indices than the three stress-response traits. Diversity indices were high for two phenological characters, days to flowering and flowering duration, but low for plant maturity. The latter is most likely an adaptive feature of chickpea, evolved to avoid increasing drought and high temperature in the late spring in most chickpea-growing regions.

Average overall diversity for the three character groups, given in Table 6, indicate relatively high diversity for phenological (H = 0.812) and morpho-physiological traits (H = 0.754), but low diversity for responses to stresses (H = 0.474). This low level of diversity underscores the importance of finding alternative sources of diversity for response the three stresses, possibly in wild evolutionary relatives of chickpea.

Table 5. Overall and regional mean diversity indices for 18 characters of kabuli chickpea accessions studied at ICARDA in 1987–88

Character	Overall diversity H_0	Mean diversity over regions H
Growth habit	0.725	0.611
Canopy width	0.857	0.812
Seeds per meter square	0.853	0.712
Seed size	0.877	0.737
Seed shape[1]	0.442	0.401
Seed colour	0.693	0.656
Texture of seed surface	0.693	0.622
Plant height	0.832	0.736
Pod dehiscence	0.585	0.570
Days to flowering	1.016	0.946
Flowering duration	0.921	0.859
Days to maturity	0.499	0.491
Biological yield	0.829	0.820
Seed yield	0.821	0.816
Seed protein content	0.837	0.820
Ascochyta-blight resistance	0.447	0.204
Cold tolerance	0.579	0.534
Leaf miner resistance	0.397	0.386

[1] Two classes only. Theoretical maximum diversity for 2 phenotypic classes = 0.693. Theoretical maximum diversity for 3 phenotypic classes = 1.099.

Multicharacter associations

A group of five characters with the strongest associations with each of the three stress-response traits was chosen by the screening and selection procedures described earlier. In each case, the two yield variables, seed yield and biological yield, showed the strongest bivariate associations with each of the three stress-response traits, and therefore, appeared in each group. These two yield variables were strongly correlated (correlation coefficients > 0.824) in all regions. For these reasons, we considered their inclusion in the multivariate association analysis to be of little interest. Hence, we omitted these two variables and selected the next five characters showing strong bivariate association with the stress-response traits. The group of five characters showing the strongest bivariate associations with response to Ascochyta blight were growth habit, canopy width, seed size, days to flowering and flowering duration. The group of characters for cold tolerance included growth habit, plant height, seed size, days to flowering and flowering duration, and the group for response to leaf-miner consisted of cano-

Table 6. Average diversity for three groups of characters in Kabuli chickpea accessions studied at ICARDA in 1987–88

Character group	Overall average diversity	Average diversity of regional means
Phenological traits	0.812	0.765
Morpho-physiological traits	0.754	0.693
Stress-response traits	0.474	0.375
SE*	0.044	0.046

* Empirical Standard error estimated from the 18 estimates of H.

py width, plant height, pod dehiscence, days to flowering and Ascochyta blight resistance. Because flowering duration was a direct function of days to flowering (correlation coefficient = −0.763), and the latter character was common to all the three groups, we excluded flowering duration from the multivariate association analysis of Ascochyta blight resistance and cold tolerance, leaving only four characters in these two groups. In order to consider the same number of characters in each group, we excluded Ascochyta blight resistance from the group for leaf miner resistance. Thus the final four characters for association analyses were chosen from the following group of six characters: growth habit, canopy width, seed size, plant height, pod dehiscence, and days to flowering.

Of the numerous possible log-linear models that fit the five-character combinations in each case, a parsimonious selection of models was pursued using both the forward-selection and backward-elimination procedures. The simplest models for response to the three stresses included both two- and three-factor interaction terms, but no independent factors (Table 7). The respective interactions in the log-linear models are symbolically expressed by two and three letters within parentheses. The model for response to Ascochyta blight shows that this trait was involved in one two-factor and two three-factor interactions, [AC], [AFW] and [AGW], whereas response to leaf miner was involved in one two-factor and one three-factor interactions, [CL] and [FHL]. On the other hand, the model for response to cold stress shows that this character was involved in three two-factor interactions, [FT], [GT] and [HT], but no three-factor interactions. Thus all the six morpho-phenological characters were interactive with responses to the three stresses, although the degree of interaction varied. Over all the nine characters, seed size (W) was involved in six second-order interactions, followed by growth habit (G) and flowering duration (F), each with four, whereas pod dehiscence (D) was involved only in two first-order interaction.

Table 7. Simplest log-linear models involving response to each of three stress conditions and four morphological and phenological traits in kabuli chickpea

Stress condition[1]	Morpho-phenological characters used in the association study[1]	Simplest log-linear model
Ascochyta blight (A)	Canopy width (C)	[AC] [CGW]
	Days to flowering (F)	[FG] [AFW]
	Growth habit (G)	[AGW]
	Seed size (W)	
Cold (T)	Days to flowering (F)	[FT] [FHW]
	Growth habit (G)	[GT] [FGW]
	Plant height (H)	[HT] [GHW]
	Seed size (W)	
Leaf miner (L)	Canopy width (C)	[CL] [CFH]
	Pod dehiscence (D)	[DF] [DH]
	Days to flowering (F)	[FHL]
	Plant height (H)	

[1] Letter within parenthesis is the alphabetic symbol used to denote the trait in the chosen log-linear model

Discussion

Although accessions from all major kabuli chickpea growing regions of the world were included in our studies, there were large differences in sample size (or replications) among regions. Some regions, such as South Central Asia was well-represented with 2107 accessions, whereas other important regions, such as the Nile Valley (n = 87) and Central America (n = 88) were poorly represented. This inequality in regional sample sizes was due to the deficiency in accessions from some regions. Relatively small number of accessions from some of the major chickpea growing regions may be the reason for the dearth of accessions with resistant or tolerant response to the three major stresses.

Among the four major grain legumes, chickpea is believed to have the smallest range of cold tolerance (Murray et al., 1988). The absence of accessions in the highest category of resistance and low diversity for the three stress-response traits supports this view, and extends further to show that the ranges of resistance to Ascochyta blight and leaf miner are even smaller than that for cold tolerance. Hence, it is necessary to undertake further exploration and collection, particularly from the regions with small numbers of available accessions, followed by a reliable evaluation of germplasm for response to the three stresses. It was also apparent that, in the future exploration and collection of genetic resources targeted for resistance to the three stresses, regions such as South Asia, South Central Asia and Europe should receive greater attention than Turkey, the putative centre of origin of cultivated chickpea.

Recent evidence suggests that some wild *Cicer* species possess high levels of resistance to cyst nematode (*Heterodera ciceri* Vovlas, Greco *et* Di Vito) (Singh et al., 1989a) and cold tolerance (Singh et al., 1990). Wild relatives of cultivated chickpea offer alternative sources for widening the genetic base for resistance to the three major stresses in the Mediterranean basin.

The joint frequency estimates for responses to the three stresses showed the paucity of accessions with multiple stress resistance. In view of the diverse origin of germplasm in our investigation, chances of finding multiple-stress resistant accessions in future collections of kabuli chickpea may be small. Furthermore, diversity for responses to all the three stresses were low. These considerations suggest that greater emphasis should be placed on collecting chickpea germplasm from regions with high frequencies of genotypes resistant to individual stresses, followed by a breeding strategy to genetically increase multiple-stress resistance.

As expected, biological yield and its component, seed yield, were strongly correlated. There were several poorly adapted accessions, characterised by extremely low seed yield, as well as biological yield. The broader categorical classification of germplasm into three broad ordinal groups minimized the effect of these extreme outliers on the overall multivariate association analysis. It is noteworthy that, despite the fact that the accessions were independently evaluated for seed yield and biological yield, and the three stress-response characters were in different evaluation nurseries in different seasons, these two groups of characters (yield and stress-response) showed the strongest associations in the discrete nonparametric association analysis. In general, kabuli chickpea accessions with low yield potential appear to be more susceptible to the three stresses. Thus for stable and sustainable yield of kabuli chickpea genotypes under semi-arid Mediterranean conditions, their response to each of the three stresses must be an important consideration. Other characters found to be associated with response to one or more of these biotic and abiotic stresses are, days to flowering, flowering duration, growth habit, canopy width, seed size, plant height and pod dehiscence. From plant breeding considerations, Muehlbauer & Singh (1987) listed six characters that are important for kabuli chickpea ideotype breeding. Three of these characters, growth habit, plant height and seed size also appeared important in our studies. The three remaining characters in their list, numbers of productive branches, pods per plant and seeds per pod were not included in our studies. However, these three characters are essentially yield variables, and like biological yield and seed yield, would almost certainly show strong association with the three stress-response traits.

Multiway frequency analysis of responses of the two biotic stresses and other characters revealed their interactions with all four characters chosen for the respective groups. Response to cold was interactive with three of the four characters chosen for the group. Days to flowering was interactive with responses to all three stresses. These interactions suggest that the six characters – days to flowering, canopy width, growth habit, seed size, plant height and pod dehiscence, are important for ideotype breeding for stress resistance or tolerance in chickpea. Adaptive significance of their non-random associations with responses to biotic and abiotic stresses warrant detailed investigations.

In an earlier evaluation of 2526 germplasm lines from 31 countries, Singh et al. (1989b) found no correlation between cold tolerance and growth habit, seed size, plant height or days to maturity. Our discrete bivariate analysis, on the other hand, revealed strong association between cold tolerance and each of these characters, except days to maturity. The possible reasons for this discrepancy are, (a) the difference in the season of evaluation, (b) considerably larger number of accessions, hence a better representation of the global chickpea gene pool in the our study, and (c) in contrast to the parametric product-moment correlation analysis in Singh et al. (1989b), the use of the nonparametric multiway frequency analysis in the present study. The correlation analysis assumes a bivariate normal-distribution of the variables (Sokal & Rohlf, 1981), which does not hold for growth habit, seed size and cold tolerance (see Singh et al., 1991). The apparent discrepancy between our results and that of Singh et al. (1989b) underscores the usefulness of multiway frequency analysis of discrete ordinal and nominal data collected from large-scale germplasm evaluation, rather than the parametric association analysis, as in Singh et al. (1989b). Notwithstanding the differences in statistical properties of the evaluation data, the importance of multiseason and multilocation evaluation of crop germplasm, prior to the use of promising materials as sources of genes for stress tolerance, cannot be overstated. Reliable information on bivariate and multivariate associations in the target species is important for ideotype breeding, as well as for developing efficient strategies for the utilisation of crop genetic resources in breeding for stress resistance.

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