Recherche Agronomique (1997), 1, 9-19
INRAA

Growth analysis and selection of wheat varieties for drought resistance using cluster analysis

A. Kameli [1] & D.M. Losel [2]

[1] *Departement de Biologie, Ecole Normale Superieure, Vieux Kouba, Alger, Algerie.*
[2] *Department of animal and Plant Sciences, University of Sheffield, Sheffield S10 2TN.*

الملخص – تم في هذا البحث دراسة نمو 12 صنفا من القمح تحت تأثير الإجهاد المائي. وقد تم تحليل النتائج باستخدام طريقة التجمعات وذلك لغرض انتقاء الأصناف ذات الاستجابات المتناقضة. احتفظت بعض الأصناف بنسبة نمو عالية (مثل الأصناف 1 و 3 و 11 و 13) تحت ظروف الإجهاد مقارنة بأصناف أخرى (صنف 2 و 5 مثلا). الشكل 1أ يوضح وجود عدة مجموعات من الأصناف عند معاملات التشابه العالية. وقد بقيت مجموعتان من الأصناف منفصلتان حتى في القيم المنخفضة لمعامل التشابه (55.0) . تضم المجموعة الأولى 4 أصناف (1 ، 3 ، 11 ، 12) وتضم المجموعة الثانية باقي الأصناف. عند معاملات التشابه العالية تنفصل الأقسام إلى تحت أقسام أقل تمايزا. وقد سجل أدنى معامل للتشابه بين أصناف المجموعة 1 و الأصناف الباقية و بالتحديد بين الصنف 12 و الصنف 5 .

بالرغم من صغر عدد الأصناف المستعملة لغرض الإنتقاء فإن بعض الأصناف أظهرت إستجابات متناقضة في النمو تحت ظروف الإجهاد المائي (مثل الصنف 3 و 5) مما يبرر مواصلة الدراسة لغرض البحث عن الفروق البيوكيميائية.

دراسة النمو | الإجهاد المائي | القمح | طريقة التجمعات

Abstract- *The growth of 12 varieties of wheat was analysed under the effect of water stress. The results were analysed using Cluster analysis in order to select varieties of contrasting response. Some varieties (e.g. 1, 3, 11 & 13) maintained relatively higher percentages of growth under water stress than others (e.g. 5 & 2). The dendrogram Fig 1(b) based on 4 variables showed several groups of varieties at a high coefficient of similarity. Only two groups stayed separate down to a low similarity coefficient of 55.0. The first of these contains four varieties (1, 3, 11 & 12), the second group contains the rest of the varieties. At higher coefficients, the two groups are divided into sub-groups that are less distinctive. The low levels of similarity were recorded between varieties in group (I) and other varieties. The lowest coefficient was between vars 12 & 5. Although the number of varieties used in this experiment was rather low for selecting varieties with contrasting responses, some varieties differed considerably in their growth responses under water stress (e.g. 3 & 5), thus justifying further investigation of their possible biochemical differences.*

Growth analysis, water stress, wheat, cluster analysis

INTRODUCTION

The selection of plant species or varieties with an ability to withstand drought conditions is certainly one important way of optimizing and improving productivity in semiarid environments. The methods on which any selection is based differ widely and depend on which criteria are regarded as more important in identifying resistant and susceptible varieties.

Growth analysis has been used to separate varieties of differe[illegible] hardiness in wheat (e.g. Clarke et al. 1984). Since growth is an integral result of many parameters both morphological & biochemical, selecting the important growth parameters, which best with represent the effect of the environmental condition and distinguish between different varieties, is of great practical importance.

It is widely recognised that in the selection and breeding of varieties for a particular environment, any tests should be rapid and sufficiently sensitive to detect important differences. The lack of good correlation between specific morphological characters & drought resistance, e.g. in Clarke et al. (1984), and the laborious and time consuming work involved in using all growth parameters in selecting varieties of different hardiness, led to the search for other tests, involving physiological & biochemical criteria, some of which are rapid and easy to measure .

It was concluded by Fowler et al. (1982) that criteria for selecting varieties should have a high correlation with field performance e.g. the correlation with field survival under low temperature (as in Fowler et al. 1982), the correlation between seedlings' osmotic adjustment and high yield under water stress (Morgan et al.1986) and between field stability index and proline level under water stress (Singh et al. 1972).

The study of the biochemical responses of plants under water stress the view to identifying characters of resistance, often involves the use of two or more varieties, known to have different abilities to withstand conditions of water stress (e.g. Kameli, 1990; Johnson et al. 1984; Wright et al. 1983; Drossopoulos et al. 1987). These characteristics have often been recognised as a result of field observations or agricultural practice.

The work presented here is an investigation of the growth responses of 12 varieties of wheat belonging to two species (Triticum aestivum & T. durum). The aim was to select two varieties showing different growth responses to water stress, to be used for further biochemical study in future work. The importance and adaptive values of some biochemical responses are dealt with in other work (Kameli & Losel, 1993 &1996) as well as the correlation between growth and biochemical responses.

MATERIELS AND METHODS

Twelve varieties of wheat including both Tritrium durum L. (durum wheat) and T. eastivum L. (bread wheat) were used. The seeds were soaked for 24 hours and germinated in vermiculite for 6 days. The seedlings

Twelve varieties of wheat including

both Tritrium durum L. (durum wheat) and T. eastivum L. (bread wheat) used in the initial selection experiment, are listed in (Table I). The varieties grouped in the first half of the table are widely cultivated in different parts of Algeria, some having originated there and some having been intro-duced. The seeds were soaked for 24 hours and germinated in vermiculite for 6 days. The seedlings were then transplanted in pots of sand, each containing a single plant. A total of 180 pots, representing 12 varieties x 5 replicates x 3 treatments (stress 1, stress 2 & control) were laid out in a completely randomised block using random digits from tables (Fisher & Yates, 1963).

Table I : The wheat varieties used in the selection experiment.

Spicies	Variety	Abreviation	Source
(Triticum durum)	Oued Zenati 368	OZ	ITGC (Algiers)
	Hedba 3	H3	
	Mohamed Ben Bachir 8037	MBB	
(Triticum aestivum)	Flaurence Aurore	FA	
	Mahon Demias	MD	
	Siete Cerros	SC	
(Triticum durum)	Capdur	CAP	NIAB (Combridge)
	Regal	R	
(Triticum aestivum)	Wembley	W	
	Minaret	Mi	
	Galahad	G	
	Mercia	Me	

At 17 days after germination when the plants had two fully-expanded leaves, water stress was applied by withholding irrigation for different periods of time. Three treatments were used: 5 day cycles (stress 1), 10 day cycles (stress 2) and a control treatment watered daily. In order to ensure a uniform supply of mineral nutrients to stressed and control plants, all the pots were watered every 10 days with full strength Rorison nutrient solution.

The watering of control and moderate stress treatments during the 10 days period was made using deionized water. After 8 weeks from germination, the plants were harvested and the following growth measurements were made:

Number of dead leaves (NDL)
Number of green leaves (NGL)
Plant height (PH)
Maximum leaf width (LW)
Total length of dead leaves (LDL)
Total length of green leaves (LGL)
Shoot dry weight (ShW)
Root dry weight (RDW)
Spikelet dry weight (SDW) when present
Total dry weight (TW)

RESULTS & DISCUSSION

The results of growth measurement from stress 1, stress 2 and control plants are presented in (Table II) .

Analysis of variance was carried out for each variable and the least significant difference (LSD) between treatments was calculated at the 0.05 level. All the variables in stress 2 treatment were significantly different from control plants but only a few from stress 1 treatment differed from controls.

Table II : Growth analysis wheat varieties (*Triticum durum* L). and (*Triticum aestivum* L). LSD was calculated at 0.05 % level

vars	treat	NDL	NGL	PH (cm)	LW (cm)	LDL (cm)	LGL (cm)	ShW (mg)	RW (mg)	TW (mg)
VAR 1	C	3.8	4.8	38.8	0.83	91.18	160.6	596	434	1030
(OZ)	S1	4.0	4.8	40.8	0.84	113.7	137.4	500	346	846
	S2	4.4	2.8	21.8	0.49	122.7	78.8	330	280	610
	LSD	0.56	1.39	7.61	0.122	27.75	43.55	122.1	61.71	174.09
VAR 2	C	3.0	5.8	53.94	0.92	72.5	155.5	622	478	1100
(H3)	S1	4.0	5.0	50.70	0.81	102.6	127.6	598	470	1070
	S2	5.0	1.8	26.40	0.52	135.5	044.0	316	199.4	515.4
	LSD	0.79	1.56	6.25	0.072	19.50	32.86	137.8	114.8	234.2
VAR 3	C	3.0	5.8	57.6	0.84	69.7	163.5	690	429	1119
(MBB)	S1	3.6	5.0	44.1	0.80	96.3	139.0	628	428	1056
	S2	3.6	3.8	35.8	0.54	92.8	82.72	356	209	565
	LSD	0.61	0.93	9.77	0.134	28.96	21.92	154.6	112.1	206.9
VAR 4	C	2.6	4.6	46.5	0.83	54.0	106.3	556	410	966.6
(R)	S1	3.4	4.0	38.0	0.81	74.6	81.8	399	331	819
	S2	4.6	2.0	22.3	0.39	87.7	37.0	196	166.6	362.9
	LSD	1.34	1.86	7.38	0.08	20.29	28.47	104.2	84.4	203.2
VAR 5	C	3.0	5.6	34.3	0.80	51.8	131.2	376.6	554.4	931
(C)	S1	3.8	5.20	33.8	0.74	79.4	107.7	424.0	372.0	795
	S2	5.2	1.40	20.14	0.39	111.5	20.2	227.0	167.6	394.6
	LSD	1.56	1.63	5.74	0.053	26.84	24.9	66.03	170.0	179.8
VAR 6	C	3.4	4.8	53.68	0.83	82.1	138.1	620	364.2	984.2
(FA)	S1	3.8	5.0	46.10	0.75	13.9	123.3	656	339	995
	S2	4.6	2.0	25.36	0.41	28.7	44.7	300	183.4	483.4
	LSD	0.69	1.41	9.44	0.106	22.91	29.33	167.8	95.43	240.1
VAR 7	C	4.0	4.2	60.22	0.89	28.9	156.2	753.3	364	1117.
(MD)	S1	4.2	4.0	56.0	0.91	29.2	129.1	704.0	330	1038
	S2	4.8	1.8	26.50	0.43	63.2	54.4	308.0	161.2	469.2
	LSD	1.09	1.74	11.45	0.14	30.6	49.05	149.5	114.9	223.8
VAR 8	C	3	4	46.7	0.92	53.8	81.1	541	229.8	770.8
(SC)	S1	4.0	3.0	43.3	0.89	84.6	61.0	693.5	262	955
	S2	5.8	1.2	24.6	0.60	117.3	22.1	213.0	122.8	436.0
	LSD	1.29	1.29	6.32	0.178	23.31	25.0	78.7	56.86	130.6
VAR 9	C	2.8	5.2	48.8	0.94	62.4	143.6	585.2	388.2	973.4
(Mi)	S1	4.0	4.0	48.56	0.88	113.4	95.1	516	368	884
	S2	3.8	2.8	19.3	0.46	94.9	61.3	332.6	122.2	454.8
	LSD	1.09	1.34	5.04	0.24	39.25	36.21	116.4	130.8	236.1
VAR10	C	2.8	4.6	39.2	0.84	49.8	116.5	348.2	453	801.2
(W)	S1	3.0	3.8	29.4	0.80	74.0	91.8	336	493	829
	S2	4.6	1.4	18.0	0.50	103.3	30.7	185.8	177.2	363
	LSD	10.96	1.19	9.84	0.126	21.9	21.23	79.50	115.5	86.63
VAR11	C	3	4.2	31.36	0.84	68.3	141.0	342.2	516.4	858.8
(ME)	S1	3.8	4.0	25.9	0.78	96.5	131.3	446	509	955
	S2	2.8	3.4	14.5	0.46	70.6	93.1	212	194	406.0
	LSD	0.49	0.65	6.35	0.167	17.76	16.32	59.4	139.9	180.6
VAR12	C	3	3.8	31.5	0.79	67.8	101.5	330.8	422.4	753.2
(G)	S1	2.6	4.0	28.0	0.78	64.0	106.4	347	472	820
	S2	3.6	2.6	12.3	0.43	88.1	63.7	228.6	268.2	496.4
	LSD	1.27	1.47	9.02	0.188	30.93	39.94	92.79	91.29	141.2

Growth was considerably affected by the severe water stress in all varieties, as indicated by the significant reduction in all growth parameters measured. Leaf number & leaf length were highly affected in some cases, making a better contrast between the varieties studied. Leaf area was not measured in this experiment, since the appropriate instrument (area meter) was not available at the time of the experiment.

The measurement of leaf length and leaf width, however, give a good indication of leaf area For both leaf number and leaf length, the measurements of dead and green leaves were made separately which gave an indication of the ability of the plants to maintain green tissue under severe water stress (i.e. ability to survive).

Although dry weight is a good indication of dry matter production and the state of the plant, it may not show the full extent of the effect of water stress, since in this experiment the dry weight of dead and green tissue were not separately measured. In order to quantify the effect of water stress on the main growth parameters measured, the number, length, width of green leaves and dry weight of stress 2 treatment were expressed as percentages of the mean values for control plants.

Table III : Growth parameters of stressed plants (S2) as percentages (%) of those in control plants.

Variety	NGL	LGL	LW	TW
VAR 1	58.33	49.06	59.03	59.22
VAR 2	31.03	28.29	56.52	46.28
VAR 3	65.51	50.59	64.28	50.50
VAR 4	43.47	34.80	46.98	37.54
VAR 5	25.00	15.39	48.75	42.38
VAR 6	32.36	32.36	49.39	49.11
VAR 7	42.28	34.82	48.31	41.99
VAR 8	30.00	27.25	65.21	56.64
VAR 9	53.84	42.86	48.93	46.72
VAR 10	30.43	26.35	59.52	45.30
VAR 11	80.95	66.02	54.76	47.27
VAR 12	68.42	62.55	54.43	65.90

It was observed that some varieties (e.g. 1,3,11 & 13) maintained relatively higher percentages of growth under water stress than others (e.g. 5 & 2). The varieties with high percentages may be regarded as more resistant to water stress than those with low percentages.Since the aim of this experiment was to select varieties showing different responses to water stress, a classification of the varieties using cluster analysis from a computer pro-gram (Genstat release 4.04B 1984, Lawes Agricultural Trust, Rotham-stead Experimental Station) was made from the data in Table 5.

The results of the cluster analysis are presented in a number of diagrams, most of which are based on the similarity between units (in this case between varieties of wheat). analysed according to the variables measured (in this case growth parameters). and the level at which they can be grouped together. Two diagrams are chosen here to show the similarity between the varieties studied:

1- Similarity matrix: which is a table showing the percentage difference between any two varieties. The very similar varieties have a similarity coefficient near 100, whereas low coefficients indicate less similar varieties. The classification is done on one or more variables (growth parameters) which can be qualitative (e.g. presence or absence) or quantitative as in this study (length & weight). Quantitative variables are scored according to absolute difference. whereas quantitative variables score either 0 or 1 and provide more contrast. The variables included in the classification are given equal weights.

2-Dendrogram: which is a graphical representation based also on a similarity coefficient scale from zero to one (often multiplied by 100 to avoid decimal places. as in this case). The dendrogram shows the classification of units (varieties) into groups according to how similar they are. The points of junction between the dotted lines read against the scale displayed at the top of the diagram. gives an indication of the similarity between the two lines at the similarity coefficient indicated by the scale (e.g. Fig 1). The very similar varieties are grouped at high coefficients. while dissimilar ones come together at low coefficients. Contrasting or distinct groups can be obtained by choosing units clustering at low similarity coefficients.

The cluster analysis in this experiment was carried out, firstly using variables NGL. LGL. LW. & TW. then taking the first three of these variables (i.e. NGL. LGL & LW) only, and the output compared. In each case. the analysis was done on all varieties (i.e. two species. durum & bread wheat) and on each species separately (i.e. 5 & 7 varieties). When looking at the ability to survive under severe water stress. the first three variables may be more important since they include only living tissue.

RESULTS OF CLUSTER ANALYSIS

The dendrogram Fig 1(b) based on 4 variables showed several groups of varieties at a high coefficient of similarity. Only two groups stayed separate down to a low similarity coefficient of 55.0. The first of these contains four varieties (1.3.11 & 12). the second group contains the rest of the varieties. The varieties in group I as indicated in Table 4.3 showed high percentages of growth under water stress which suggests that they represent the more resistant varieties. compared with varieties in groupII.

At higher coefficients. the two groups are divided into subgroups which are less distinct. It is of interest to note that the varieties in group I were divided into two subgroups containing varieties 1 & 3 which are durum wheats and are the only varieties originating in Algeria (semi-arid climate). The other subgroup contains two winter wheat varieties (11& 12).

***** SIMILARITY MATRIX ***** (A)

VAR01	----											
VAR02	62.4	----										
VAR03	81.4	59.2	----									
VAR04	50.4	70.4	47.2	----								
VAR05	39.2	76.8	36.1	75.5	----							
VAR06	61.9	81.0	58.7	84.5	77.4	----						
VAR07	55.6	76.7	52.4	93.7	81.7	90.8	----					
VAR08	65.5	78.0	65.9	48.4	56.8	63.9	54.7	----				
VAR09	69.6	71.9	66.5	80.7	69.6	86.7	86.0	50.6	----			
VAR10	63.1	93.8	61.2	66.0	74.8	74.8	72.2	81.6	65.7	----		
VAR11	65.1	55.4	69.3	48.9	37.8	57.2	54.1	35.2	68.2	49.2	----	
VAR12	76.8	46.1	65.6	39.8	28.7	51.3	45.1	42.4	59.1	39.9	76.2	----
	1	2	3	4	5	6	7	8	9	10	11	12

*** DENDROGRAM *** (B)

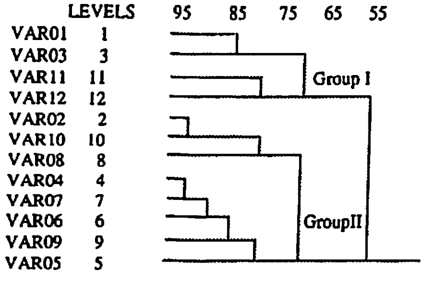

fig 1 : Using 4 variables (NGL, LGL, LW, TW) From the data in table 5. The analysis is presented in the form of similarity matrix (a) and dendrogram (b) .

This classification suggests that tolerance of winter conditions (winter wheat) or drought (durum wheat) may involve similar mechanisms. The similarity matrix (Fig 1a) clarifies the analysis by computing similarity coefficients between any two varieties (i.e. all the combinations). The low levels of similarity were recorded between varieties in group (I) and other varieties. The lowest coefficient was between vars 12 & 5.

It was clear from the dendrogram (Fig 1b) that if two varieties with different responses are to be selected. it is likely to be from group (I) & (II) (i.e. one from each group). The variety 5 showed also low similarity with varieties 1. 3 & 11. This gave a first indication that variety 5 which showed low percentages of growth under water stress may be a possible choice as a lessresistant or drought-susceptible variety to be compared with a variety from group (I).

On the basis of the 4 variables. varieties 12 & 5 may be classified as the most dissimilar or distinct among the varieties used. these varieties belong to two different species (i.e. T. durum & T. aestivum) when the cluster analysis was repeated for each species (Fig 2 & 3). using the same variables. varieties 1 & 3 showed low similarity and appeared in a different group from var 5 among durum wheats. Among bread wheat varieties. low similarity was found between varieties 11 & 12 and 8 & 10. On the basis of 3 variables (TW not included), the cluster analysis (Fig 4, 5 & 6) revealed similar results, except that var 3 showed a very low similarity coefficient with var 5 (3.4) among durum wheat varieties.

***** SIMILARITY MATRIX *****

VAR01	----				
VAR02	49.4	----			
VAR03	77.3	46.8	----		
VAR04	37.9	63.8	35.2	----	
VAR05	20.8	71.4	18.2	66.7	----
	1	2	3	4	5

*** DENDROGRAM ***

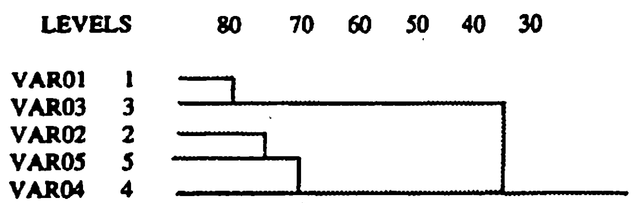

Fig 2: cluster analysis on 5 varieties of durum wheat using 4 variables (NGL, LGL, LW, TW).

***** SIMILARITY MATRIX *****

VAR06	----						
VAR07	89.1	----					
VAR08	59.8	48.9	----				
VAR09	84.3	83.6	44.1	----			
VAR10	71.7	68.8	78.9	61.1	----		
VAR11	49.6	46.3	25.3	62.7	41.1	----	
VAR12	42.7	35.5	33.1	52.0	29.4	71.8	----
	1	2	3	4	5	6	7

*** DENDROGRAM ***

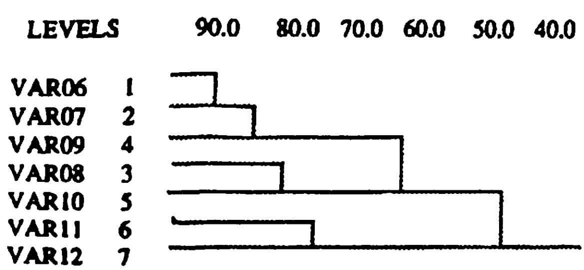

Fig 3: Cluster analysis on 7 varieties of bread whe(T. aestivum) including two winter wheats (11&12) using 4 variables (NGL, LGL, LW,TW).

***** SIMILARITY MATRIX *****

VAR01	—											
VAR02	65.1	—										
VAR03	85.5	50.6	—									
VAR04	59.3	70.9	44.8	----								
VAR05	38.8	73.7	24.3	73.0	----							
VAR06	61.1	78.0	46.6	92.9	77.7	----						
VAR07	61.1	74.0	46.6	96.8	76.1	96.0	----					
VAR08	57.1	82.8	61.8	53.7	59.1	60.8	56.8	----				
VAR09	74.3	63.1	59.8	85.1	64.5	85.1	86.8	45.9	----			
VAR10	67.1	92.9	54.4	63.7	69.9	70.8	66.9	88.7	55.9	----		
VAR11	67.5	41.8	62.8	43.3	22.8	45.1	45.1	24.6	58.3	34.6	----	
VAR12	77.0	51.2	72.2	53.1	32.6	54.8	54.8	34.0	68.0	44.1	90.2	----
	1	2	3	4	5	6	7	8	9	10	11	12

*** DENDROGRAM ***

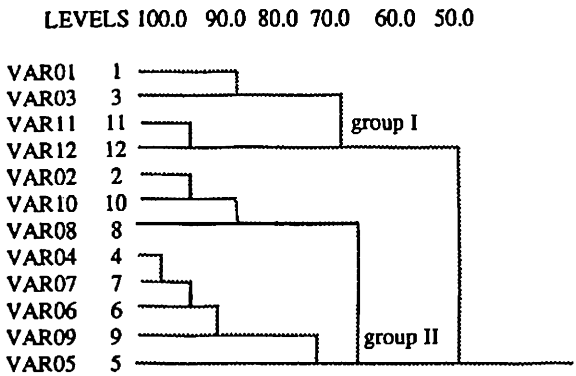

Fig 4 : Cluster analysis repeated on the same 12 varieties - this time using 3 variables (NGL, LGL, LW, TW).

***** SIMILARITY MATRIX *****

VAR01	----				
VAR02	52.5	----			
VAR03	83.1	35.6	----		
VAR04	50.5	65.2	33.6	----	
VAR05	20.3	67.9	3.4	63.0	----
	1	2	3	4	5

*** DENDROGRAM ***

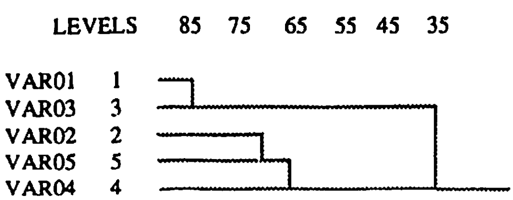

Fig 5 : Cluster analysis on 5 durum wheat varieties using 3 variables (NGL, LGL, LW).

***** SIMILARITY MATRIX *****

VAR06	----						
VAR07	95.4	----					
VAR08	56.9	52.3	----				
VAR09	82.5	84.6	39.3	----			
VAR10	67.6	63.0	87.7	50.1	----		
VAR11	35.4	35.8	13.5	51.2	24.2	----	
VAR12	47.0	47.4	23.8	62.7	34.5	88.4	----
	1	2	3	4	5	6	7

*** DENDROGRAM ***

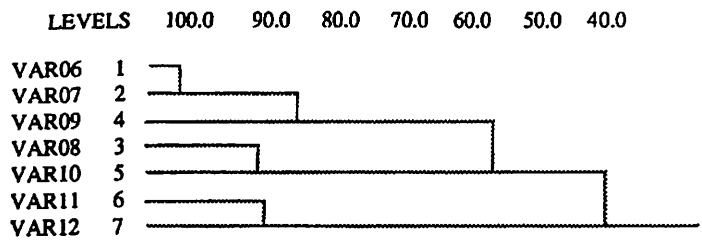

Fig 6 :: Cluster analysis on 7 varieties of T. aestivum using 3 variables (NGL, LGL, LW).

In order to carry out further biochemical studies on two varieties, differing in their responses to water stress and, based on the results on Table 4.3 and cluster analysis, two durum wheat varieties (3 & 5) were selected, since most previous studies have concentrated on Triticum aestivum , whereas little information, especially on the biochemical side, is available on Triticum durum which is widely grown in semiarid and mediterranean climates, such as, in Algeria and is reported to have originated in such conditions.

Although the number of varieties used in this experiment was rather low for selecting varieties with contrasting responses,some varieties differed considerably in their growth responses under water stress (e.g. 3 & 5), thus justifying further nvestigation of their possible biochemical differences. No study of the response of var 5 to water stress has been encountered. The local Algerian varieties (i.e. var 1 & 3) which showed characteristics of resistance in this study, were also classified as resistant among 19 varieties of wheat studied by Monneveux & Nemmar (1986). The metabolic responses of variety 3 (MBB) and 5 (Capdur) is being investigated (Kameli & Losel, 1993; 1995 &1996), in order to look for possible biochemical differences between them.

REFERENCES

Clarke, J.M., Townley-Smith, T.F., McCaig, T.N. and Green, D.G. (1984) Growth analysis of spring wheat cultivars of varying drought resistance. Crop Sciences 24, 537 - 541.

Drossopoulos, J.B., Karamanos, A.J. and Niavis, C.A. (1987) Changes in ethanol soluble carbohydrates during the development of two wheat cultivars subjected to different degrees of water stress. Annals of Botany 59, 173 - 180.

Fisher. R.A. and Yates, F. (1963) Statistical Tables for Biological, Agricultural and Medical Research. Olivier and Boyd, Edinburgh.

Fowler, D.B., Gusta, L.V. and Tyler, N.J. (1982) Selection for winter hardiness in wheat. III- Screening methods. Crop Sciences 22, 896 - 901.

Genstat release 4.04B (1984) LAWES Agricultural Trust, Rothamstead Experimental Station).

Johnson, R.C., Nguyen, H.T. and Croy, L.I. (1984) Osmotic adjustment and solute accumulation in two genotypes differing in drought resistance. Crop Sciences 24, 957 - 962.

Kameli, A. (1990) Metabolic responses of wheat plants to water stress and their role in drought resistance. Ph.D. Thesis, University of Sheffield, UK

Kameli, A. & Losel, D.M.(1993): Carbohydrates and water status in wheat plants under water stress. New Phytologist 125 , 609-614.

Kameli, A. & Losel, D.M.(1995): Contribution of carbohydrates and other solutes to osmotic adjustment in wheat plants under water stress. *Journal of Plant Physiology* 145, 363-366.

Kameli, A. & Losel, D.M.(1996): Growth and sugar accumulation in wheat plants under water stress. *New Phytologist* 132, 57-62.

Monneveux, P. and Nemmar, M. (1986) Contribution a l'etude de la resistance a la secheresse chez le ble tendre Triticum aestivum L. et chez le ble dur Triticum durum Desf. : Etude de l'accumulation de la proline au cours du cycle de development. *Agronomy* 6, 583 - 590.

Morgan, J.M., Hare, R.A. and Fletcher, R.J. (1986) Genetic variation in osmoregulation in bread and durum wheats and its relationship to grain yield in a range of field environments. Australian Journal of Agricultural Research 37, 449 - 457.

Singh, T.N., Aspinall, D. and Paleg, L.G. (1972) Proline accumulation and varietal adaptability to drought in barley: a potential metabolic measure of drought resistance. Nature New Biology 236, 188 - 189.

Wright, G.C., Smith, R.C.G. and Morgan, J.M. (1983) Difference between two grain sorghum genotypes in adaptation to drought stress. III- Physiological responses. Australian Journal of agricultural Research 34, 637 - 651.