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Evaluation of Indices for Identification of Pearl Millet Ecotypes (*Pennisetum glaucum*) Adapted to Stress and non Stress Conditions

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ABSTRACT

Selection of drought adapted ecotypes having efficient use of water is the most important goal in breeding programs for drought stress environments. In this study, three ecotypes of pearl millet [*Pennisetum glaucum* (L.) R. Br.] were evaluated under drought stress (17% of irrigation requirement) and optimum (well watered) conditions to study their responses to drought and to identify the traits that are associated with drought adaptation. Results showed that deficient irrigation reduced plant height and this reduction was more severe for genotype with long stem. In addition, water stress caused a grain yield reduction by decrease of panicle number per m^2, grain yield panicle and panicle weight. Pearl millet ecotypes differed significantly for all traits studied under stress as well under non-stress conditions. The differences among individual ecotypes for their average yielding ability were considerable. Comparison among ecotypes showed that the effect of the drought was much more severe for KS ecotype, which is the most productive ecotype under favourable conditions. The least productive ecotype in favourable conditions was least vulnerable to drought. Ecotype having ability to maintain a higher panicle number under deficient irrigation, performed better under drought stress and may be used for developing drought tolerant varieties.

Key words: Germplasm, Tunisian ecotype, water deficit, mediterranean climate, grain yield, pearl millet

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INTRODUCTION

Many environmental factors play very significant roles in reducing agricultural production worldwide[1] but water shortage is one of the most important restricting factors in crop production in the world[2]. Food security depends on the ability to increase the crop production with decreasing availability of water.

One challenge of the future will be to maintain or even increase crop production with less water and to develop water-efficient genotypes that produce higher yields with limited water supply and equal or greater yields than current varieties under favourable growing conditions without stress[3].

Deficient irrigation is practiced in many arid areas of the world and increased demand on water supplies worldwide suggests the practice must increase[4]. In fact; the cost of irrigation pumping and inadequate irrigation scheme capacity as well as limited water sources are among the reasons that force many farmers to reduce irrigation applications. In order to realize an efficient water management at farm level and to increase the crop water use efficiency, Deficient or Regulated Deficient Irrigation is one way of water saving in regions where water resources are limited without having negative incidences on the crop yields.

The reactions of plants to water stress differ significantly at various organizational levels depending upon intensity and duration of stress as well as plant species and its stage of growth[5,6]. It has been proved that drought stress declines plant growth and production[7]. It affects both elongation and expansion growth[8,9,10]. Water deficit stress mostly reduced leaf growth and in turn the leaf areas in many species of plant[11,12,13]. The yield components, such as grain number and grain size were decreased under drought stress[14,15,16].

The drought resistance of a cultivated plant reflects its capacity to limit the impact of these changes on the economic yield in biomass production and distribution[17]. High yield potential under drought stress is the target of crop breeding. In many cases, high yield potential can contribute to yield in moderate stress environment[18,19] and greater plant fresh and dry weights under water limited conditions are desirable characters. Blum[20] pointed out that high yield under water-limited conditions is generally associated with increased WUE mainly because of high water use. However, some genotypes showed better stress tolerance than the others. Therefore, selecting ecotypes with superior performance under water-saving technologies could result in a significant improvement in water productivity of irrigated crop.

Pearl millet (*P. glaucum* (L.)R. Br.) is a drought-tolerant cereal grain typically grown as grain crop in Tunisia (about 3000 ha). It is mainly cultivated as summer annual crop completely irrigated in the arid areas, therefore selection of tolerant genotypes to water deficit and irrigation optimisation application due to water scarcity in the region is very important.

Pearl millet needs relatively less water than the other crops, because it has short growing season[21]. However, there is no report of any clear optimum irrigation volume for this crop in mediterranean climate. The amounts of irrigation are very variable and generally there is much wasting of water. Some work on water demand of this crop has already been published[22] and this paper deals with water stress thresholds and ecotypes behaviour in relation to water stress.

This experiment was conducted to compare yield and yield components and some morphological traits in three autochthonous pearl millet ecotypes under deficient irrigation conditions. This approach may help to understand how the ecotypes respond to water deficits and with this information growers can reduce current levels of irrigation at least to the point at which no more water is applied than necessary for replacement of water used by the crop. The information should also show the capability of the three pearl millet ecotypes to cope with water scarcity and the importance of such a crop in the regions with limited water resources.

MATERIALS AND METHODS

The experiment was carried out at Ariana's station of the Tunisian Agricultural Research Institute during the cropping seasons of 2006 and 2007. The site is located at 36°51' latitude, 10°11' longitude and 10 m altitude. It has a Mediterranean climate. Average annual rainfall is 400 mm. The soil of the experimental site is clay loam.

Experimental design was split-plot based on randomized complete block with four replications. Each replication had two main plots as irrigation treatments (control and deficient irrigation). In deficient irrigation treatment, the rate of irrigation was 17% crop water requirement. FAO method was used to determine the water requirement[23]. Control irrigation volume of 580 mm corresponding to 100% ETM was applied. Electrical conductivity of irrigations water was 1 dS m^{-1}. Irrigation was applied weekly. All the experimental treatments were irrigated at the same time and water applications were the same for all treatments except volume of water.

Each main plot consisted of three sub-plots as autochthonous millet ecotypes: KS, D and EC (Table 1). The sampling area was 5 m² (5-meter-long rows). Sowing was done in hills and row to row distance of 50 cm and hill to hill distance of 30 cm were used. Each sub-plot had five planting rows. Sowing date was 23 May. A basal dose of 50 kg N in the form of ammonium nitrate 33% fertiliser was applied at sowing. At final harvest, all data were measured on five plants in each plot (n = 20 for each treatment), panicles were threshed and grain number and weight were determined.

Data were recorded on plant height (HAT) in cm, panicle length (LOC) in cm, total panicle weight per main shoot (PCP) in g, grain yield per panicle (RGC) in g, harvest index of panicle (seed yield of panicle/total panicle weight: HI) in %, seed yield (RDT) in t/ha, 1000 kernel weight (PMG) in g.

All the statistical data obtained in this study were analysed by STATITCF statistical package. All data were compared using analysis of variance (in STATITCF) from the ANOVA output at 1% or 5% probability level.

RESULTS AND DISCUSSION

The effect of water stress on plant height (HAT): Significant differences were observed for plant height among the ecotypes. KS ecotype (232 cm) was the tallest ecotype followed by EC (207 cm) (Fig. 1). D ecotype attained minimum plant height (187 cm). Water stress-

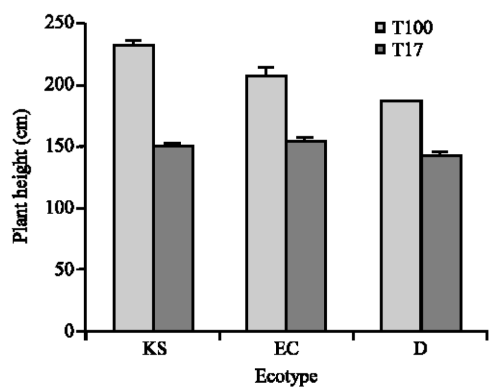

Fig. 1: Mean height of autochthonous pearl millet ecotypes under different water supply (T_{100}: Control irrigation volume of 580 mm corresponding to 100% ETM, T_{17}: Deficient irrigation treatment corresponding at 17% crop water requirement)

Table 1: Ecological parameters of autochthonous pearl millet ecotypes

Ecotype	Origin	Duration of cycle (j)	Climate	Annual rainfall (mm)	Annual average temperature (°C)	January average temperature (°C)	July average temperature (°C)
EC	Mahdia	Medium 70<D<90	Arid (Sup)	200-400	19.5	11.9	26.3
KS	Kairouan	Long >90	Arid (Med)	200-400	19.9	11.5	28.7
D	Djerba Island	Short<70	Arid (Inf)	100-200	21.3	12.4	26.9

Data according to the National Institute of Meteorology (INM), 2006, Tunisia

Table 2: Mean grain yield and yield components of pearl millet ecotypes under stress and non-stress conditions

Variable	Control (T_{100})	Stress (T_{17})	Reduction (%)
PL (cm)	12.9a	11.8b	8.5
PW (g)	37.2a	24.6b	33.9
PG (g)	27.6a	18.1b	34.8
PM²	49.2a	32.3b	34.2
KW (g)	10.5a	9.0b	14.3
SY (t ha^{-1})	7.7a	4.2b	45.5
HI (%)	74.2a	73.8a	0.5

Means followed by the same letters in each column are not significantly different at the 5% level of probability, PL = Panicle length, PW = Panicle weight, PG = Grain panicle yield, PM² = Panicle number per m², KW = Thousand kernel weight, SY = Total seed yield, C = Control, S = Stress

Table 3: Means of grain yield and yield components of three pearl millet ecotypes in well-watered and stress treatments

	PL (cm)		PW (g)		PG (g)		KW (g)		PM²		SY (t ha^{-1})	
	C	S	C	S	C	S	C	S	C	S	C	S
Ecotype	(Treatment)											
KS	14.4a	12.5b	48.6a	27.9b	34.3a	19.8b	10.7a	8.2b	42.3a	26.3b	9.7a	4.4b
EC	12.8a	11.7b	38.0a	23.7b	29.3a	17.7b	9.7a	8.8b	38.0a	35.3b	6.2a	4.0b
D	11.5a	11.2a	25.0a	22.1b	19.1a	16.8b	11.1a	10.1b	67.3a	35.3b	7.1a	4.1b

Means followed by the same letters in each column are not significantly different at the 5% level of probability, PL = Panicle length, PW = Panicle weight, PG = Grain panicle yield, PM² = Panicle number per m², KW = Thousand kernel weight, SY = Total seed yield, C = Control, S = Stress

treatment had significant effect on plant height of autochthonous pearl millet ecotype. The stem length decreased under water deficit conditions with significant differences among genotypes. Plant height for KS stressed was reduced by 35% significantly ($p = 0.01$) than control plants while it decreased by 26% in EC and D ecotypes. Effects of water deficits on plant height have been determined for other crops and pearl millet[24,25,26,27,28,29,30].

The reduction in plant height was associated with a decline in the cell enlargement and more leaf senescence under water stress[8]. For pearl millet, Shao[10] demonstrated that water stress greatly suppresses cell expansion and cell growth due to the low turgor pressure and osmotic regulation can enable the maintenance of cell turgor for survival or to assist plant growth under severe drought conditions. Seghatoleslami[31] attributed the reduction in plant height to a reduction in internodes and ear length. Significant inter-specific differences between species have been found in plant height under water deficit[12,32]. For pearl millet, genotypes with long stem are more vulnerable to water deficit[33].

The effects of water stress on yield and yield components: Data obtained from the study showed that grain yield was significantly ($p<0.01$) affected by water deficit (Table 2).

As is evident, moisture stress resulted in serious grain yield reduction (45.5%). Seghatoleslami[31] also reported 43.3% seed yield reduction under drought stress in proso millet. Other authors[32,33,26] also reported that water stress in millet reduced seed yield. Similarly, Singh and Singh[34] in a study of agronomic and physiological responses of sorghum, maize and pearl millet to irrigation showed that drought stress had significant effect on yield. They attributed yield reduction to reduced net assimilation rate when drought stress increased.

In the present study, grain yield under stress decreased due to reduced panicle number per m² (34%), grain yield panicle (35%) and panicle weight (33.9%). Nagaz[35] reported similar results. Yadav[7] demonstrated that water stress in pearl millet reduces seed yield through reduction of tiller number per m^2, seed number per ear and seed weight[36] reported that grain yield per ear changed with the application stage and amount of water used for irrigation and observed a close relationship between the amount of irrigation water and panicle size. The reduction in panicle number can be a regulative mechanism. It regulates physiological sinks to assimilate production[31].

Panicle harvest index did not change much under stress. Similar result was found by Maqsood and Azam Ali[26] for two pearl millet landraces. Maintenance of similar panicle harvest index by ecotypes under mild stress conditions reflects their capacity for grain yield changes proportionate to changes in biomass under severe water stress conditions. This might primarily be due to their unaffected panicle harvest index under stress conditions when compared to non-stress conditions[37].

In pearl millet, co-mapping of the harvest index and panicle harvest index with grain yield revealed that greater drought tolerance was achieved by greater partitioning of dry matter from stover to grains[38].

Pearl millet ecotypes differed significant ($p<0.01$) for all traits under stress as well as under non-stress conditions (Table 3).

The differences among individual ecotypes for their average yielding ability were considerable: the range was from 9.7 to 6.2 t ha^{-1} under favourable conditions. The

Table 4: Means of reduction in grain yield and yield components of three pearl millet ecotypes in well-watered and stress treatments

	Reduction (%)					
Ecotype	PL (cm)	PW (g)	PG (g)	KW (g)	PM²	SY (t ha^{-1})
KS	13.2a	42.6a	42.3a	23.4a	37.8b	65a
EC	8.6b	37.6b	39.6b	9.2b	7.1c	36c
D	2.6c	11.6c	12.0c	9.0b	47.5a	42b

Means followed by the same letters in each column are not significantly different at the 5% level of probability, PL = Panicle length, PW = Panicle weight, PG = Grain panicle yield, PM² = Panicle number per m², KW = THOUSAND kernel weight, SY = Total seed yield, C = Control, S = Stress

highest grain yield 9.7 t ha^{-1} was recorded for KS ecotype followed by D ecotype (7.1 t ha^{-1}) under well-irrigated conditions. The lowest seed yield was obtained for EC ecotype. These results indicated that ecotypes differed in their potential yield. Pearl millet is known to vary greatly in grain yield[39,40,41].

Differences between ecotypes in grain yield were evident in the well-watered but less under the stress conditions. Under water deficit, all three ecotypes has similar grain yield (about 4 t ha^{-1}). However, comparison among ecotypes shows that the water stress was much more severe for KS ecotype which was the most productive under favourable conditions. Yield reduction (65%) of KS was due both to lower grain yield panicle and lower panicle number. Ecotype with longer duration tended to have lower grain yield under stress conditions[42,43].

For D ecotype, yield reduction was caused primarily by a reduction in panicle number. It was interesting to note that EC ecotype, the least productive under favourable conditions, was less vulnerable to drought. Grain yield reduction (36%) of EC was related to a fall in seed yield panicle and not in panicle number (Table 4). Ability to maintain a higher panicle number is associated with drought tolerance[37,44].

CONCLUSION

Drought stress affects the growth and harvestable yield in pearl millet but the tolerance of any ecotypes to this menace varies remarkably.

Genotypes with long stem, longer duration and with higher grain yield in well-watered conditions tended to have lower grain yield in the stressed conditions. However, ecotype, the least productive under favourable conditions, was less vulnerable to drought. This drought tolerance ability is associated to maintain a higher panicle number. So, selecting ecotypes with superior performance under water-saving technologies could result in a significant improvement in water productivity of irrigated crop.

REFERENCES

1. Boyer, J.S., 1982. Plant productivity and environment. Science, 218: 443-448.
2. Umar, S., 2006. Alleviating adverse effects of water stress on yield of sorghum, mustard and groundnut by potassium application. Pak. J. Bot., 38: 1373-1380.
3. Farooq, M., N. Kobayashi, O. Ito and S.M.A. Basra, 2009. Chapter 6 strategies for producing more rice with less water. Adv. Agron., 101: 351-388.
4. FAO, 2000. Eau et Agriculture. Division de la mise en valeurs des terres et des eaux. FAO, Rome, pp: 28.
5. Chaves, M.M., J.S. Pereira, J.P. Maroco, M.L. Rodrigues and C.P.P. Ricardo *et al*., 2002. How plants cope with water stress in the field: Photosynthesis and growth. Ann. Bot., 89: 907-916.
6. Jaleel, C.A., R. Gopi and R. Panneerselvam, 2008. Growth and photosynthetic pigments responses of two varieties of *Catharanthus roseus* to triadimefon treatment. Comp. Rendus. Biol., 331: 272-277.
7. Yadav, R.S., C. Tom Hash, F.R. Bidinger, M.S. Dhanoa and C.J. Howarth, 1999. Identification and Utilization of Quantitative Trait Loci to Improve Terminal Drought Tolerance in Pearl Millet (*Pennisetum glaucum* (L.) R. Br. In: Proceedings of the Workshop on Molecular Approaches for the Genetic Improvement of Cereals for Stable Production in Water-Limited Environments, Ribaut, J.M. and D. Poland (Eds.). CIMMYT., Mexico, pp: 108-114.
8. Bhatt, R.M. and R.N.K. Srinivasa, 2005. Influence of pod load response of okra to water stress. Indian J. Plant Physiol., 10: 54-59.
9. Kusaka, M., M. Ohta and T. Fujimura, 2005. Contribution of inorganic components to osmotic adjustment and leaf folding for drought tolerance in pearl millet. Physiol. Plant., 125: 474-489.
10. Shao, H.B., L.Y. Chu, M.A. Shao and C. Abdul Jaleel and M. Hong-Mei, 2008. Higher plant antioxidants and redox signaling under environmental stresses. Comp. Rend. Biol., 331: 443-451.
11. Zhang, M., L. Duan, Z. Zhai, J. Li and X. Tian *et al*., 2004. Effects of plant growth regulators on water deficit-induced yield loss in soybean. Proceedings of the 4th International Crop Science Congress, September 26-October 1, 2004, Brisbane, Australia, pp: 122.
12. Wullschleger, S.D., T.M. Yin, S.P. DiFazio, T.J. Tschaplinski, L.E. Gunter, M.F. Davis and G.A. Tuskan, 2005. Phenotypic variation in growth and biomass distribution for two advanced-generation pedigrees of hybrid poplar. Canad. J. For. Res., 35: 1779-1789.

13. Farooq, M., A. Wahid, N. Kobashi, D. Fujita and S.M.A. Basra, 2009. Plant drought stress: Effects, mechanisms and management. Agron. Sustain. Dev., 29: 185-212.
14. Kamara, A.Y., A. Menkir, B. Badu-Apraku and O. Ibikunle, 2003. The influence of drought stress on growth, yield and yield components of selected maize genotypes. J. Agric. Sci., 141: 43-50.
15. Monneveux, P., C. Sanchez, D. Beck and G.O. Edmeades, 2006. Drought tolerance improvement in tropical maize source populations: Evidence of progress. Crop Sci., 46: 180-191.
16. Edward, D. and D. Wright, 2008. The effects of winter water-logging and summer drought on the growth and yield of winter wheat (*Triticum aestivum* L.). Eur. J. Agro., 28: 234-244.
17. Kage, H., M. Kochler and H. Stutzel, 2004. Root growth and dry matter partitioning of cauliflower under drought stress conditions: Measurement and simulation. Euro. J Agron., 20: 379-394.
18. Blum, A., 1996. Constitutive Trait Saffecting Plant Performance Under Stress. In: Proceedings of the Symposium, Developing Drought and Low N Tolerant Maize, Edmeades, G.O., M. Banziger, H.R. Mickelson and C.B. Pena-Valdivia (Eds.). CIMMYT., Mexico, pp: 131-135.
19. Richards, R.A., G.J. Rebetzke, A.G. Condon and A.F. van Herwaarden, 2002. Breeding opportunities for increasing the efficiency of water use and crop yield in temperate cereals. Crop Sci., 42: 111-121.
20. Blum, A., 2005. Drought resistance, water-use efficiency and yield potential-are they compatible, dissonant, or mutually exclusive? Aust. J. Agric. Res., 56: 1159-1168.
21. Baltensperger, D.D., 2002. Progress with Proso, Pearl and other Millets. In: Trends in New Crops and New Uses, Janick, J. and A. Whipkey (Eds.). ASHS Press, Alexanderia, USA., pp: 100-103.
22. Radhouane, L. and H.J. Mallouli, 2007. Effets d'un stress hydrique sur les rendements de deux ecotypes locaux de Mil (*Pennisetum glaucum* (L.) R. Br.). Cahiers Agric., 16: 17-22.
23. FAO, 1994. Water Policies and Agriculture. In: : The State of Food and Agriculture: Agriculture Series, No. 25, FAO, FAO, Rome, pp: 228-297.
24. Pace, P.F., T.H. Cralle, S.H.M. El-Halawany, J.T. Cothren and A.S. Senseman, 1999. Drought-induced changes in shoot and root growth of young cotton plants. J. Cotton Sci., 3: 183-187.
25. Cakir, R., 2004. Effect of water stress at different development stages on vegetative and reproductive growth of corn. Field Crops Res., 89: 1-16.
26. Maqsood, M. and S.N. Azam Ali, 2007. Effects of environmental stress on growth, radiation use efficiency and yield of finger millet (*Eleucine coracona*). Pak. J. Bot., 39: 463-474.
27. Wu, Q.S., X.R. Xia and Y.N. Zou, 2008. Improved soil structure and citrus growth after inoculation with three arbuscular mycorrhizal fungi under drought stress. Eur. J. Soil Biol., 44: 122-128.
28. Mahalakshmi, V., F.R. Bidinger and D.S. Raju, 1987. Effect of timing of water deficit on pearl millet (*Pennisetum americanum*). Field Crop Res., 15: 327-339.
29. Daouda, O.S., R. Emmanuel and P. Marini, 1993. Role du Systeme Racinaire Dans la Resistance a la Secheresse Chez le Mil: Analyse de la Rhizogenese Post-Florale. In: Le mil en Afrique. Diversite Genetique et Agro-Physiologique: Potentialites et Contraintes Pour l'amelioration et la Culture, Serge, H. (Ed.). ORSTOM., Paris, pp: 205-215.
30. Madakadze, I.C., K. Stewart, P.R. Peterson, B.E. Coulman and D.L. Smith, 1999. Switchgrass biomass and chemical composition for biofuel in eastern canada. Agron. J., 91: 696-701.
31. Seghatoleslami, M.J., M. Kafi and E. Majidi, 2008. Effect of drought stress at different growth stages on yield and water use efficiency of five proso millet (*Panicum miliaceum* L.) genotypes. Pak. J. Bot., 40: 1427-1432.
32. Mahalakshmi, V. and F.R. Bidinger, 1985. Flowering response of pearl millet to water stress during panicle development. Ann. Applied. Biol., 106: 571-578.
33. Kumari, S., 1988. The effects of soil moisture stress on the development and yield of millet. Agron. J., 57: 480-487.
34. Singh, B.R. and D.P. Singh, 1995. Agronomic and physiological responses of sorghum, maize and Pearl millet to irrigation. Field Crops Res., 42: 57-67.
35. Nagaz, K., I. Toumi, I. Mahjoub, M.M. Masmoudi and N.B. Mechlia, 2009. Yield and water-use efficiency of pearl millet (*Pennisetum glaucum* (L.) R. Br.) under deficit irrigation with saline water in arid conditions of Southern Tunisia. Res. J. Agronomy, 2: 9-17.
36. Kanber, R., A. Yazar and M. Eylen, 1990. Cukurova Kosullarinda Bugdaydan Sonra Yetistirilen Ikinci Urun Misirda Su-Verim Iliskisi. Koy Hizmetleri Arastirma Enstitusu Yayinlari, Tarsus, pp: 75.
37. Yadav, O.P., E. Weltzien-Rattunde and F.R. Bidinger, 2003. Genetic variation in drought response of landraces of pearl millet [*Pennisetum glaucum* (L.) R. Br.]. Ind. J. Genetic, 63: 37-40.
38. Yadav, R.S., C.T. Hash, F.R. Bidinger, K.M. Devos and C.J. Howarth, 2004. Genomic regions associated with grain yield and aspects of postflowering drought tolerance in pearl millet across stress environments and testers background. Euphytica, 136: 265-277.

39. Manivannan, P., C.A. Jaleel, A. Kishorekumar, B. Sankar and R. Somasundaram *et al.*, 2007. Changes in antioxidant metabolism of *Vigna unguiculata* (L.) Walp. by propiconazole under water deficit stress. Colloids Surfaces B: Biointerfaces, 57: 69-74.
40. Rachie, K.O. and J.V. Majmudar, 1980. Pearl Millet. Pennsylvania State University Press, University Park PA. USA., Pages: 307.
41. Kumari, B.M. and P. Nagarajan, 2008. Variability and heritability analysis in pearl millet (*Pennisetum glaucum* (L.) R.Br.). Mad. Agric. J., 96: 190-192.
42. Dijak, M., A.M. Modarres, R.I. Hamilton, L.M. Dwyer, D.W. Stewart, D.E. Mather and D.L. Smith, 1999. Leaf reduced-stature maize hybrids for short-season environments. Crop Sci., 39: 1106-1110.
43. Radhouane, L., 2008. Correlation between germination and adult stage under water stress in some Tunisian autochthonous pearl millet ecotypes (*Pennisetum glaucum* (L.) R. Br.). Comput. Rendus Biol., 331: 623-630.
44. Burton, G.W. and J.B. Powell, 1968. Pearl millet breeding and cytogenetics. Adv. Agron., 20: 68-89.